WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

SUCCESSFUL DELIVERY REWARD CRITERIA REPORT CONFIRMATION OF THE PROJECT DETAILED DESIGN

LCN Fund Low Carbon Networks THE UNIVERSITY OF WARWICK PARSONS BRINCKERHOFF

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1 List of Abbreviations

Abbreviation	Term
AIS	Air Insulated Switchgear
AVC	Automatic Voltage Control
CDM	Construction, Design and Management
CT	Current Transformer
DG	Distributed Generation
DPCR5	Distribution Price Control Review 5
EHV	Extra High Voltage (voltages above 22,000V)
FCL	Fault Current Limiter
FFL	Finished Floor Level
FGL	Finished Ground Level
FL	Fault Level
FLM	Fault Level Monitor
GIS	Gas Insulated Switchgear
GSP	Grid Supply Point
GT	Grid Transformer
HV	High Voltage (voltages above 1,000V but below 22,000V)
I_f	Fault Current
LCN Fund	Low Carbon Networks Fund
LV	Low Voltage
MTBF	Mean Time Between Failures
NGET	National Grid Electricity Transmission
NOP	Normally Open Point
OCB	Oil filled Circuit Breaker
OCEF	Overcurrent & Earth Fault
P	Real Power [MW]
PICAS	Paper Insulated Corrugated Aluminium Sheath cable
PILC	Paper Insulated Lead Covered cable
Q	Reactive Power [MVAr]
REF	Restricted Earth Fault
R	Resistance
RfI	Request for Information
rms	Root Mean Square
S	Apparent Power [MVA]
SF_6	Sulphur Hexafluoride
SBEF	Stand-by Earth Fault
SDRC	Successful Delivery Reward Criteria
SWA	Steel Wire Armoured
V_l	Nominal Phase to Phase Voltage
VT	Voltage Transformer
X	Reactance
X_d''	Sub Transient Reactance
XLPE	Cross-Linked Polyethylene

2 List of Definitions/Glossary of Terms

Fault Level	Fault level is a commonly used parameter that provides a measure of the energy flows experienced during a fault at a point on the network. It can be specified for electrical sources as the amount of power that will be generated in to a fault, or for electrical components as the amount of power they are capable of withstanding and continuing to operate. Fault level, expressed as apparent power, can be calculated from the rms fault current which flows at the respective phase to phase voltage level. $$S_{FL} = \sqrt{3} \times V_l \times I_f$$
Fault Level Mitigation	When fault levels encroach upon the levels stipulated by equipment withstand or capability ratings there is a need to intervene. Numerous methods exist to mitigate against rising fault level, including limiting the fault level by increasing the network impedance or Fault Current Limiting (FCL) devices, network splitting, or replacement of compromised assets. Research and analysis of the Birmingham HV network has established that the optimal solution for mitigation within the Birmingham area is via FCL devices [1]. All references to Fault Level Mitigation within this document are stated as FCL in order to avoid any confusion with Fault Level Monitoring (FLM) devices.
Continuous Current Rating	The continuous current rating is the maximum permissible current that can continuously flow without causing damage due to excessive heating and/or degradation.
Network Contingency (n-1)	A power network designed to a n-1 contingency is one which can sustain a single outage without loss of supply continuity.
Short Circuit Current Rating	The short circuit current rating is the maximum permissible current that can be withstood for a short and specified period of time usually between 0.2 - 3 seconds due to excessive heating and/or degradation. This magnitude of current typically flows when there is a fault on the network.
X/R Ratio	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 [2].
FCL Impedance and X/R	The Birmingham urban 11kV network already exhibits, in places, very high X/R ratios. The consequence of adding what is effectively a large lump of impedance to the network is that it will possibly alter this X/R ratio by a significant margin. The change in X/R ratio will depend on the FCL adopted. For instance, a Resistive

	Superconducting Fault Current Limiter will decrease the X/R ratio when the device is triggered. A Fault Limiting Reactor on the other hand will increase the X/R ratio permanently.
Compound Insulation	Prior to the use of rubber "sleeves" or "boots" for insulation in HV equipment, bitumen compound was used to control electrical breakdown between phases and/or earth. The compound is mostly commonly found in busbar compartments and cable boxes on pre-1970 installations. Modifications to these compartments (either extensions or new connections) require the compound to be melted by use of heat lamps and cleaned to make the necessary modifications. Following the modifications, the old compound is replaced with a new resin filler (such as Guroflex). When attempting to undertake modifications to compound filled equipment, careful consideration must be taken to ensure that the overall breakdown strength is not compromised.
Distribution Price Control Review 5	The current price control applicable to electricity Distribution Network Operators (DNOs). This is known as DPCR5 (Distribution Price Control Review 5). This price control runs from 1 April 2010 until 31 March 2015.
Dry Type Box	A cable box that is air insulated (i.e. no Compound Insulation), where the cable connector employs insulated plugs or boots.
Joggle Box	The commonly used term for describing the transition panel used to connect one type of switchgear busbar to another type of switchgear busbar.
Legacy Switchgear	Generally considered as switchgear that utilises oil-filled circuit breakers (oil as the insulating medium and a turbulator mechanism to facilitate arc extinguishing and associated fault clearance). This type of switchgear due to its design has overall fault clearance times from fault inception through to an extinguished arc that can be in excess of 500-750ms. This compares to modern SF6 gas or vacuum circuit breakers which can complete the same operation in less than 100ms in certain instances.
Headroom	Headroom is a reference to the existing substation fault level when compared with the new declared value following the introduction of FCL Technologies. In context, where a substation is declared at its maximum fault level and FCL Technology installation reduces this value, the shift in value is therefore the difference between the original values and the declared value following installation of the FCL Technology.
Parallel	Parallel is an expression which defines the nature of how a HV network can be operated – in this instance, a means of providing a duplicate supply to ensure one single outage does not result in a loss of supply.
Primary Substation	A step-down substation on the distribution network that generally converts EHV to HV, such as a 132/11kV or 33/11kV substation.
Radial	Radial is an expression which defines the nature of how a HV network can be operated – in this instance from the point of supply to the remote end as a single circuit. Following an outage, this type of network would be restored via manual

	or automated switching.
SDRC	The SDRC is an Ofgem definition of the various milestones and achievements relevant to the delivery of FlexDGrid.
Source	With GB DNOs, the source can be defined as the normal point of in-feed from the NGET Transmission network.

3 Introduction

The LCN Fund Tier 2 FlexDGrid project seeks to offer an improved solution to the timely and cost effective integration of customers' generation and demand within Birmingham's urban HV electricity network. Three separate methods have been identified within FlexDGrid to achieve these objectives: an enhanced fault level assessment process; the real time management of fault level; and by use of fault level mitigation [FCL] technologies. These three methods are referred to as Method Alpha, Method Beta and Method Gamma respectively.

It is the latter of these two methods, namely Beta and Gamma, which this document considers. For the development of Method Beta, a fault level monitoring device will be installed in ten primary substations within the Birmingham area. The operation of these devices will facilitate a greater understanding of actual fault levels on Western Power Distribution's networks, allowing for a potential increase in fault level headroom and the release of DG connection capacity.

Method Gamma sets out to proactively increase the available fault level headroom on the 11kV network. This is the value of fault level increase which can be realised, through the integration of DG, before equipment ratings are approached. To achieve this it is planned to incorporate fault current limiting devices in five primary substations within the Birmingham area. This shall enable Western Power Distribution to minimise connection times and reduce the connection costs for customers wishing to connect DG to the network.

In order to ensure the timely progression of the project the following document will map out the basis of the "confirmation of project detailed design" as detailed in Successful Delivery Reward Criteria (SDRC) 2 [1]. SDRC-2 is summarised below:

- Confirmation and justification of ten primary substations that have been identified for installation of fault level monitoring technology
- Confirmation and justification of five primary substations for installation of fault level mitigation technology
- Availability of the detailed design documents to other DNOs

In addition to the criteria above, the following project deliverables form part of the collaboration agreement between Western Power Distribution and Parsons Brinckerhoff.

- A summary report which makes recommendations to WPD on which technologies are favourable for procurement.
- Detailed design of primary substation modifications, including assessments of required updates to electrical systems, protection systems, SCADA systems, civil, security systems, access/egress requirements and maintenance requirements.

4 Overview

This document has been structured as follows:

- Management of Fault Level - This section provides an overview of the calculation of fault level on a typical Distribution Network. It also explains how network configurations influence the fault level at a given point on the power network, and how it can be managed.
- Installation Objectives of FLM and FCL– Identifies the high level need case for the integration of FLM and FCL Technologies to the Birmingham HV Network. It also defines the basis on which the FCL design parameters are calculated in order to satisfy FlexDGrid's objectives to accommodate additional generation relevant to each site.
- Substation Selection Process – This section provides a background for the processes implemented to establish the suitability of the Birmingham primary substations, starting from the original eighteen sites identified in the FlexDGrid bid phase to those most suitable for technology installations.
- Basis of Optioneering – This establishes the technical options considered at the various sites to facilitate the integration of the technologies.
- Protection Philosophy – This provides background on the various aspects of the HV power system protection requirements for the FCL and FLM device integrations.
- Risk Register – Work package risk register, providing risk, effect and actions required to mitigate the risk identified.
- References – Provides details of documents referenced throughout this document.
- Supporting Information – This is facilitated through two distinct annexes.
    - Appendix A – Substation Assessment Matrix
    - Appendix B – Substation Optioneering

5 Management of Fault Level

5.1 Overview

The delivery of Methods Beta and Gamma builds on the fundamentals of power network design through to the installation of plant and equipment on the Birmingham HV network.

The fault level associated with a particular position on the network is a function of the network configuration feeding to that point. The positioning of fault level technologies, within the network, are influenced by the existing network configurations and the different fault levels associated with proposed changes in network conditions.

The following sections present a simplified process of how fault level is calculated and how changes to network configuration can influence the prospective fault level. Also, the benefits of integrating FCL devices in to networks are demonstrated.

It should be noted that earth fault conditions are not considered here. Values of earth fault currents are limited on the WPD system by existing plant called neutral earthing resistors. Values for these resistors are generally stipulated within policy documentation, based on the local network topography.

5.2 System Impedance

The power system comprises a number of components including overhead lines, cables, transformers and switchgear. Each of these components contribute to the overall system impedance when viewed from the Source. The system impedance is inversely proportional to the prospective fault level for a particular point in the network as shown in the equation below:

$$S_{FL} = \frac{V_l^2}{Z_{system}}$$

Where V_l is the nominal phase to phase voltage and Z_{system} is the total system impedance from the source to the fault.

The components which contribute most to the overall system impedance are power transformers. These have the most significant impact on fault current distribution. This implies that the impedance of a transformer essentially dictates the value of fault level which can appear beyond the transformer itself.

It is very common to operate the power system, especially power transformers and circuits, in "parallel" operation to increase supply capacity and security to customers. In this instance, the system impedance will be reduced compared with "radial" operation and as a result of this the fault level will increase. Figure 5-1 demonstrates the prospective fault level on a single radial transformer, whereas Figure 5-2 shows the parallel operation of two identical transformers fed from the same source. Figure 5-3 shows the case of parallel transformers, however in this case with separate sources.

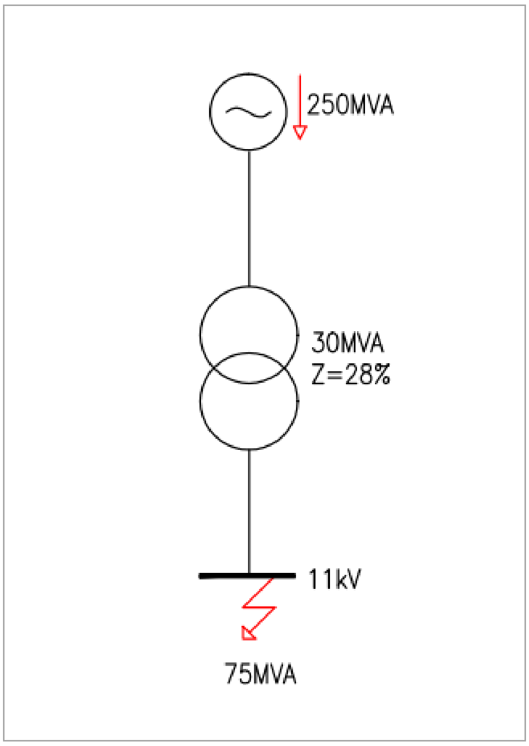


Figure 5-1: Fault Level with Radial circuit

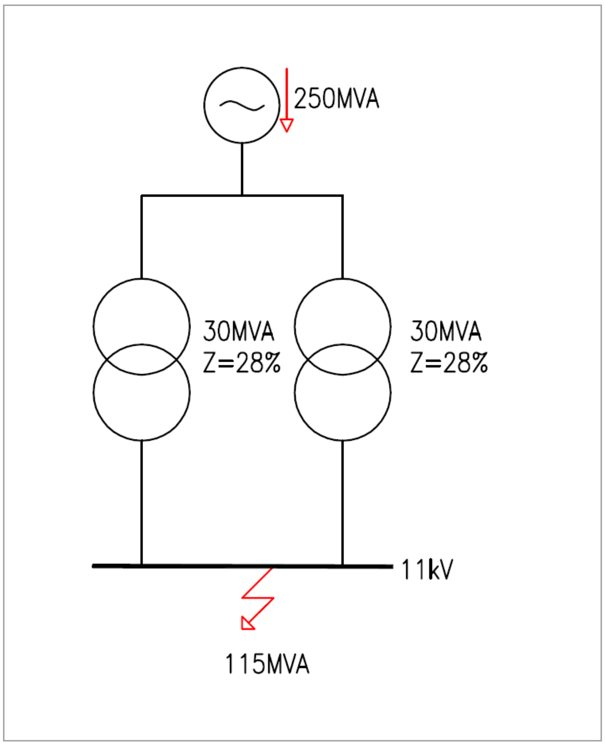


Figure 5-2: Fault Level with Parallel Circuits

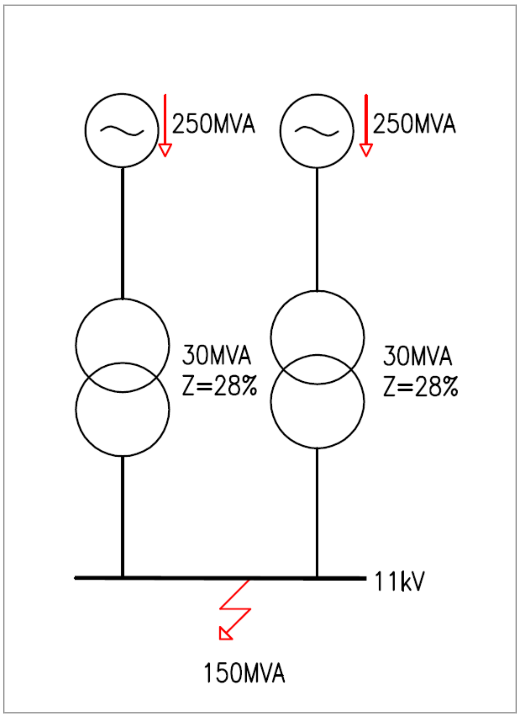


Figure 5-3: Fault Level with Parallel Circuits & Separate Sources

It can be seen that when two transformers are operated in parallel, the fault level increases by 40MVA to 115MVA compared with single radial operation. However the fault level simply doubles when independent sources are applied to parallel transformers.

5.3 Practical Aspects

Operation of the power network in parallel operation is generally preferred, compared to radial operation, due to system security and capacity benefits. For instance, when a radial network is subject to a fault all customers connected to that radial network will be off supply until the network can be restored. This restoration can be via manual switching or, as deployed within the Birmingham HV network, by automated sequence switching. This means of automated switching ensures the HV network is reconfigured within one minute to minimise any associated interruption to the HV network.

A network which is run in parallel provides n-1 security, whereas a radial network requires manual or automated sequence switching to restore the network. As noted previously, running networks in parallel inherently increases the prospective fault level. Under certain circumstances the increased fault level can exceed the capability of existing system equipment. Operation of the network with fault levels exceeding equipment ratings cannot be permitted as the equipment may not be able to sustain / interrupt the resultant current. The simplest method to reduce the fault level at a primary substation is to "split" the sources by opening bus-sections or couplers as shown in Figure 5-4 below.

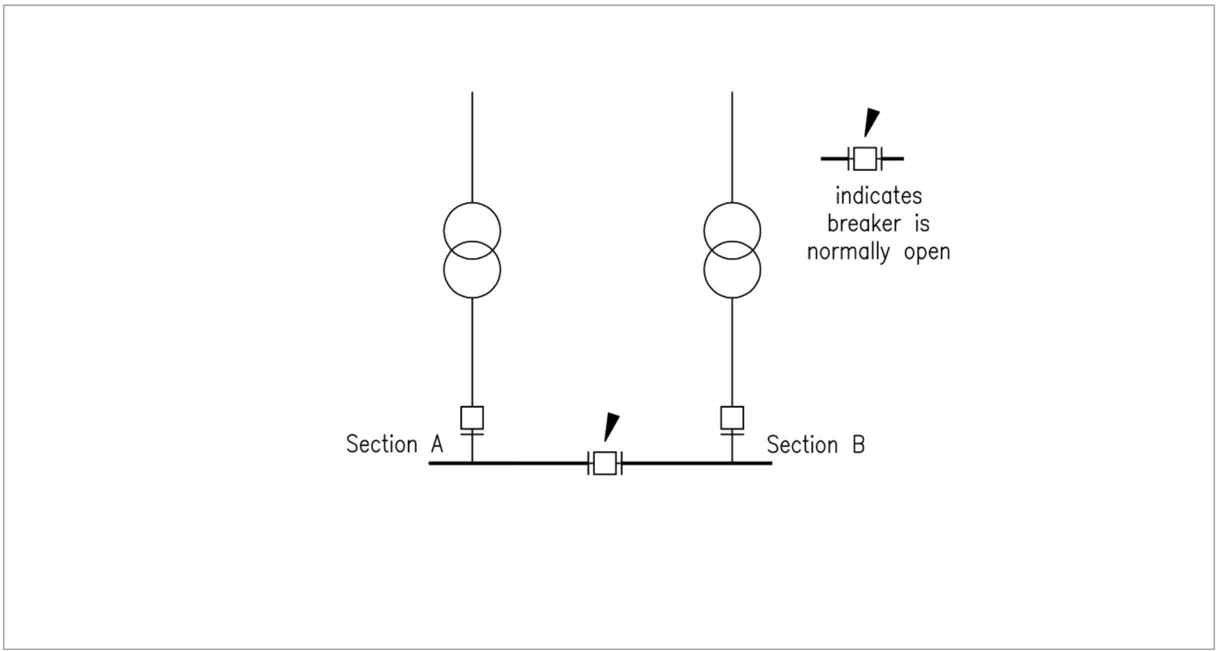


Figure 5-4: Substation Running in Split Arrangement

The disadvantage with the system configuration as shown in Figure 5-4 is that the security of supply to customers fed from 11kV busbar Section A and Section B is reduced.

5.4 Fault Current Limiter

An alternative method of controlling fault level is by utilising a FCL. The example shown in Figure 5-5 below shows the application of a FCL across a normally open bus-section. With this arrangement, when a fault is experienced on the 11kV network the fault level contribution from one source is reduced through the FCL. Amongst the FCL technologies considered for FlexDGrid are units designed such that under normal operation it appears as almost zero impedance compared to fault conditions, where it will appear as a large, dominating, impedance. Other potential applications may include the more traditional FCL solutions, such as bus-section reactors, which provide a continuous static impedance in to the network.

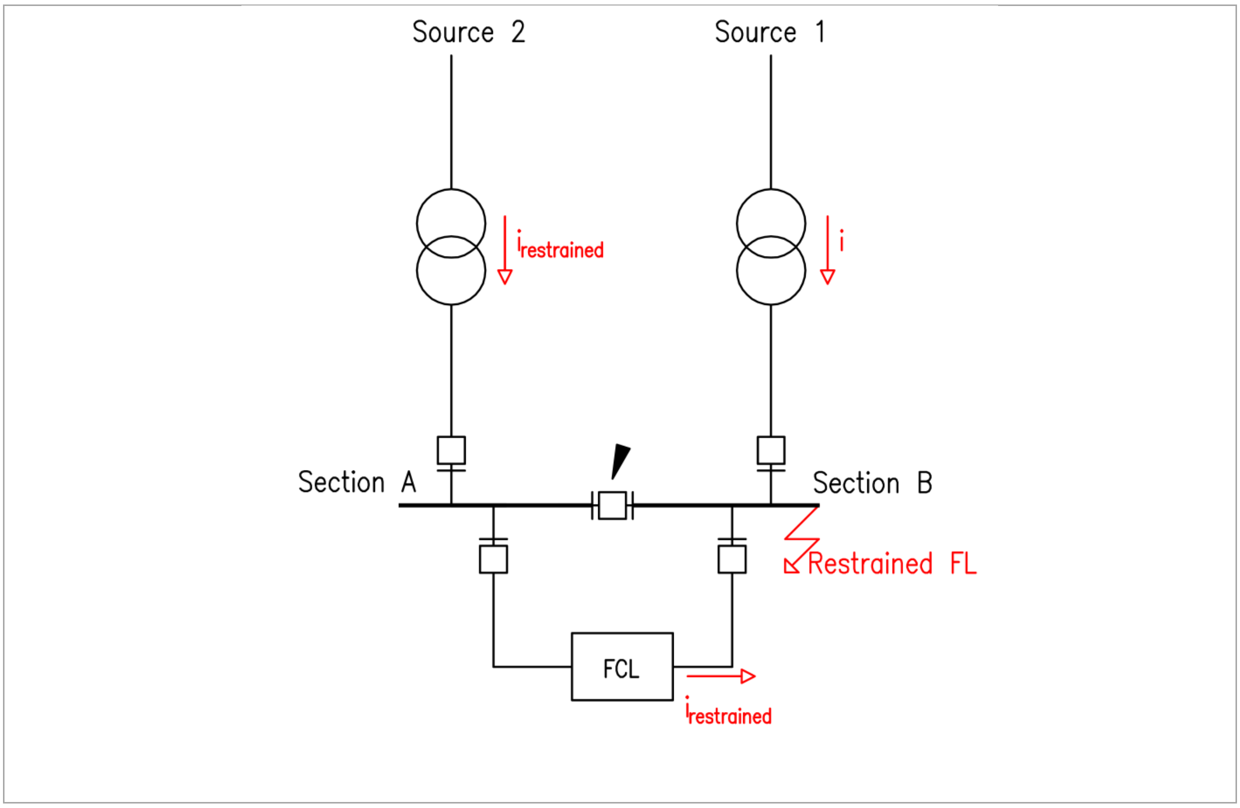


Figure 5-5: Application of FCL across Bus-Section

With a FCL integrated in to the network, security of supply is equivalent to parallel operation whilst fault levels are controlled to ensure equipment ratings are not exceeded and headroom is maximised for additional generation connections.

6 Installation Objectives of FLM and FCL

6.1 Fault Level Monitoring

The objective for Method Beta is to establish measured values for fault level whilst providing a means of comparison with calculated fault level. The data and learning from this method will feed into those from Method Alpha (details of which can be found in SDRC-1 FlexDGrid "Develop an enhanced fault level assessment process").

6.2 Generation Headroom

The objective for Method Gamma is that, following the installation of an FCL, the chosen primary substation shall be able to accommodate additional generation, up to 10% of the firm capacity of that primary substation, without exceeding the equipment ratings.

For the purposes of FlexDGrid, a contribution of 4.5MVA per 1MVA of generation (equivalent of Xd" = 0.22 p.u.) has been used [3].

6.3 Equipment Limitations

The maximum fault level for the Birmingham 11kV distribution network has been determined as 250MVA (breaking fault level). This limitation is due to the legacy switchgear which is found on the 11kV network, particularly at 11/0.415kV distribution substations, where equipment short-circuit ratings are generally 13.1kA (250MVA). In addition, the 250MVA limit ensures that any customer installations (which are not necessarily accessible to WPD) are kept within the 250MVA rating limit.

6.4 Fault Reduction

The level of reduction required by the FCL within the primary substation can be expressed as a proportion of the prospective fault current that would flow if limitation was not present, i.e. a direct parallel connection was established between the two busbars. This reduction is expressed in two ways. The first is to express the reduction as a proportion of the total parallel fault level. The second is to express the reduction as a proportion of the fault contribution from the alternative source – refer Figure 5-5 (Source 2 in this instance). This second calculation provides an evaluation of the reduction to realise the restrained fault current flow through the FCL.

$$\frac{FL\ reduction\ from\ FCL}{total\ parallel\ FL\ without\ FCL} \times 100\% \qquad \frac{FL\ reduction\ from\ FCL}{FL\ from\ parallel\ source\ without\ FCL} \times 100\%$$

7 Substation Selection Process

7.1 Overview

The bid stage of FlexDGrid identified 18 primary substations that should be considered for Method Beta and Gamma due to their proximity to Birmingham City Centre and fault level information.

As part of the process of selecting suitable sites for the implementation of FCL and FLM technologies, site visits were undertaken to gain an overall understanding of the shortlisted primary substations. Following these initial site visits, a selection process took place to determine which sites were most suitable for the installation of FLMs and FCLs. The selection process was informed by scoring each primary substation against the criteria detailed in Section 7.2. The overall ranking for the shortlisted sites can be found in Appendix A.

7.2 Criteria

A number of criteria were considered to inform the selection of primary substations for inclusion of FLM and FCL technologies. For each site the following criteria were considered:

- Availability of Space: What is the amount of available space at the site for situating FLM/FCL technology?
- Network Connection: How can the connection of the technology be realised? For example, are spare circuit breakers available or would a new switchboard be required?
- Substation Access: What are the access arrangements for the primary substation? Are there any restrictions for delivering/offloading the technologies?
- Investment Plans: Are there any other works planned for the site which may influence the connection of a FLM or FCL?
- Auxiliary Supply Capacity: Is there sufficient capacity on the 110V, 48V and LVAC auxiliary systems to allow for connection of the technologies?

A weighting was assigned to each item above to determine an overall individual score for each primary substation, these are listed in Table 7-1 below. In particular, the practical aspects of each primary substation were a major factor in influencing the decision whether to install FLM or FCL technologies.

The availability of space within the primary substation to accommodate the technologies is critical to ensuring FlexDGrid is delivered on time and within budget. Where substations do not have sufficient space additional land could be purchased, however, this process is often time consuming and expensive with no guarantee of successful purchase of land. For this reason a weighting of 37.5% is assigned to this criterion.

Connection of the technologies can also impact the cost and programme for each installation. Although there are often many options for connection, these can vary substantially in complexity and therefore a weighting of 27.5% is assigned to this criterion.

With many of the chosen primary substations located in built-up areas of Birmingham, ease of access for delivering/installing/removing equipment was an important factor for the installation and future maintenance of the new and existing equipment. As such, a weighting of 20% was assigned to substation access.

A number of the shortlisted primary substations have investment projects planned or currently in progress. If the plans are in the early stages of design, it is highly likely that the proposed technology installation can be coordinated with such investment plans. For projects that are in construction, it would be possible to integrate technologies, however, carrying out modifications to newly built equipment should try to be avoided where possible. Therefore a weighting of 10% was assigned to this criterion as it is unlikely to affect the delivery of the technology solution.

Finally, the availability of auxiliary supply capacity was assigned a weighting of 5%. This weighting reflects the fact that most primary substation auxiliary systems could easily be extended to accommodate the new technologies.

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	**100.00%**

Table 7-1: Weighting for substation selection criteria

The calculated scores and subsequent ranking of each primary substation is shown in Appendix A.

7.3 Allocation of FCL & FLM Installation

The following five primary substations have been selected for installation of FCL and FLM technology. The substation matrix in Appendix A summarises their scoring against the criteria chosen for substation selection outlined in Table 7-1.

- Substation A
- Substation B
- Substation C
- Substation D
- Substation E

7.4 Allocation of FLM Only Substations

The following primary substations have been selected for installation of FLM technology. The substation matrix in Appendix A summarises their scoring against the criteria chosen for substation selection outlined in Table 7-1.

- Substation F
- Substation G
- Substation H
- Substation I
- Substation J

7.5 FlexDGrid Reserve Sites

After careful consideration following the surveys of the below primary substations, it was assessed that they would not be utilised for installation of FCL or FLM technology, unless a preferred site became unavailable. The substation matrix in Appendix A summarises their scoring against the criteria chosen for substation selection outlined in Table 7-1.

- Substation K
- Substation L
- Substation M
- Substation N
- Substation O
- Substation P

In addition to the list above to ensure a full and complete suite of contingency sites, site visits were carried out at Substation X and Substation Y.

7.6 Sites for no further consideration

7.6.1 Substation Q

It was assessed that Substation Q would not be surveyed as it is a five transformer substation with major capital investment plans to transfer over approximately 60% the demand to a new purpose built primary substation planned as Substation Z. At this time, Substation Z has not been proposed for detailed design given the current staging of the Substation Z project. Whilst not proposed for the FCL or FLM inclusion, should there be a requirement to include Substation Z, it would be envisaged that any design works for the integration of FLM or FCL technologies could readily be absorbed into the overall Substation Z design.

7.6.2 Substation R

It was assessed that Substation R would not be surveyed as it is scheduled to be de-commissioned upon completion of the Substation P works. At this time, all 11kV circuit breakers are currently running as network open points with the transformers energised until commencement of the decommissioning programme. At this stage the feasibility of re-using the land at Substation R is unclear.

8 Basis of Optioneering

8.1 Overview

The following sections describe the various options available for the electrical point of connection for the Fault Level Monitor and Fault Current Limiter technologies. The differing constraints/benefits driving these options are a function of both electrical and civil limitations/advantages which vary between primary substations.

Amongst the key criteria of the project, is that the installed equipment must not adversely impact the continuity of supply or operation of the existing system. Therefore, the options considered for integration of these technologies shall ensure that they can be electrically disconnected and the network returned to normal arrangements as and when required. This may come in the form of a "by-pass" arrangement or simply by disconnection through the use of a circuit breaker. For instance, three of the FCL connection options described in Section 8.2 encompass a 5 circuit breaker switchboard to ensure that the FCL is sufficiently protected and can be by-passed if required.

The use of circuit breakers in all situations, opposed to isolators etc., provides greater control and faster protection for these new technologies whose effective operation may be more critical than compared to traditional network components. In addition, any proposal to utilise isolators or busbar cable end boxes would require the units to be progressed through the ENA assessment process to support the plant progressing to "assessed product" status.

The FLM is designed to be connected as a shunt on to the existing network. As such it should have a negligible impact on the electrical system. Where possible the FLM has been connected to allow for measurement on more than one section of 11kV busbar. At primary substations where FCLs are proposed to be installed, the FLM has been connected in a position to measure the reduction in fault level.

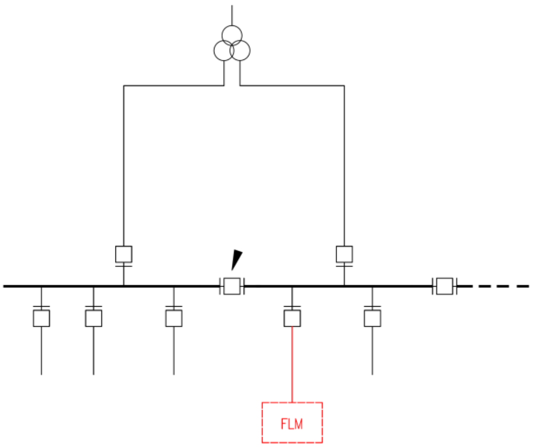
To manage fault levels the FCL can be connected in a variety of different ways, most commonly; in series with the transformer secondary winding, in series with an outgoing feeder, across a bus section/interconnector or in series with a distributed generator incomer [4]. There is also the potential to install the FCL between the secondary windings of separate transformers. Each connection option carries forward different benefits. The most suitable option for each primary substation depends on a combination of; fault limitation required, flexibility of operation, complexity of network modifications, feasibility of civil undertakings, coordination/impact with/on existing WPD projects and other specific network limitations.

The following sections outline the various connection options that have been considered along with their advantages and disadvantages.

8.1.1 FLM Locations

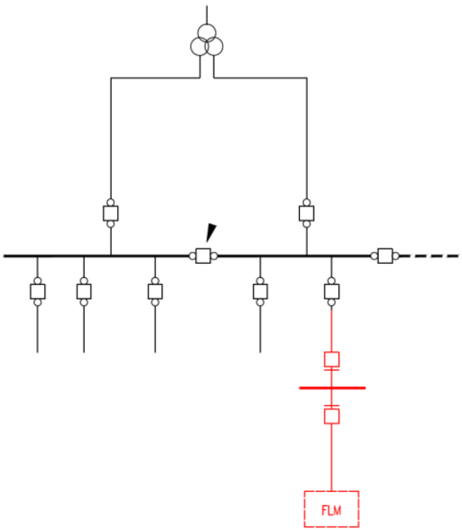
The network connections identified as options within this project for integration of FLM are described below:

Spare Breaker



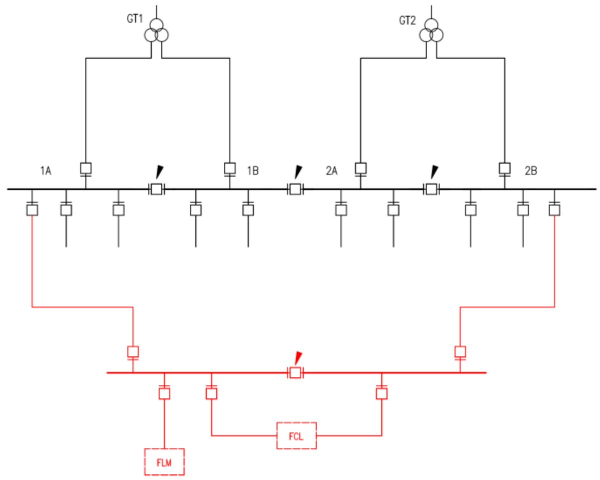
Utilise existing spare circuit breakers where the protection and operation times are fast enough to satisfy the requirements (i.e. fault can be rapidly cleared to ensure up-stream tripping does not occur).

Spare OCB



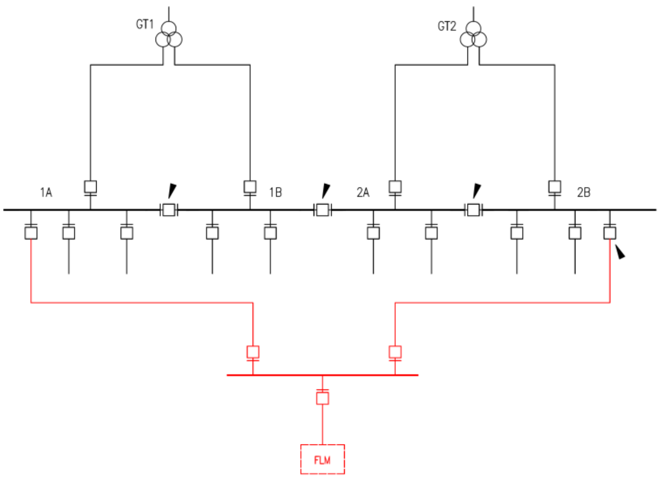
Utilise existing spare legacy oil circuit breakers to supply a new two-circuit breaker switchboard to connect the FLM. This will ensure protection and operation times are fast enough to satisfy the requirements (i.e. fault can be rapidly cleared to ensure up-stream tripping does not occur).

Connect to FCL switchboard

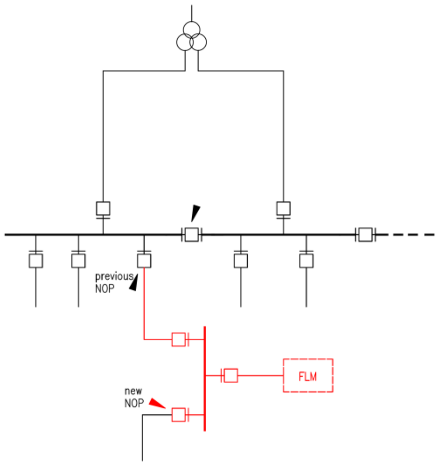
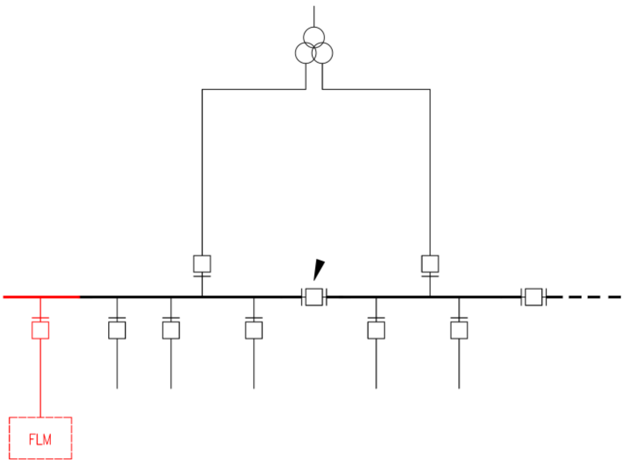


Where there is no facility to connect to another modern operating circuit breaker, the FLM could be connected on the new switchboard associated with the FCL (where installed).

Integrate in to interconnector



The FLM can be integrated in to an existing interconnector to allow measurement on more than one section of busbar. This requires a new three circuit breaker switchboard with busbars rated to match that of the interconnector.

Integrate in to normally open feeder with 3 circuit breaker switchboard 	At a number of primary substations there are one or more circuit breakers that have a "normally open" status. In these situations a new three circuit breaker switchboard can be incorporated in to the outgoing feeder and the "normally open" point moved to the new three circuit breaker switchboard to allow for measurement of fault level on the busbar. In addition to normal operational procedures to ensure the FLM circuit breaker is open before the NOP is closed, an addition electrical interlock shall be provided to trip the FLM circuit breaker should the NOP be switched to the closed position.
Extension of existing switchgear 	Where existing equipment permits, the FLM can be incorporated by means of a switchgear extension.

8.2 FCL Options

The proposed FCL connection options within this project are described in the following sections. These are summarised in Table 8-1 below.

FCL Connection	Description
FCL In Series With Secondary Winding	Installation of FCL within the LV tails of a 132/11kV transformer
FCL Across Bus-Section	Installation of FCL across a bus section
FCL Within Interconnector	FCL installation within the interconnector between two sections of switchboard
FCL Between Transformers	Installation of the FCL between two separate transformer secondary windings

Table 8-1: Summary of proposed FCL network connections

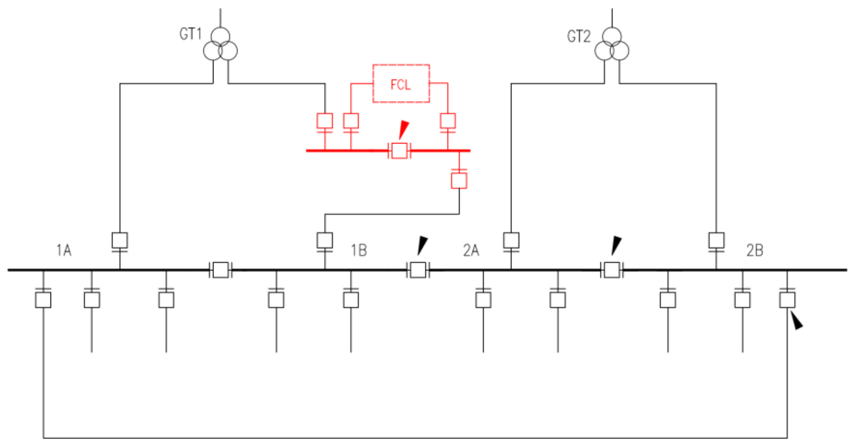
It should be noted that for placement of the FCL within a single outgoing feeder, busbar fault levels will not be significantly reduced (dependant on the fault level contributing load / generation on the feeder) and hence gains in fault level headroom could be minimal. The option for placement of the FCL within a generator incomer will only reduce fault level contribution from that generator source, and hence may not have significant impact on the existing system fault level [4] [5]. For these reasons these electrical options have not been advanced within the optioneering.

In order to provide a basis for comparing each of the options, the following generic list of advantages and disadvantages have been developed and detailed for each accordingly. These are summarised in Table 8-2 below.

FCL Network Connection Optioneering			
Advantage	**Description**	**Disadvantage**	**Description**
[A1]	Increased security of supply	[D1]	Transformer outage required
[A2]	Off line build possible	[D2]	Modifications to existing protection is required
[A3]	Reduction in fault level	[D3]	Use of FCL lost for GT outage
[A4]	Alternative combinations possible via network reconfiguration	[D4]	Can only be utilised at sites scheduled for asset replacement
[A5]	Use possible with single GT outage	[D5]	Busbar or interconnector circuit breaker outages required
[A6]	Only two circuit breakers required against a base requirement of five	[D6]	Six circuit breakers required against a base requirement of five
-	-	[D7]	Operation complexities created

Table 8-2: Summary of generic advantages and disadvantages for proposed FCL network connections

8.2.1 FCL In Series With Secondary Winding

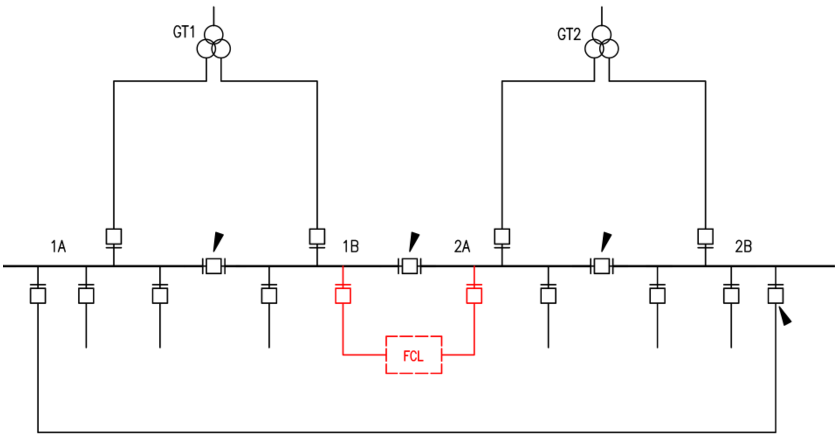


Description

In this option the FCL is positioned in series with the secondary winding of the transformer. To facilitate this connection the FCL is connected in to the 11kV cables from the transformer to the incoming circuit breaker 1B. This option is generally considered when parallel operation of two separate transformers is not possible (i.e. fed from separate GSPs) and the only feasible parallel is between 1A and 1B secondary windings.

Advantages	Disadvantages
– [A1] Security of Supply improved on the 11kV sections supplied from *GT1A* and *GT1B* – [A2] FCL and associated plant can be built off line ready for final connection and commissioning – [A3] Compared to existing parallel fault levels, the fault level will be reduced for 11kV sections supplied from *GT1A* and *GT1B* – [A4] Could be reconfigured to facilitate parallel operation between *GT1B* and *GT2A*	– [D1] Transformer outage required to facilitate final connection and commissioning – [D2] Modifications required to existing Transformer protections – [D3] Use of FCL lost for GT1 Transformer outage

8.2.2 FCL Across Bus-Section

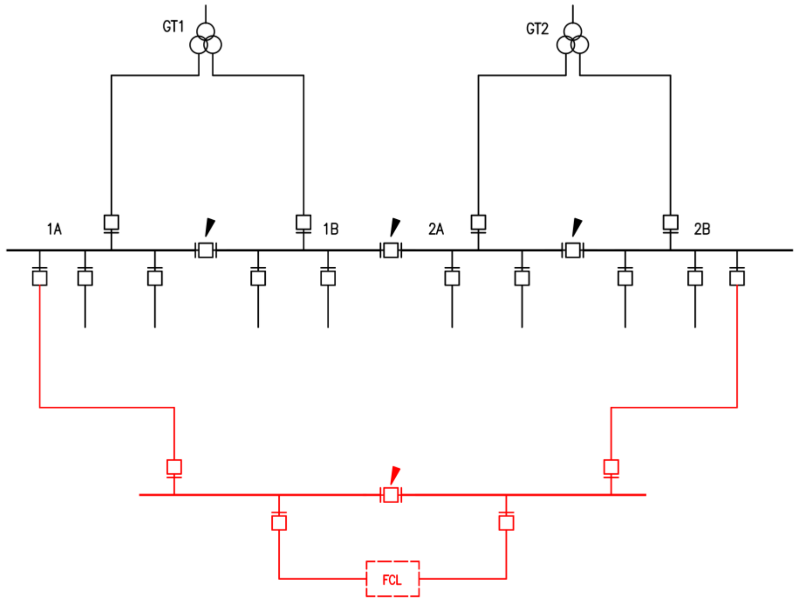


Description

This option comprises installing the FCL across a bus-section circuit breaker. Generally with existing switchgear it is not feasible to carry out this installation as it requires two busbar rated circuit breakers either side of a bus-section circuit breaker. Hence, this option is tailored towards primary substations where new switchgear is being installed**.**

Advantages	Disadvantages
– [A1] Security of Supply improved on the 11kV sections supplied from *GT1B* and *GT2A* – [A2] FCL and associated plant can be built off line ready for final connection and commissioning – [A3] Compared to existing parallel fault levels, the fault level will be reduced for 11kV sections supplied from *GT1B* and *GT2A* – [A5] For outage of *GT1, GT2A* and *GT2B* can be operated in parallel (and vice versa for loss of *GT2*) – facilitated via interconnector – [A6] Only two circuit breakers required to facilitate connection	– [D4] Only applicable to sites where the install can be comined with asset replacement of existing switchgear

8.2.3 FCL Within Interconnector

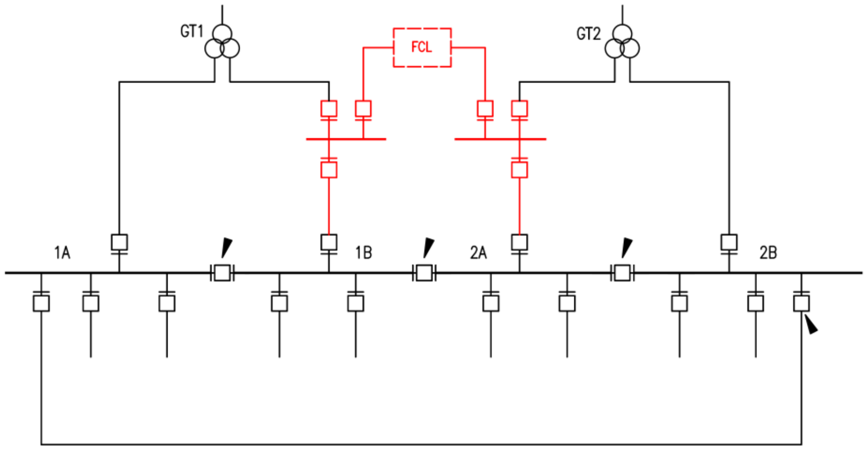


Description

This option incorporates the FCL in to the interconnector between two sections of switchboard (Sections 2B and 1A in this instance). A five circuit breaker switchboard is required to ensure that the interconnector circuits are protected and the FCL can be by-passed if necessary.

Advantages	Disadvantages
– [A1] Security of Supply improved on the 11kV sections supplied from *GT1A* and *GT2B* – [A2] FCL and associated plant can be built off line ready for final connection and commissioning – [A3] Compared to existing parallel fault levels, the fault level will be reduced for 11kV sections supplied from *GT1A* and *GT2B* – [A5] For outage of *GT1, GT2A* and *GT2B* can be operated in parallel (and vice versa for loss of *GT2*) – facilitated via FCL switchboard	– [D5] – Two 11kV Interconnector circuit breaker or full 11kV section outages required (subject to existing plant)

8.2.4 FCL Between Transformers



Description

The FCL is incorporated between two separate transformer secondary windings. To facilitate this connection the FCL is connected in to the 11kV cables from GT1B and GT2A. When considering the application of the FCL in this position a number of fundamental requirements must firstly be considered.

Advantages	**Disadvantages**
– [A1] Security of Supply improved on the 11kV sections supplied from *GT1B* and *GT2A* – [A2] FCL and associated plant can be built off line ready for final connection and commissioning – [A3] Compared to existing parallel fault levels, the fault level will be reduced for 11kV sections supplied from *GT1B* and *GT2A* [A5] For outage of *GT1, GT2A* and *GT2B* can be operated in parallel (and vice versa for loss of *GT2*) – facilitated via FCL switchboard	– [D1] – Transformer outage required to facilitate final connection and commissioning – *Two off* – [D6] Six circuit breakers required to facilitate connection – [D7] Creates operational complexities by combining two transformers within one operational arrangement

8.2.5 Asset Replacement Works

As noted in Section 0, the solution to integrate either of the FLM or FCL Technologies within a new switchboard being installed as part of the DPCR5 asset replacement works, can be managed through design integration between FlexDGrid and the asset replacement team. This limits the number of circuit breakers to facilitate a connection (e.g. two to facilitate a FCL connection versus five circuit breakers to interface with existing plant). As a result, in some instances, this would only leave one degree of protection between the FCL Technology circuit breakers and the transformer incoming circuit breakers.

Accounting for the possibility of the FCL Technology still being in its infancy at any point of installation, both a main and a back-up protection shall be provided on the FCL circuit breakers. This would require three points of failure before the operation of a transformer incomer protection – namely, the failure itself of the technology, a failure of the main protection and a failure of the back-up protection. Analysis could be carried out on the mean time between failures (MTBF) for the main and back-up protections to establish the likelihood of a complete failure; however one precaution should be to specify two different manufacturers for the main and back-up protections to eliminate the possibility of a common manufacturer fault.

9 Protection Philosophy

9.1 FCL Protection

The protection philosophy for the FCL technologies will vary depending on the individual units proposed following the tender process. As a base assumption, the data available from a previous RfI process suggests the nature of the main protection applied will consist of a current differential scheme. However this will have to take account of the dynamic nature of the device impedance under through fault conditions.

Back-up protection must be graded to ensure appropriate grading margins are maintained under normal system operation with the FCL in service whilst set to operate for any faults on the plant being protected (or in-zone faults) which occur and are not cleared by the main protection – WPD protection policy allows for a clearance time deemed practicable for the operation of back-up protection following a main protection failure. It is envisaged that this will take the form of industry standard overcurrent and earth fault protection.

9.1.1 System wide protection implications

The existing 11kV system for any given primary substation will have protection settings based on the fault levels established through the latest network models based on ER G74. If the installation of a FCL Technology results in a revised fault level being declared following detailed modelling, then there will be a requirement to carry out a full protection grading study for the site to ensure full protection discrimination at the new declared fault level.

9.1.2 In-line solution - Implication on existing transformer protection

In addition to the layout established in Section 0 full protection requirements are detailed in the specific design documents, however a number of operational constraints must be considered. Two key options to maintain instantaneous protection clearances within the transformer LV 'zone' are available. The first would be to include the full 5 circuit breaker switchboard within the overall transformer LV Restricted Earth Fault zone, whilst creating 'exclusion zones' by wiring in/balancing off CTs within the new switchboard. The second option would be to duplicate the transformer LV protection on the new incoming circuit breaker and overlap subsequent zones with busbar and current differential protection schemes. The second option would be the preferred on sites with legacy transformer protection, which employ electro-mechanical protection devices, to avoid complex vector shifts through inter-posing CTs on older protection schemes.

9.2 FLM Protection

The protection philosophy for the FLM technologies will vary depending on the individual units proposed following the tender process. As a base assumption, the data available from a previous RfI process suggests the nature of the main protection applied will most likely consist of an industry standard overcurrent and earth fault scheme. It may be appropriate to employ a back-up thermal protection in the event of a scenario whereby a fault condition is maintained within the FLM during a routine measurement.

10 Risk Register

Table 10-1 below documents the high level project risks associated with the implementation of Methods Beta and Gamma as part of FlexDGrid.

Ref	Risk	Effect	Action
R1	Delay in FCL Tender and/or delivery	Civil arrangements cannot be finalised Delay to project completion date	FCL ITT approved and issued in time. Effective programming and management of FCL manufacturers
R2	Suppliers unable to progress technologies through from proto-type status to network ready status	Unable to procure relevant technology Delay to project completion date May not be able realise the full benefit of the range of FCLs and the ability to limit the associated to fault current contribution	Detailed tender assessment on technical aspects of the technology. Ensure risks are captured during tender assessments with requests for detail of progress on proto-type units
R3	Working in live 132/11kV substation	Potential harm to persons	All works shall comply with the Distribution Safety Rules
R4	Access roads and bridges on transport routes inadequate for vehicles	Unable to deliver technologies to site	Undertake a transport survey to determine adequacy of route prior to Technology delivery
R5	Handling of contaminated materials during excavation, dismantling and construction	Potential harm to persons / Lost Time Incident	Contamination survey (COSSH) to be carried out. Identify any contaminated oil and spoil. Provide suitable handling, transport and storage facilities for contaminated spoil and waste. Disposal of spoil and equipment to be carried out by approved suppliers using licensed and approved disposal facilities

Table 10-1: Method Beta & Gamma Risk Register

11 References

[1] Western Power Distribution, “FlexDGrid Full Submission Proforma,” Ofgem, 2012.

[2] B. Bridger, “Tech Brief - X/R Ratio,” 2009. [Online]. Available: http://www.netaworld.org/files/neta-journals/NWwtr09_TechBrief.pdf. [Accessed 23 April 2013].

[3] KEMA, “The Contribution to Distribution Network Fault Levels from the Connection of Distributed Generation,” Department of Trade and Industry Technology Programme, 2005.

[4] A3.10, Cigre working Group, “Fault Current Limiters in Electrical Medium and High Voltages,” Cigre, 2003.

[5] S. M. Blair, N. K. Singh, C. D. Booth and G. M. Burt, “Operational Control and Protection Implications of Fault Current Limitation in Distributed Networks,” in *Proceedings of the 44th International Universities Power Engineering Conference (UPEC)* , 2009.

Appendices

Appendix A - Substation Assessment Matrix

Appendix B - Substation Optioneering Analysis

Appendix A – Substation Assessment Matrix

Ranking	1	2	3	4	5	6	7	8	9
Criteria	Substation A	Substation B	Substation C	Substation D	Substation E	Substation F	Substation G	Substation H	Substation I
Availability of Space	Ample	Ample	Ample	Ample	Ample	Extensive	Constrained	Limited	Ample
	Free areas in the south and east of the substation plot. Security may be an issue at the site	GT3 Future bay can be utilised for accommodating FLM/FCL	Spare area adjacent to the 132kV compound	Spare area adjacent to switchroom and spare outdoor oil bays	Spare areas at 11kV switch house and entrance	Area in the south of the 132kV compound	Spare area in compound is in close proximity to exposed 132kV busbars	Utilise existing oil tank plinth	Two spare areas adjacent to switchrooms
Network Connection	Use spare CBs	Switchgear extension	Use spare CBs	Use spare CBs	New switchboard	New switchboard	Use spare CBs	Use spare CBs	New switchboard
	Spare circuit breakers will be used for FLM and FCL	Extension of existing Eclipse switchgear using space in switch room	Connection to new switchboard being installed	Connection to new switchboard being installed	Install new switchboard in empty 11kV switchroom	Install new switchboard in empty switchroom or spare transformer bay	Spare circuit breakers could be used for FLM and FCL	Spare circuit breakers could be used for FLM. New switchboard required for FCL	New switchgear required for connection of FLM and/or FCL
Substation Access	No issues	No issues	No issues	Some limitations	No issues	Some limitations	No issues	Some limitations	Some limitations
	Adequate access for off-loading of plant	Adequate access for off-loading of plant	Adequate access for off-loading of plant	Residential street and smaller than average access gate	Adequate access for off-loading of plant	Access to 132kV compound hampered position of equipment	Adequate access for off-loading of plant	Residential street and smaller than average access gate	Substation located at a busy junction - off loading of large equipment may be difficult
Auxiliary Supply Capacity	Sufficient spare capacity	Sufficient spare capacity	None - can be extended	Sufficient spare capacity	Sufficient spare capacity	Limited - can be extended	Sufficient spare capacity	None - can be extended	Sufficient spare capacity
	Spare capacity available on batteries and LVAC	Spare capacity available on batteries and LVAC	Auxiliary systems to be extended as part of the switchgear replacement project	Spare capacity available on batteries and LVAC	Spare capacity available on batteries and LVAC	Spare capacity on batteries, LVAC may need to be extended	Spare capacity available on batteries and LVAC	New battery is likely to be required	Spare capacity available on batteries and LVAC
Investment Plans	No plans	No plans	Major scheme planned	Major scheme planned	No plans	No plans	No plans	No plans	Minor scheme planned
	Substation recently built. No plans for capital work	Substation recently built. No plans for capital work	DPCR5 scheme is underway for the replacement of 11kV switchgear	Planned DPCR5 replacement of Grid Transformers and 11kV switchgear	No plans for capital work	No plans for capital work	No plans for capital work	No plans for capital work	Customer connection to 11kV switchgear
Score %	92.5	85.6	83.3	79.2	78.8	78.3	77.5	75.8	68.8
Technology Proposed	FLM & FCL	FLM & FCL	FLM & FCL	FLM & FCL	FLM & FCL	FLM	FLM	FLM	FLM

Ranking	10	11	12	13	14	15	16	17	18
Criteria	Substation J	Substation K	Substation L	Substation M	Substation N	Substation O	Substation P	Substation Q	Substation R
Availability of Space	Limited	Limited	Limited	None	None	None	None	None	None
	Spare space will become available once switchgear has been replaced	Space available adjacent to 132kV sealing end tower	Space available in the 11kV compound	Tier-1 project to install FLM will mean that space extremely limited	No space available for additional plant	No space available for additional plant	Asset repalcement scheme underway	Asset repalcement scheme underway	Site being decommissioned
Network Connection	Use spare CBs	New switchboard	New switchboard	New switchboard	Connection not possible	Connection not possible	Connection not possible	Connection not possible	Connection not possible
	Connection to new switchboard being installed	A new switch house may need to be installed as there are no spare CBs	A new switch house may need to be installed as there are no spare CBs	Possible to extend switchgear, however, evidence of PD would suggest a new switchboard is better	No space available for additional plant	No space available for additional plant	Asset repalcement scheme underway	Asset repalcement scheme underway	Site being decommissioned
Substation Access	Restricted/Tight	Restricted/Tight	Restricted/Tight	Some limitations	Restricted/Tight	Restricted/Tight	Restricted/Tight	Restricted/Tight	Restricted/Tight
	Equipment would need to be located on the upper level using the existing crane	Plant would be situated in close proximity to the 132kV tower with no access road	Installation of additional equipment may restrict the replacement of transformers	Only a small driveway on the site with limited scope for off-loading of large plant	No space available for additional plant	No space available for additional plant	Asset repalcement scheme underway	Asset repalcement scheme underway	Site being decommissioned
Auxiliary Supply Capacity	Sufficient spare capacity	Limited - can be extended	Limited - can be extended	Limited - can be extended	None - cannot be extended	None - cannot be extended	None - cannot be extended	None - cannot be extended	None - cannot be extended
	Auxiliary systems to be extended as part of the switchgear replacement project	Spare capacity on LVAC and batteries to be confirmed	Spare capacity on LVAC and batteries to be confirmed	Spare capacity on LVAC and batteries to be confirmed	No space available for additional plant	No space available for additional plant	Asset repalcement scheme underway	Asset repalcement scheme underway	Site being decommissioned
Investment Plans	Major scheme planned	No plans	No plans	Major scheme planned	No plans	No plans	Major scheme planned	Major scheme planned	Major scheme planned
	Planned DPCR5 replacement of 11kV switchgear	No plans for capital work	No plans for capital work	Installation of FLM and 11kV switchgear under Tier-1 project	No plans for capital work	No plans for capital work	Asset repalcement scheme underway	Asset repalcement scheme underway	Site being decommissioned
Score %	65	56.7	56.7	41.7	32.3	32.3	25.6	25.6	25.6
Technology Proposed	FLM	None	None	None	None	None	None	None	None

Appendix B – Substation Optioneering Analysis

FCL Technology HV Network Integration – Optioneering Analysis					
Option	1 In-series with TX secondary	2 Across Bus-Section	3 Within Interconnector	4 Between Transformers	Chosen Option
Substation A	✓	×	✓	✓	**<u>Option 3 – Within Interconnector</u>** It is not possible to install the FCL across the existing bus-sections at Substation A as there are no spare busbar rated circuit breakers, therefore Option 2 was not considered. Options 1 and 4 were discounted for Substation A as the additional work required (protection modifications to transformers) and additional risk to the system (outages of transformers) were higher than Option 1. Hence, integrating the FCL in to the interconnector between sections U and Z offered the best solution.
Substation B	✓	×	×	×	**<u>Option 1 – In Series in GT1A secondary winding</u>** As GT1 and GT2 at Substation B are fed from two separate GSPs, it is not possible to parallel across transformers, therefore options 3 and 4 are not considered. In addition, it is not possible to install the FCL across the existing bus-sections (no spare busbar rated circuit breakers). Hence, Option 1 within the GT1A winding (with the ability to parallel with GT1B winding) has been chosen for Substation B.
Substation C	✓	✓	✓	✓	**<u>Option 2 – Over New Bus-Section (replaced under DPR5 scheme)</u>** As the switchgear at Substation C is being replaced as a separate scheme under DPCR5, the most cost effective solution is to incorporate the FCL across the new bus-section between GT2 and GT3. This option is effectively the same as installing across an interconnector, however, it only requires two circuit breakers.
Substation D	✓	✓	✓	✓	**<u>Option 2 – Over New Bus-Section (replaced under DPR5 scheme)</u>** Similar to Substation C, Substation D 11kV switchgear is being replaced as a separate scheme under DPCR5. Hence, the most cost effective solution is to incorporate the FCL across the new bus-section between GT5 and GT6.
Substation E	✓	×	✓	✓	**<u>Option 3 – Within Interconnector</u>** Similar to Substation A, it is not possible to install the FCL across the existing bus-sections and options 1 and 4 offered further work and risk. Hence, option 3 integrating the FCL in to the interconnector between sections B and E offered the best solution.

FLM Technology HV Network Integration – Optioneering Analysis							
Option	1 Spare CB	2 FCL Switchboard	3 Within Interconnector	4 Normal Open Point	5 Legacy Spare CB	6 Switchgear Extension	Chosen Option
Substation A	✓	✓	✓	✓	n/a	✓	**Option 1 – Spare CB** As there is an existing spare circuit breaker with sufficient protection and operation times, this was chosen as it is the least cost solution
Substation B	×	✓	✓	✓	n/a	✓	**Option 6 – Switchgear Extension** The extension of the existing 11kV switchgear was chosen as this will facilitate monitoring on both transformers.
Substation C	✓	✓	✓	✓	n/a	n/a	**Option 1 – Spare CB** As new switchgear is being installed under a separate DPCR5 scheme, the most cost effective solution was to connect to a new circuit breaker
Substation D	✓	✓	✓	✓	n/a	n/a	**Option 1 – Spare CB** As new switchgear is being installed under a separate DPCR5 scheme, the most cost effective solution was to connect to a new circuit breaker
Substation E	×	✓	✓	✓	✓	×	**Option 2 – FCL Switchboard** As the switchgear at Substation E is legacy equipment, the least cost solution is to install one new circuit breaker on the FCL switchboard for the FLM
Substation F	×	n/a	✓	✓	×	✓	**Option 4 – Normal Open Point** As the switchgear at Substation F is legacy equipment, the least cost solution is to install a new three circuit breaker switchboard on the Normal Open Point. No spare circuit breakers are available and the interfacing with the interconnector or providing a extension is not recommended
Substation G	✓	n/a	✓	✓	×	✓	**Option 1 – Spare CB** As there is an existing spare circuit breaker with sufficient protection and operation times, this was chosen as it is the least cost solution
Substation H	×	n/a	✓	×	✓	×	**Option 3 – Within Interconnector** To ensure that plans to replace the legacy switchgear at Substation H were not affected by the FLM installation, a new FLM switchboard

FLM Technology HV Network Integration – Optioneering Analysis							
Option	1 Spare CB	2 FCL Switchboard	3 Within Interconnector	4 Normal Open Point	5 Legacy Spare CB	6 Switchgear Extension	Chosen Option
Substation I	×	n/a	✓	✓	×		
Substation J	✓	n/a	✓	✓	×		

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