WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

FlexDGrid

Advanced Fault Level Management in Birmingham

Workshop programme

02.05.2013

Jonathan Berry (WPD)
Samuel Jupe (PB)

Introductions, aims and objectives

- Health and safety briefing

- Introductions
  - Who are you and what is your role?
  - Why are you here?
  - What do you hope to gain from today?

- Aims and objectives
  - Raise awareness of the FlexDGrid project
  - Develop networks
  - Share learning and collaborate

Comments will be treated with anonymity

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Programme for the day

10:00 – 10:30	Arrival and pre-workshop refreshments
10:30 – 11:30	Introduction to FlexDGrid and the project aims / objectives Summary of initial survey results on fault level modelling
11:30 – 12:45	Session 1 – Topic focus: Sharing best practice in modelling fault level
12:45 – 13:30	Lunch
13:30 – 14:45	Session 2 – Topic focus: Exploration of processes to enhance DNOs' knowledge of fault level
14:45 – 15:00	Break
15:00 – 15:30	Summary of workshop results and closure

FlexDGrid: Project Overview
Jonathan Berry

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

FlexDGrid

Advanced Fault Level Management in Birmingham

EFLA DNO Workshop
02.05.2013

Jonathan Berry
Innovation and Low Carbon Networks Engineer
FlexDGrid Project Manager

FlexDGrid – What and Why

What are we doing?

Understanding, Managing and Reducing the Fault Level on an electricity network

Why are we doing it?

Facilitating the early and cost effective integration of Low Carbon generation

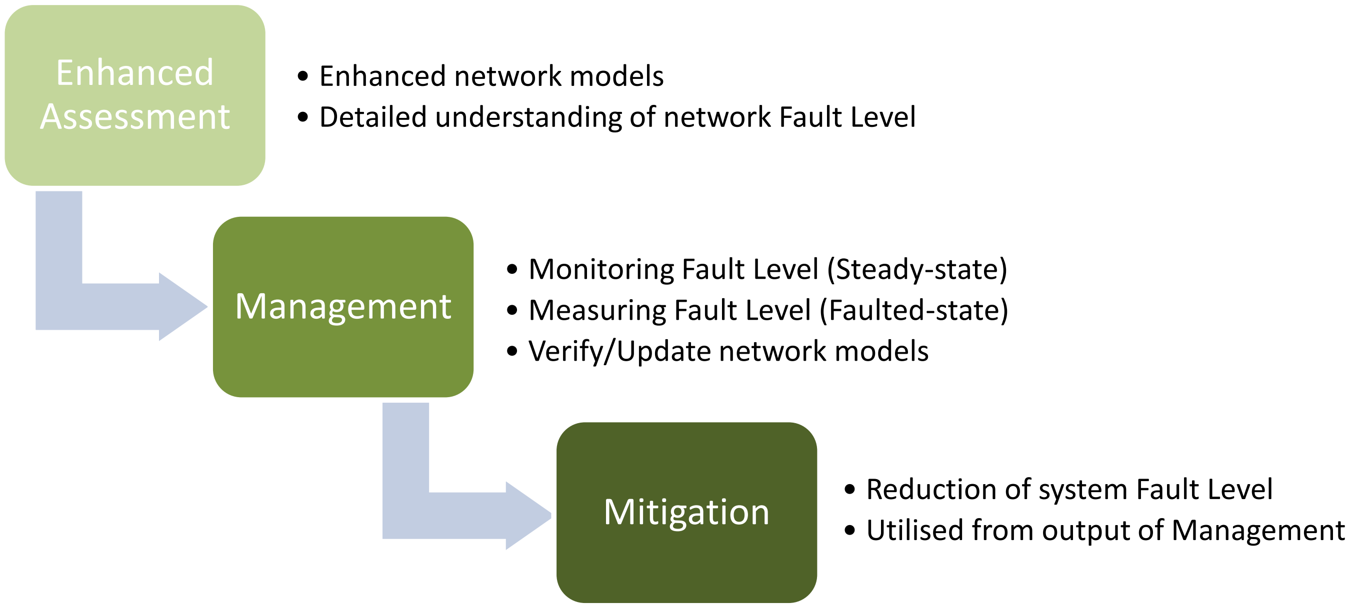
Why are we doing it now?

Supporting the Carbon Plan – Connection of generation to the grid and development of heat networks – reducing carbon emissions

Scenario	Total annual heat generation (TWh(h)/yr)	Total annual electricity generation (TWh(e)/yr)	Total electricity generation capacity (MW)	Number of homes connected to district heating	Annual carbon emission saving compared to the UK generation mix and gas boilers (kt)
Scenario 1: 10% of homes in Birmingham	0.6	0.4	71.2	41,000	60
Scenario 2: Trial Fault Level Mitigation Technology substations	1.95	1.22	214.5	123,379	180
Scenario 3: 50% of homes in Birmingham	3.3	2.0	356.4	205,000	300
Scenario 4: 50% of homes in the UK	210	131	23,051	13,258,500	19370
Scenario 5: 140 substations in the UK with Fault Level Mitigation Technologies	54.7	34.2	6,006	3,454,601	5050

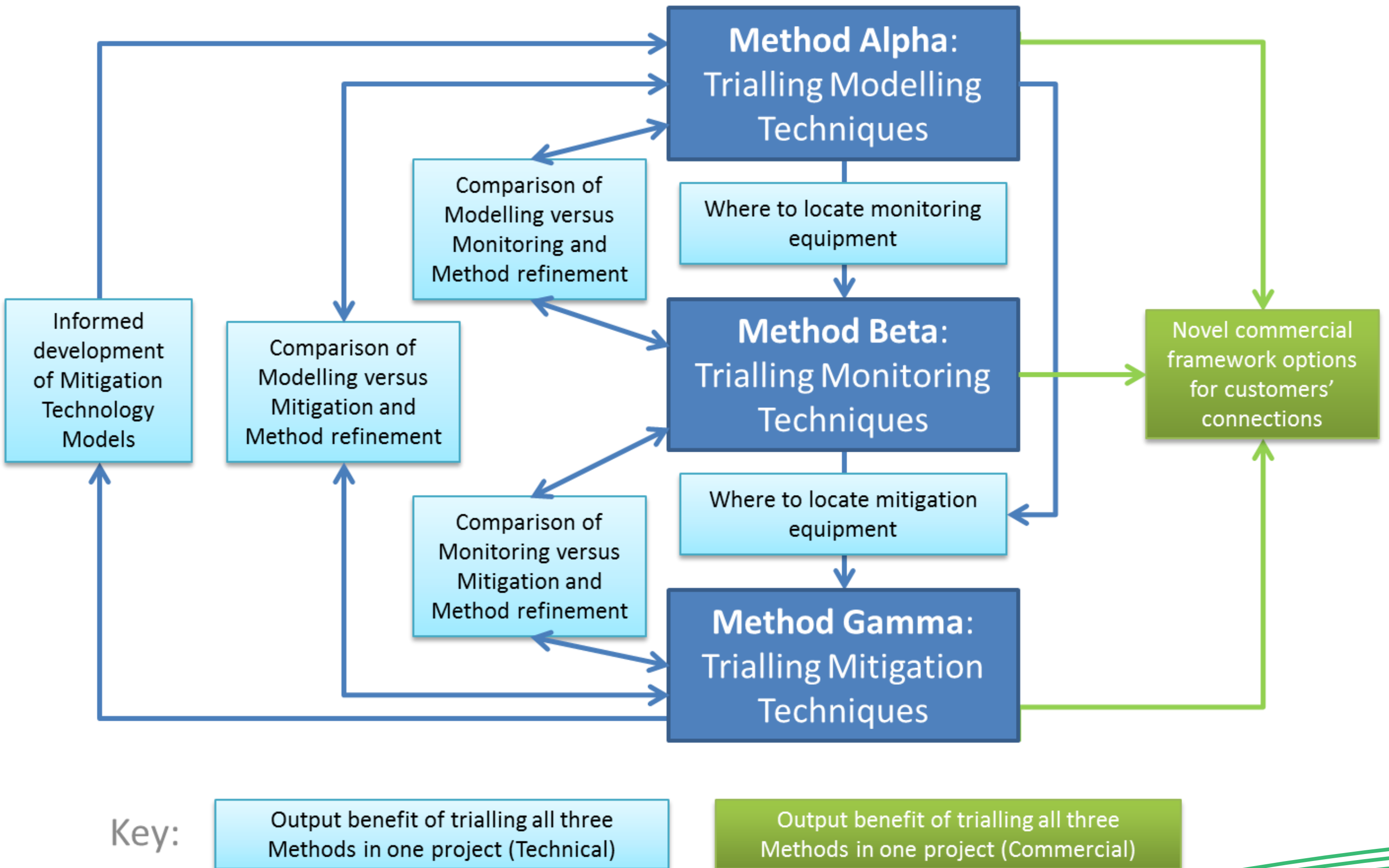
FlexDGrid - Overview

Three integrated Methods leading to quicker and cost effective customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network Fault Level



Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional generation

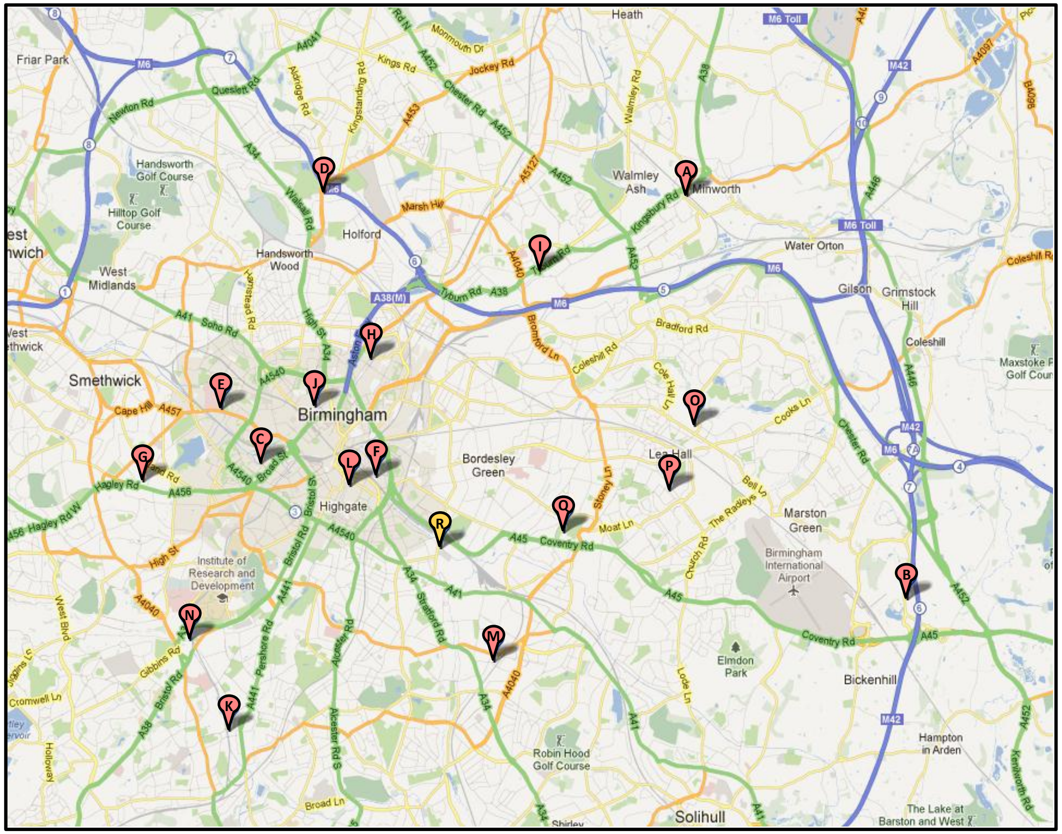
FlexDGrid Integrated Method Approach



WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

FlexDGrid – Where

Potential Primary Substations to be used in the Trials



map data © 2012 Google

Methods

Alpha – Develop enhanced network model for all of Birmingham

Beta – Install FL Monitoring and Measurement in 10 Substations

Gamma – Install FL Mitigation Technologies in 5 of the 10 (in Beta) Substations

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

QUESTIONS

?

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

FlexDGrid: Initial survey results

Samuel Jupe

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Initial survey results on fault level modelling

- Survey sent out to each GB DNO
  - Responses received representing 6 DNO licence areas

- All respondents agree that there is merit in G74 review
  - G74 is over 20 years old
  - Generator technologies have changed (DFIGs, generators with fully-rated converters)
  - A common methodology for modelling new generation types would be useful
  - Fault level is a growing concern, in-house approaches are being developed to incorporate embedded generation within G74 / IEC60909 calculations
  - Consistent approach will help demand and generation customers
  - It will be beneficial to assess results and application processes from other DNOs

Initial survey results on fault level modelling

- Development of a simple but comprehensive test network
  - Work has already been done in ASG / OSG X/R group of ENA
  - May not be widely known about

- Potential limitations of G74
  - Method options to calculate fault level can give very different results (e.g. X/R ratio)
  - Provides a general consistent approach for voltage levels at 33kV and above, but difficult to apply at HV levels
  - Elements may need updating / expanding

Initial survey results on fault level modelling

- Both IEC60909 (hand calculations) and G74 standards (computer simulations) are used
  - DINIS
  - IPSA
  - PSS/E

- Extent of HV network model
  - 33kV, 11kV and 6.6kV networks modelled in detail with 132kV (slack busbar) connections
  - Separate model for EHV network to HV primary busbars and HV primary substation busbars to corresponding HV distribution networks
  - From National Grid SGTs to 11kV / 6.6kV busbars

Initial survey results on fault level modelling

- Issues encountered with application of G74
  - Some software does not facilitate variable time constants for transient / sub-transient components
  - Limited guidance on the modelling of power electronics (DFIGs, PV, STATCOM)
  - A.C. decrement of fault level and modelling plant with very short A.C. time constants

- DG modelling assumptions
  - Inverter-connected generation modelled as equivalent synchronous model
  - 33kV: DG modelled
  - 11kV: DG modelled , DG modelled as an equivalent in EHV model
  - 0.4kV: DG modelled as an equivalent in EHV or mixture or not at all

Initial survey results on fault level modelling

- Load fault contribution modelling assumptions:
  - Different approaches taken by DNOs
- Is the load fault contribution of sufficient accuracy?
  - Yes
  - Unsure
  - No - it's unclear whether the values are still representative of today's loads
  - At what point should we move from HV to LV load modelling
- Safety margins between calculated fault levels and switchgear ratings vary from 0% - 5%

Initial survey results on fault level modelling

- Short-term paralleling allowed to exceed ratings by some DNOs
- Some DNOs have issues with data for generation connection studies
  - Difficult to obtain detailed technical data from customers
  - Due to the need for an equivalent synchronous in-feed
- Fault level is currently or expected to be a constraint on the connection of generation in some urban areas
- Number of uneconomic connections (due to fault level) unknown – DNO does not find out why customers do not proceed with developing projects

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Programme for the morning

- 10:30 – 11:30

  Introduction to FlexDGrid and the project aims / objectives

  Summary of initial survey results on fault level modelling

- 11:30 – 12:45

  Session 1 – Topic focus: Sharing best practice in modelling fault level

- 12:45 – 13:30

  Lunch

Topic Focus 1: Sharing best practice in fault level modelling

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Topic Focus: Sharing best practice with modelling fault level in HV networks

- What modifications are needed to G74 to address fault level modelling issues?
- How should these modifications be made?
- How should these modifications be tested?

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Topic Focus: Sharing best practice with modelling fault level in HV networks

- How are staff trained to conduct fault level studies?

- What are the benefits, issues and challenges arising from enhancements to fault level calculations from the following perspectives:

  - Political
  - Economic
  - Social
  - Technological
  - Legislative
  - Environmental

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

FlexDGrid: Lunch break

Food for thought:
Should we move towards probabilistic fault level assessments?

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Programme for the afternoon

- 13:30 – 14:45

  Session 2 – Topic focus: Exploration of processes to enhance DNOs' knowledge of fault level

- 14:45 – 15:00

  Break

- 15:00 – 15:30

  Summary of workshop results and closure

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Topic Focus 2
Processes to enhance DNOs' knowledge of fault level

Topic Focus: Exploration of processes to enhance DNOs’ knowledge of fault level

1. Base-line current approaches (covered this morning)
2. Explore assumptions and their impact on fault level calculations
3. Increasing the granularity of fault level assessments
4. Monitoring / measuring fault level
5. Mitigation of fault level
6. Novel commercial frameworks to offer connection options to customers

- What are the benefits and challenges with utilising probabilistic fault level assessments?

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Topic Focus 2: Processes to enhance DNOs’ knowledge of fault level

1. Base-lining

Topic Focus 2:
Processes to enhance DNOs' knowledge of fault level

2. Exploration of assumptions and sensitivity analysis

Topic Focus 2:
Processes to enhance DNOs' knowledge of fault level

3. Increasing the granularity of fault level assessments

Topic Focus 2: Processes to enhance DNOs' knowledge of fault level

4. Measuring and monitoring fault level

Topic Focus 2:
Processes to enhance DNOs' knowledge of fault level

5. Mitigating fault level issues

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Topic Focus 2:
Processes to enhance DNOs' knowledge of fault level

6. Novel commercial contracts

Topic Focus 2:
Processes to enhance DNOs' knowledge of fault level

Voting on priorities

FlexDGrid:
Summary of today's outcomes and recommendations

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

FlexDGrid: Closing comments

FlexDGrid: Workshop closure

Thank you for your time

Please complete the feedback form

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Fault Level Mitigation Technologies
DNO Workshop

Wednesday 4th September 2013

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Agenda

10:00 – 10:30	**Arrival – Refreshments and Networking**
10:30 – 11:10	Round table introductions to include delegates background in FCL work
11:10 – 11:30	Overview of FlexDGrid and the purpose of the workshop
11:30 – 12:00	Presentation 1 – Topic Focus: Modelling and Enhanced Fault Level Assessment
12:00 – 12:45	Presentation 2 – Topic Focus: Mitigation Technologies and approach to connection
12:45 – 13:30	Lunch and Networking
13:30 – 14:30	Discussion on FCL installation and implementation
14:30 – 14:45	Break
14:45 – 15:15	Sharing best practice options
15:15 – 15:30	Summary of workshop results and next steps
15:30	**Close**

Welcome and Introductions

DNO	Name	Job Title
WPD	Jonathan Berry	Innovation Engineer
WPD (Power Academy)	Aimée Slater	Student Engineer
WPD (Parsons Brinckerhoff)	Samuel Jupe	FlexDGrid EFLA Lead
WPD (Parsons Brinckerhoff)	Neil Murdoch	FlexDGrid Distribution Lead
UKPN	Ian Cooper	Senior Technology Transfer Engineer
UKPN	Allan Boardman	Network Design Standards Manager
UKPN	David Boyer	Solution Design Authority - Low Carbon London
SSE	Tawanda Chitifa	R&D Project Manager
SPEN	Eric Leavy	Head of Design
ENWL	Geraldine Bryson	Future Networks Technical Manager
NPG	Dr. Roshan Bhattarai	System Planning Engineer

Overview of FlexDGrid and workshop aims

Jonathan Berry

Western Power Distribution

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Methods Alpha and Beta

Enhanced fault level assessment and modelling

Samuel Jupe MEng PhD CEng MIET

Senior Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks
THE UNIVERSITY OF WARWICK
PARSONS BRINCKERHOFF

Agenda

- Overview of Methods
- Method Alpha
  - Processes
  - Emerging learning
  - Next steps
- Method Beta
  - Trials
  - System design
  - Next steps
- Integrated Methods

Overview of Methods

- There are three separate Methods identified in FlexDGrid:
  - Method Alpha: Enhanced Fault Level Assessment
    - Focus on modelling fault levels at 15 Primary Substations and 11kV network
    - Provide datum metrics by which benefits of practical trials can be assessed
  - Method Beta: Real-time Management of Fault Level
    - Focus on measurement and monitoring of 11kV fault level at 10 Primary Substations
  - Method Gamma: Fault Level Mitigation Technologies

Method Alpha: Enhanced fault level assessment processes

1. Baseline the consistency of application of present fault level assessment methods
2. Explore assumptions and carry out a sensitivity analysis of standard fault level calculation methods
3. Increasing the frequency and granularity of fault level assessments
4. Design and deployment of fault level measurement and monitoring technologies
5. Design and deployment of fault level mitigation technologies
6. Connection offers based on novel commercial frameworks

Emerging learning: DNO Questionnaire Conclusions

1. Engineering Recommendation G74 requires clarifications on its application:
   a) Guidance on new forms of generation
   b) Modelling of aggregated loads
   c) Validity of general load contribution

2. Sensitivity analysis would provide useful learning

3. Open source database of generation / motor plant types would be beneficial

Emerging learning: DNO Questionnaire Conclusions

4. Open source fault current limiter models would be of benefit to the DNO community

5. Increased frequency and granularity of fault level assessments could be beneficial but would need to outweigh increased modelling effort

6. A move to probabilistic fault level assessments was not deemed to be feasible due to ESQCR and H&S implications

7. There is a need for training processes to be documented

Emerging learning: SDRC-1 Recommendations

1. The 6 process identified and detailed in the SDRC-1 document will be followed
2. A follow-on workshop will be organised with other DNOs to feedback baseline and sensitivity analysis results
3. It is not clear how the values for general load contribution were originally derived:
   a) Load mixes and fault contributions will be investigated
   b) Introduction of fault level monitoring equipment

Emerging learning: SDRC-1 Recommendations

4. An industry-wide review of G74 should be conducted with a focus on the consistent application of G74 to HV networks

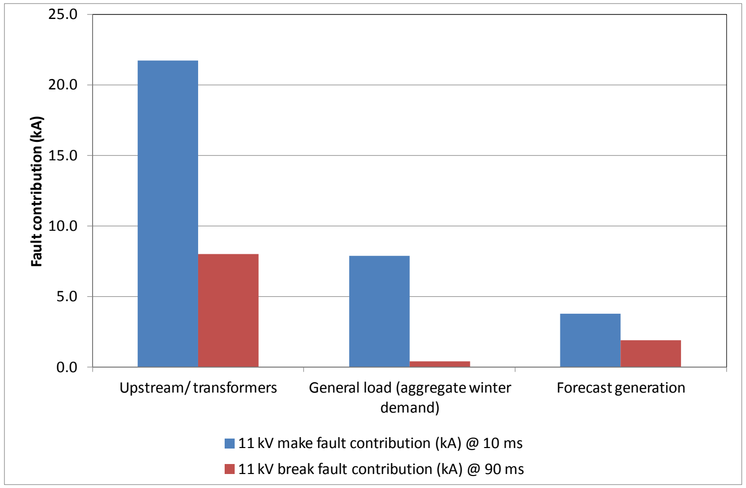
5. For training and consistency, DNOs should formally document their connection study process

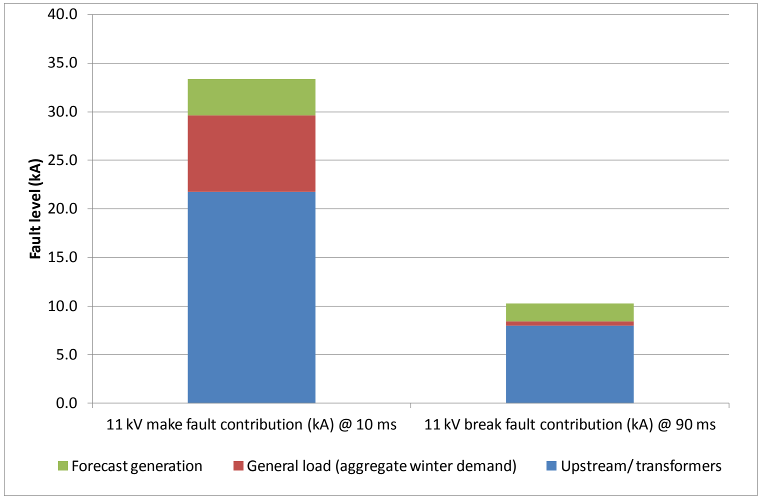
6. Development of integrated EHV and HV electricity network models

7. Confirm the need to de-rate switchgear in line with CIGRE Recommendation 304

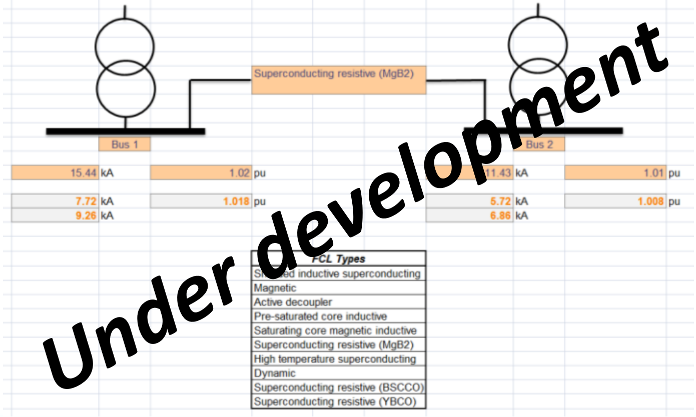
Method Alpha: Next Steps

- Fault level decomposition





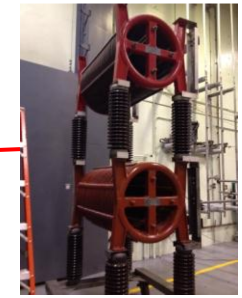
- Fault current limiter models
  - Functional specification
  - Excel interface
  - PSS/E 'black box'



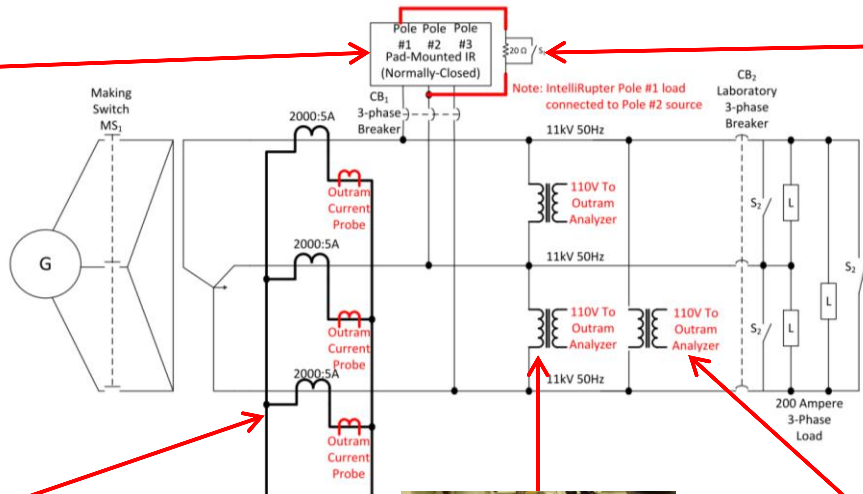
Method Beta: Real-time fault level management

Example monitoring system

IntelliRupter



Inductor

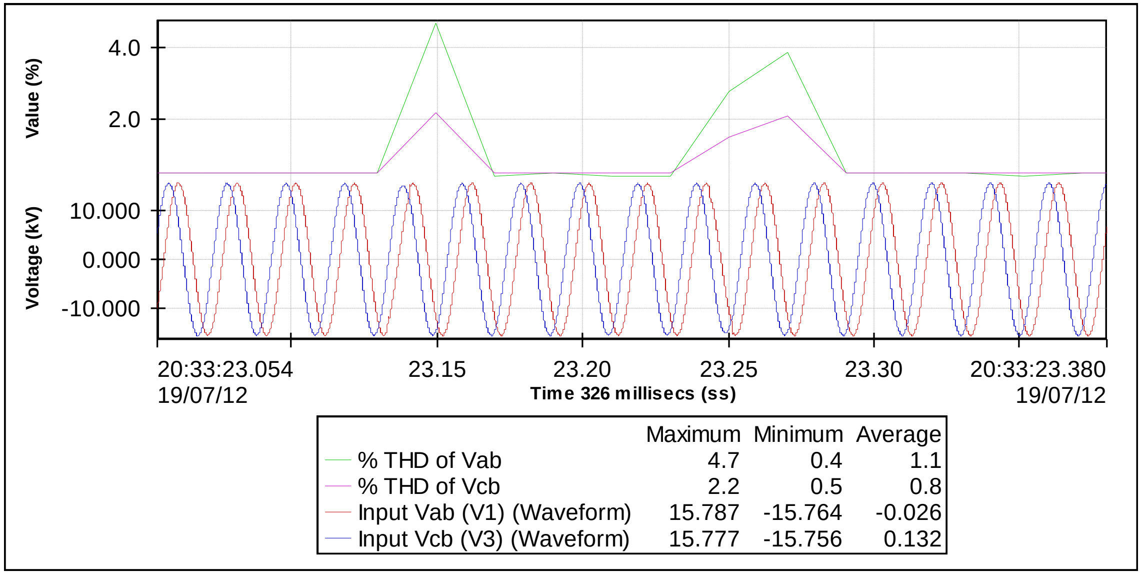


Current Transformers

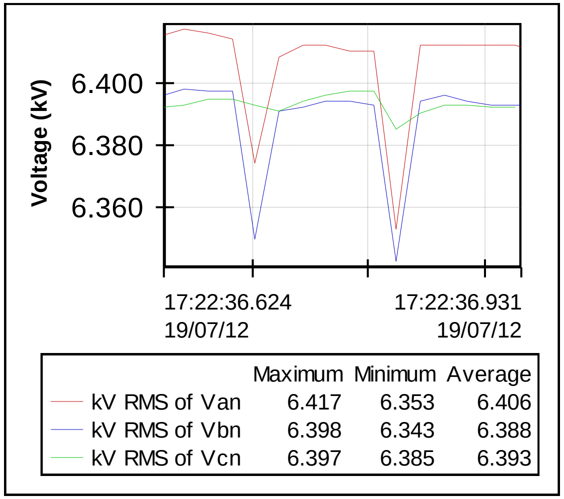
Voltage Transformers

PM7000 - FLM

Method Beta: Results



Harmonic distortion caused by FLM

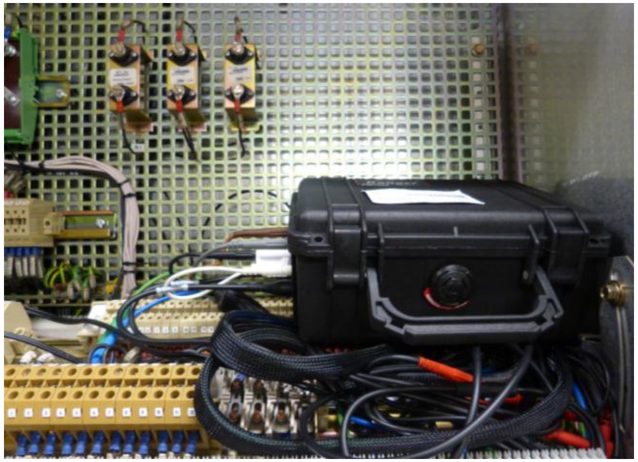


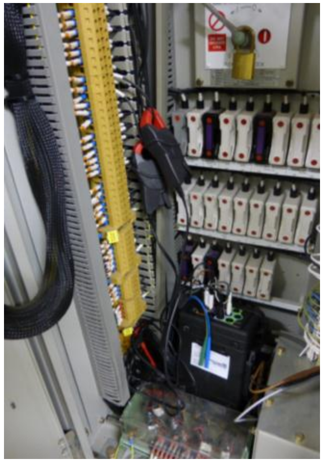
Voltage fluctuation caused by FLM

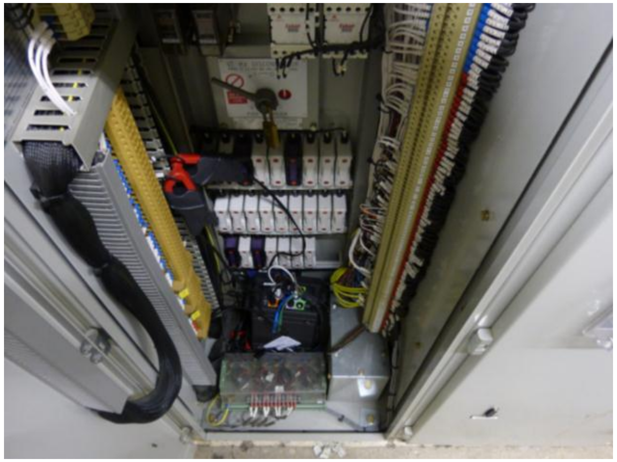
- Both tests were carried out using the factory acceptance test arrangement
- Maximum voltage fluctuation is 1% in a 300ms timeframe (ER P28 compliant)
- Maximum Total Harmonic Distortion is 4.7% in a 300ms timeframe (ER G5/4 compliant)
- **Fault Level prediction accuracy within 4.5%**

Method Beta: Next Steps

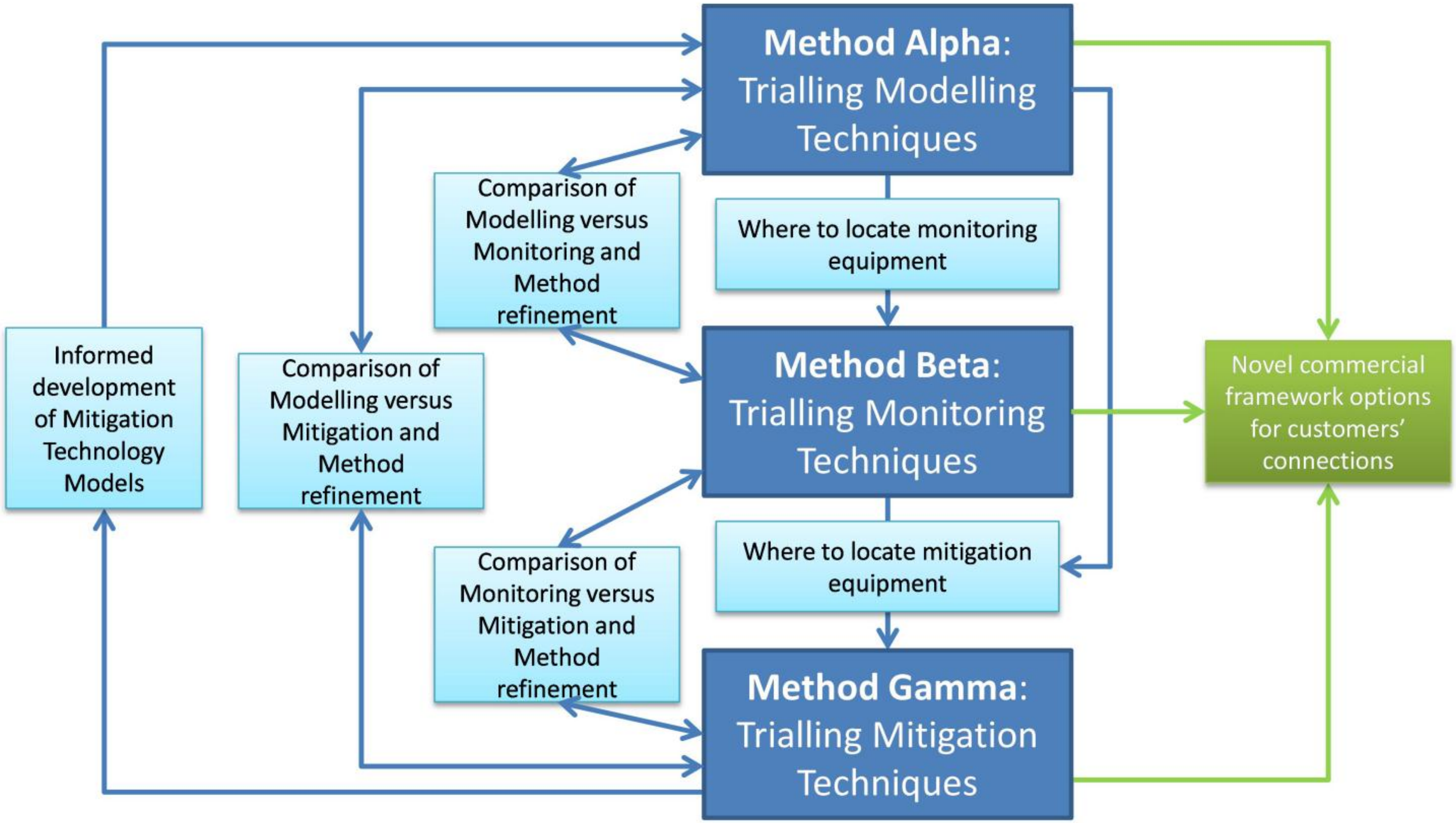
- Currently out to tender for fault level monitoring devices
- PM7000 measurement devices have been installed at 3 out of 10 Primary Substations to date







Integrated Methods and Expected Learning



Any Questions?

Date for the diary:
DNO Workshop on the Implementation of
Enhanced Fault Level Assessment Processes
Wednesday 23 October 2013
Austin Court, IET Birmingham

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Method Gamma

Proposed Methodology for Method Gamma

LCN Fund Low Carbon Networks
THE UNIVERSITY OF WARWICK
PARSONS BRINCKERHOFF

Agenda

- Method Gamma Objectives
- Fault Level Mitigation Methods
- Overview of Emerging Fault Current Limiter Technologies
- Substation Selection Process
- Connection Options for Technologies
- Technology Integration for FlexDGrid Substations

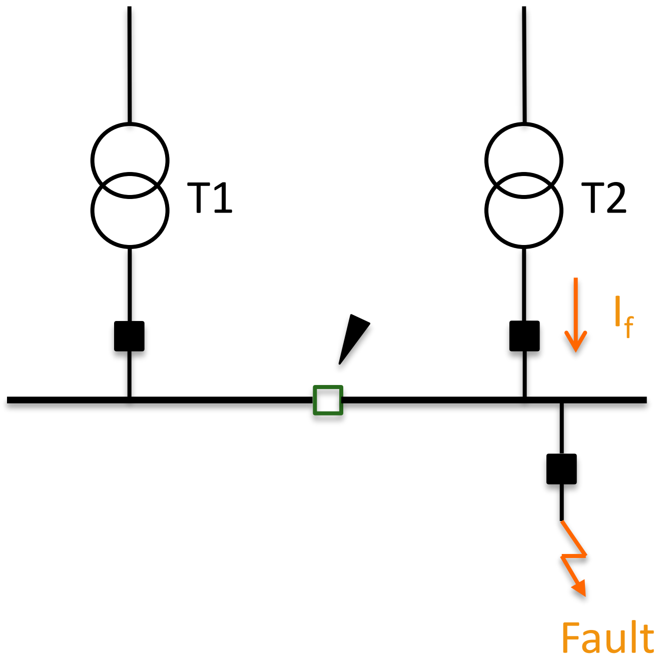
Method Gamma Objective

- There are three separate methods identified for FlexDGrid:
  - Method Alpha: Enhanced Fault Level Assessment
  - Method Beta: Real-time Management of Fault Level
  - Method Gamma: Fault Level Mitigation Technologies
    - Build on knowledge learned through IFI, ETI and LCNF Projects
    - Install 5 FL Mitigation Technologies in 5 separate WPD substations
    - Test & Trial Technologies to quantify performance and network benefit

Fault Level Mitigation Methods

- There are number of established and emerging methods to manage Fault Level on Power Networks.
  - Network Operation, running “split” or “open”
  - Bus-section reactor
  - Pre-Saturated Core FCL
  - Resistive Superconducting FCL
  - Power Electronic FCL

Network Running "Open"



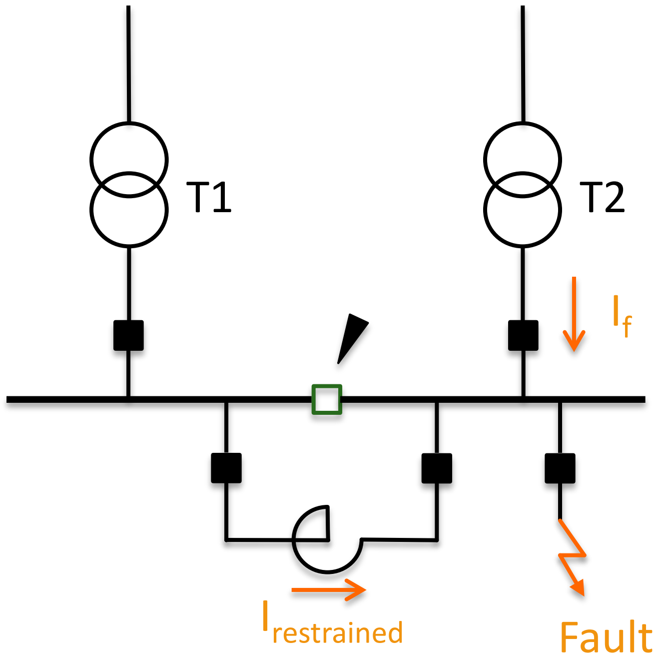
- Run the network "open" or "split" to avoid parallels between two sources

✓ Simple to implement
✓ Large reduction in FL
✓ Zero cost

✗ Large reduction in security
✗ Can reduce firm capacity
✗ Loads on busbars need to be balanced (tx sharing)

Bus-Section Reactor

– Install a reactor between two busbars to create a "loose couple" arrangement



- ✓ Proven technology
- ✓ Security of supply
- ✓ Installation/Maintenance similar to transformer

- ✗ Losses
- ✗ Limited fault level reduction
- ✗ Can limit load flow as well as fault level

Emerging FCL Technologies Considered

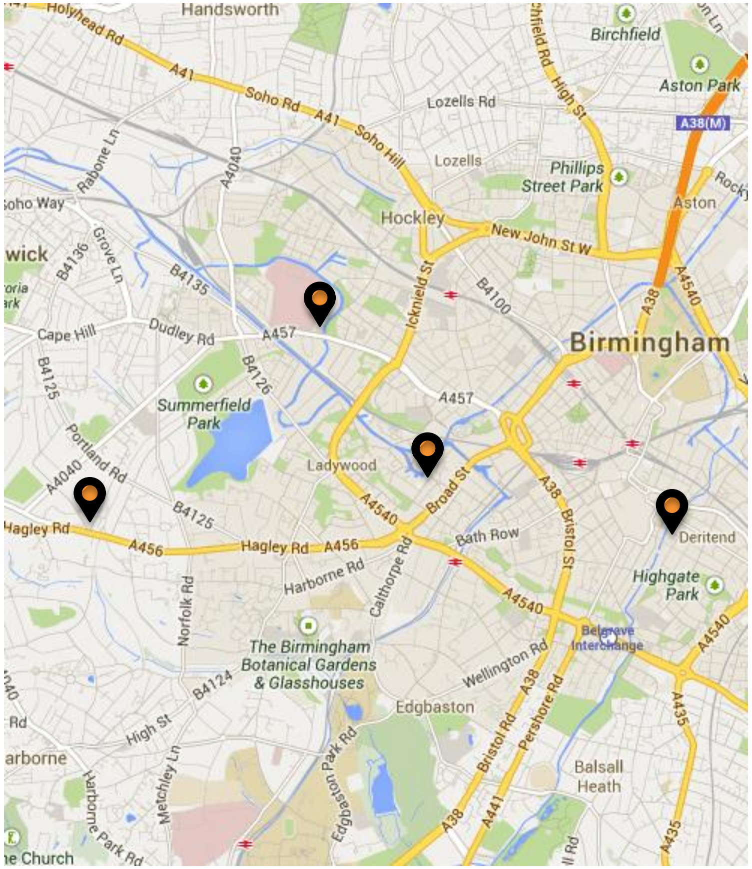
- Pre-Saturated Core FCL
  - Design similar to a transformer, the iron core is normally saturated by a DC coil secondary winding (can be superconducting)
- Resistive Superconducting FCL
  - High Temperature Superconductor inserted in series with the network. Can be used in conjunction with a shunt reactor / resistor
- Power Electronic FCL
  - Uses self-commutated semiconductor devices to interrupt fault current

Emerging FCL Technologies Considered

- Open, competitive tender process currently ongoing for FlexDGrid
- New technologies must be fail-safe to allow connection to the network
- Advantages of new technologies include
  - High percentage FL reduction
  - 'Invisible' during normal operation
  - Low losses

Substation Selection

- 18 substations identified in and around Birmingham with FL issue
- 5 sites for FCL selected:
  - Availability of Space
  - Network Connection
  - Substation Access
  - Investment Plans
  - Auxiliary Equipment



Availability of Space

- Purchase of land can be expensive and time consuming
- Use of spare land considered in proximity to the connection point
- Checks with Primary System Engineers to ensure land is not required for future developments

Network Connection

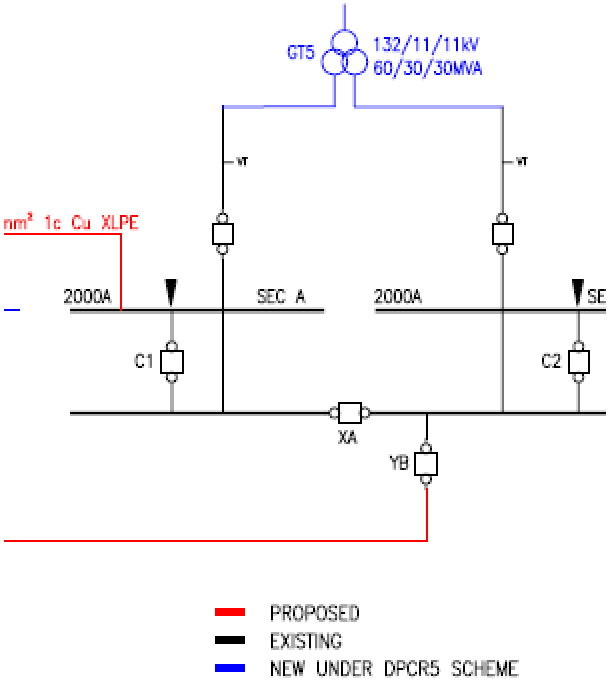
- Consider the complexity of connection to the 11kV network
- Where possible avoid extensive alterations to protection schemes
- Connection options are considered later in the presentation

Substation Access

- FCLs can be large in size
- Ensure delivery and off-loading of equipment in built areas is feasible without major alterations to the substation
- Be aware of clearances and access for future replacement of transformers etc.

Investment Plans

- Careful consideration for substations that are earmarked for load and non-load related reinforcement
- Avoid locating equipment where it may hinder future expansion/replacement
- Savings by incorporating FCL switchgear in plans



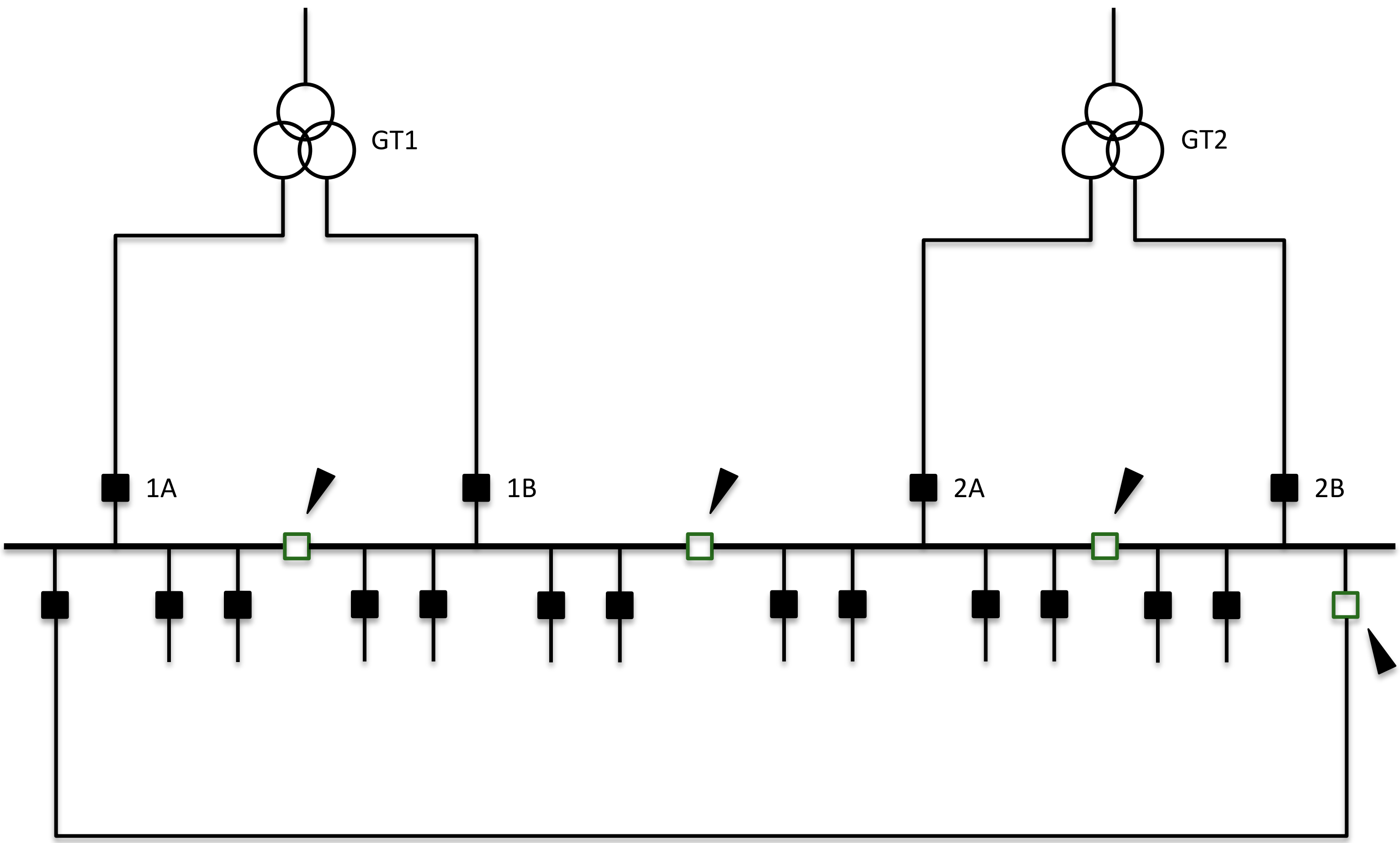
Auxiliaries

- Check the availability/capacity of existing systems (LVAC, 110V, 48V and SCADA)
- New FCL equipment (and switchgear) may require extensions and/or replacement of these systems

Birmingham Distribution Network

- The network in Birmingham has evolved over time and there is limited 33kV network in the area
- All of the sites shortlisted for FlexDGrid were 132/11kV substations with higher 11kV fault levels than would be seen at a normal 33/11kV substation
- The majority of substations have dual wound, 132/11kV, 60/30/30MVA transformers

Typical substation configuration



Operating Arrangement

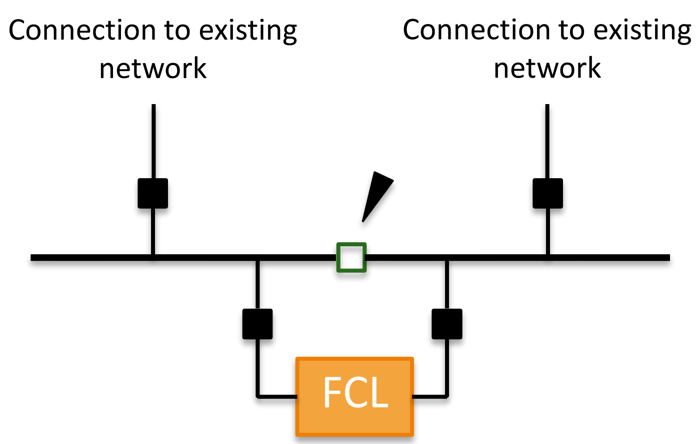
- To minimise the impact of fault level on the network, bus-sections are run open
- 11kV primary and secondary switchgear have a ‘break’ rating of 250MVA
- Auto-switching schemes are in place to restore customers following interruptions to the incoming supply

FCL Connection Options

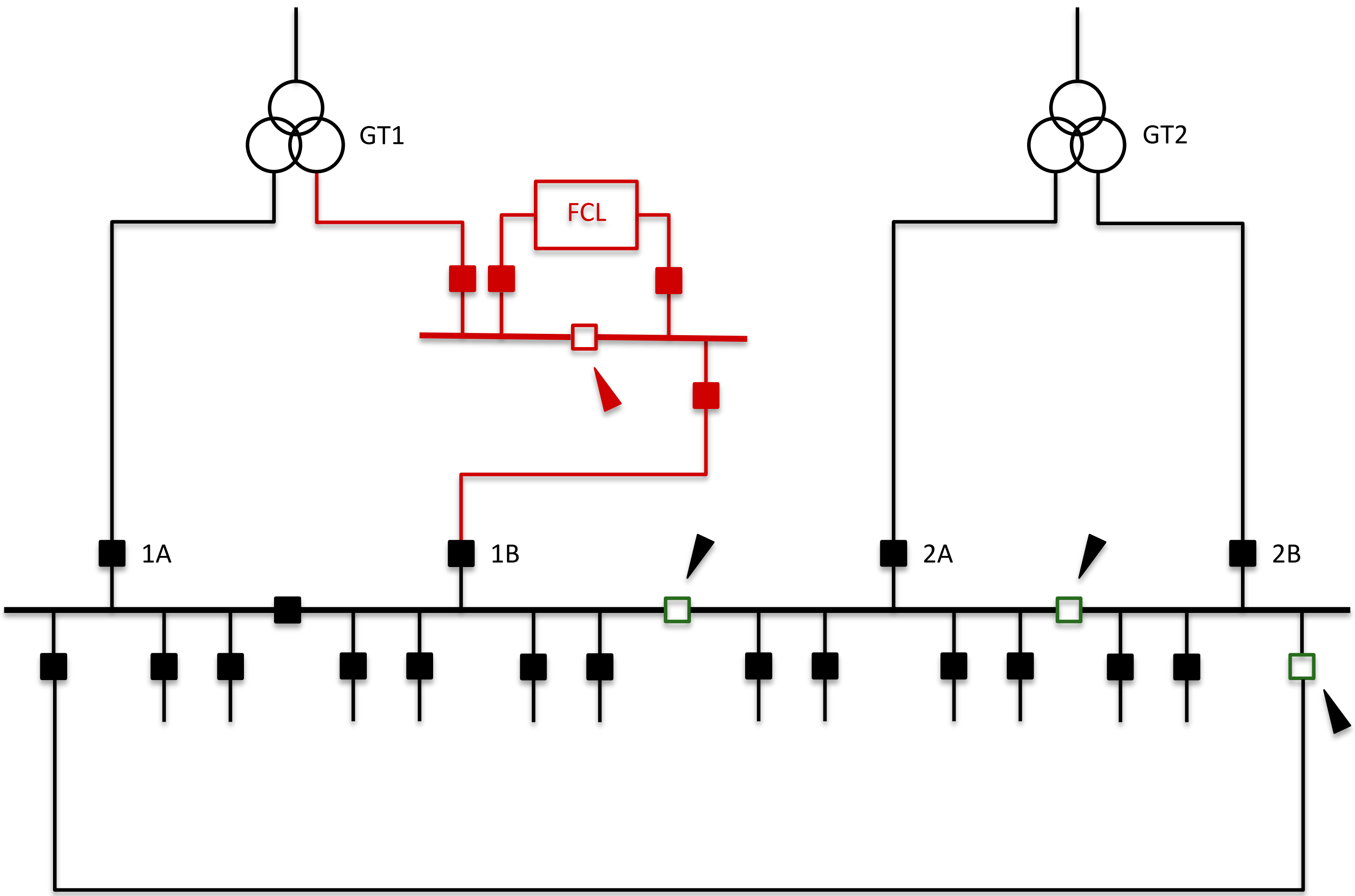
- In series with secondary winding
- Across Bus-Section
- Within Interconnector
- Between Transformers

Network Integration

- Connection of the FCL shall provide the facility to return to the existing network configuration
- FCL can be by-passed for maintenance or during abnormal running

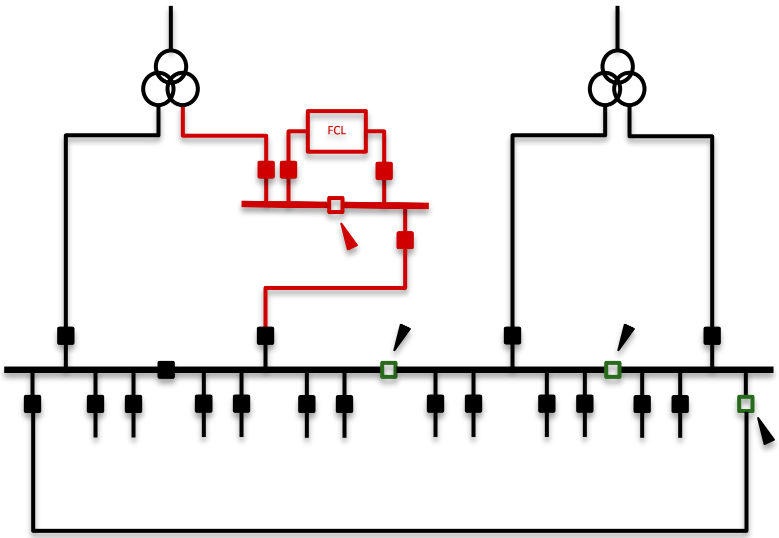


FCL in series with secondary winding



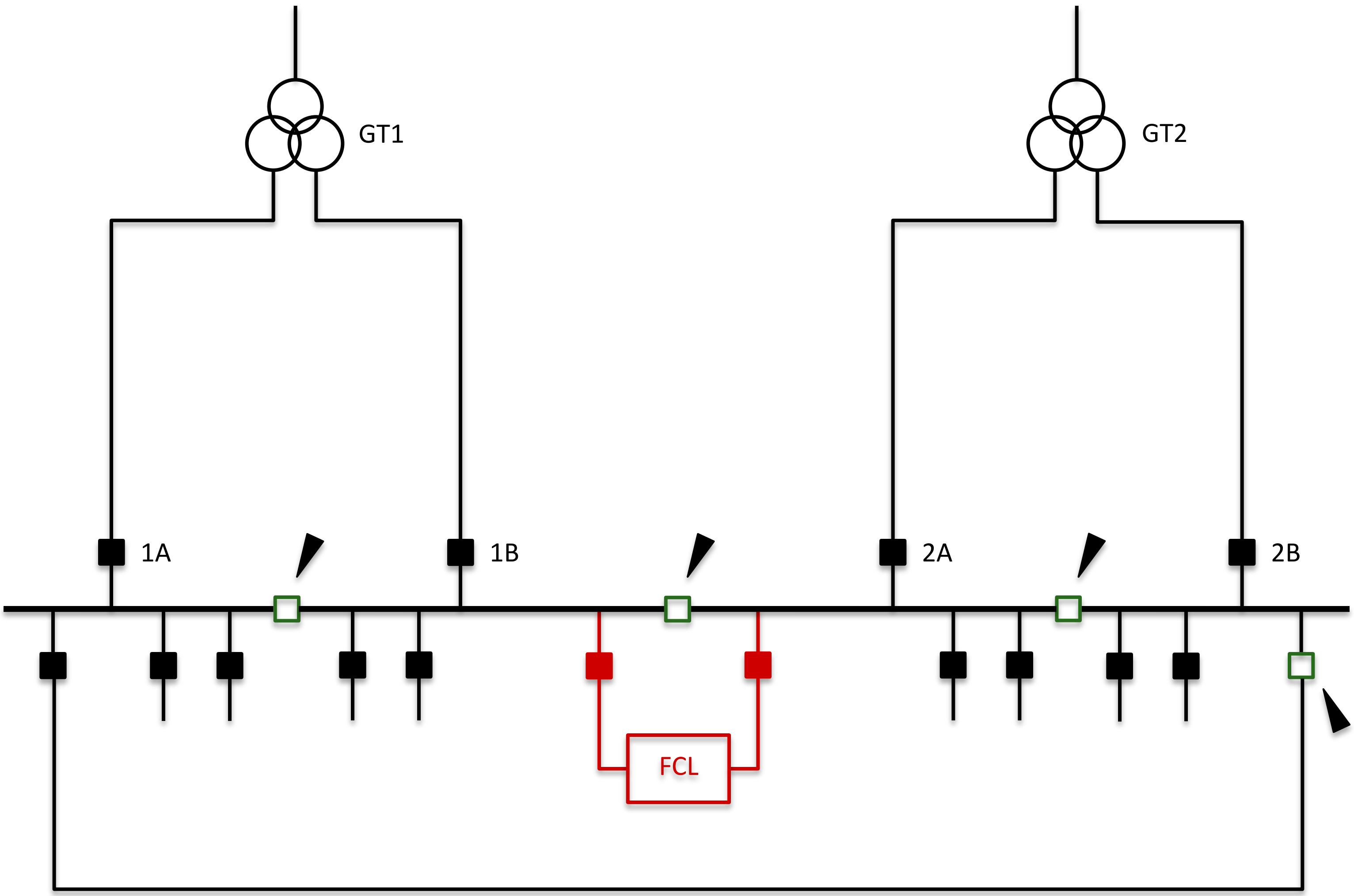
FCL in series with secondary winding

- GT1A and GT1B in parallel
- Consider this option when paralleling two separate transformers is not possible



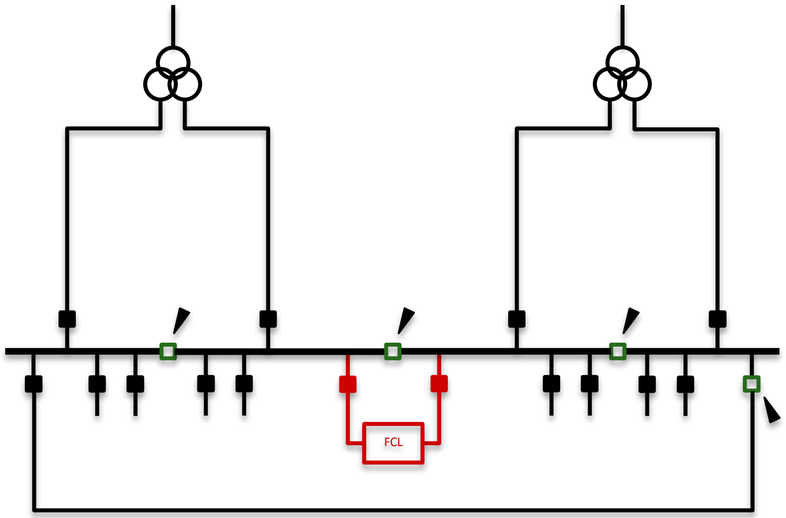
- ✓ Security of supply
- ✓ Equipment can be installed off line prior to final connection
- ✗ Transformer outage required
- ✗ Modifications required to transformer protection

FCL across Bus-Section



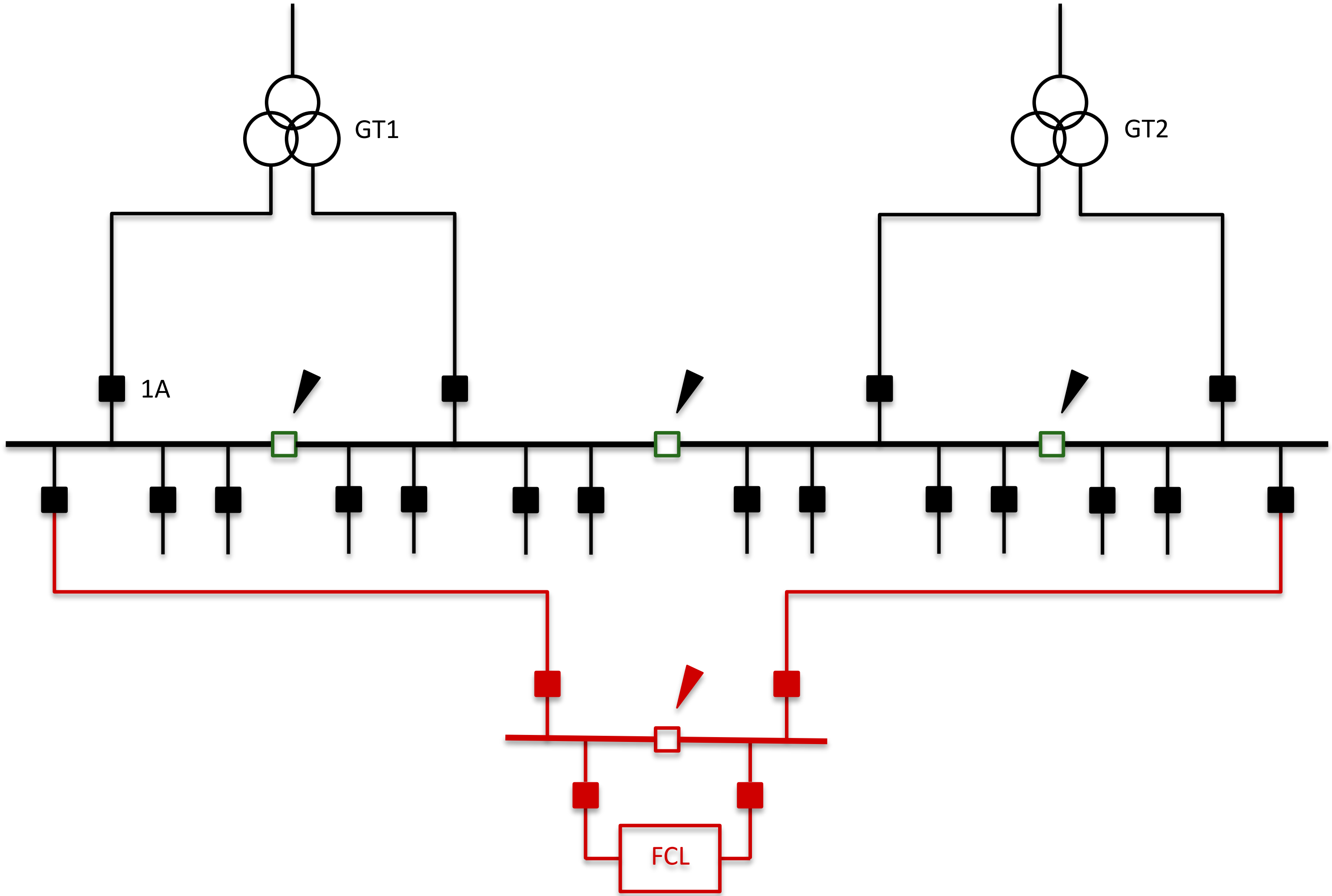
FCL across Bus-Section

- GT1B and GT2A in parallel
- Considered for installations where new switchgear is being installed



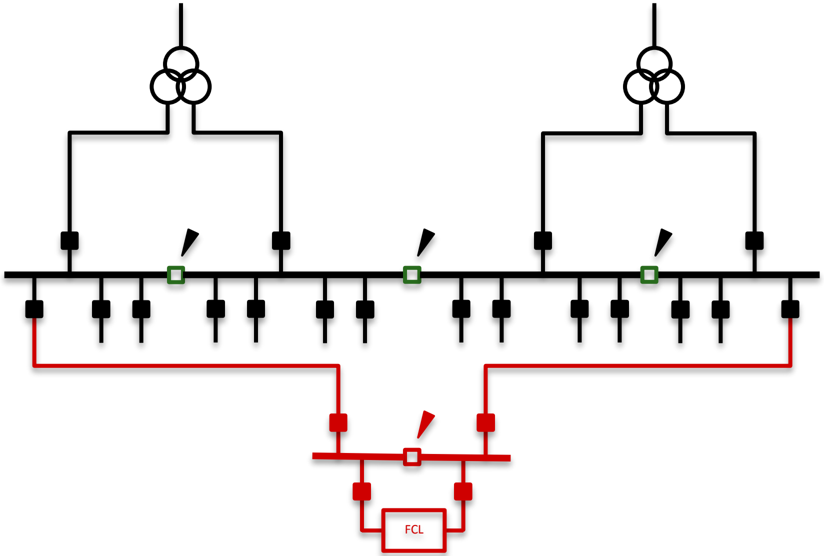
- ✓ Equipment can be installed off line prior to final connection
- ✓ Security of supply
- ✓ Only two circuit breakers required for connection
- ✗ Only applicable where existing switchgear is being replaced

FCL within interconnector



FCL within interconnector

- GT1A and GT2B in parallel
- FCL is connected into the 11kV interconnector

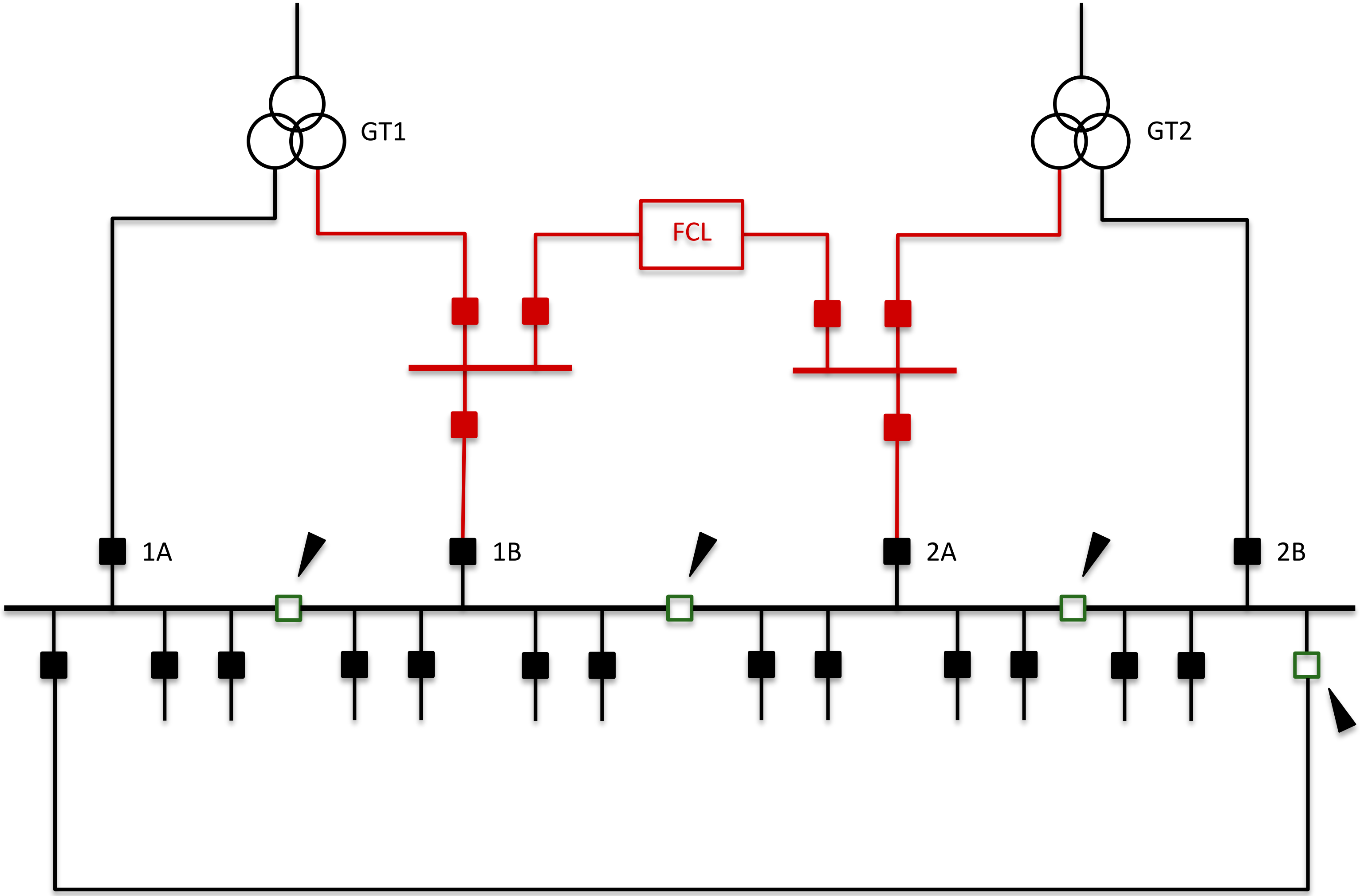


✓ Equipment can be installed off line prior to final connection

✓ Security of supply

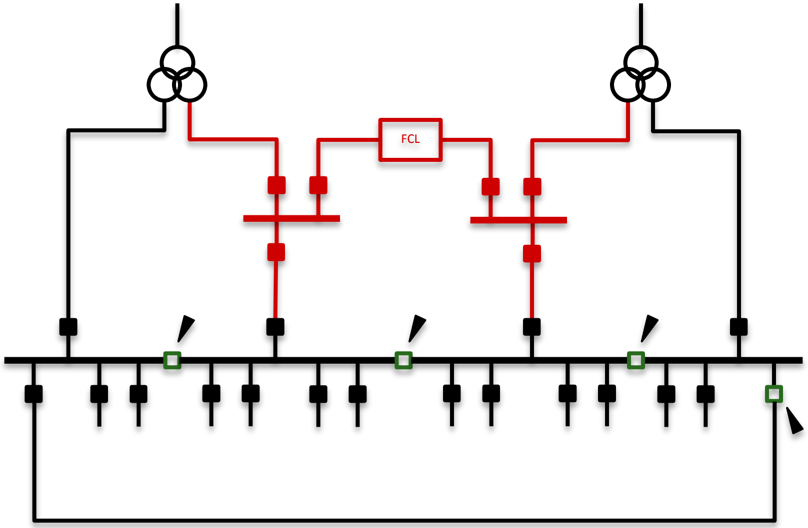
✗ Interconnector (or busbar) outages required for connection

FCL between transformers



FCL between transformers

- GT1B and GT2A in parallel
- Considered generally as a last resort for FCL connection



✓ Equipment can be installed off line prior to final connection

✓ Security of supply

✘ Two transformer outages required for connection

✘ Six circuit breakers required for connection

✘ Complex operating arrangement

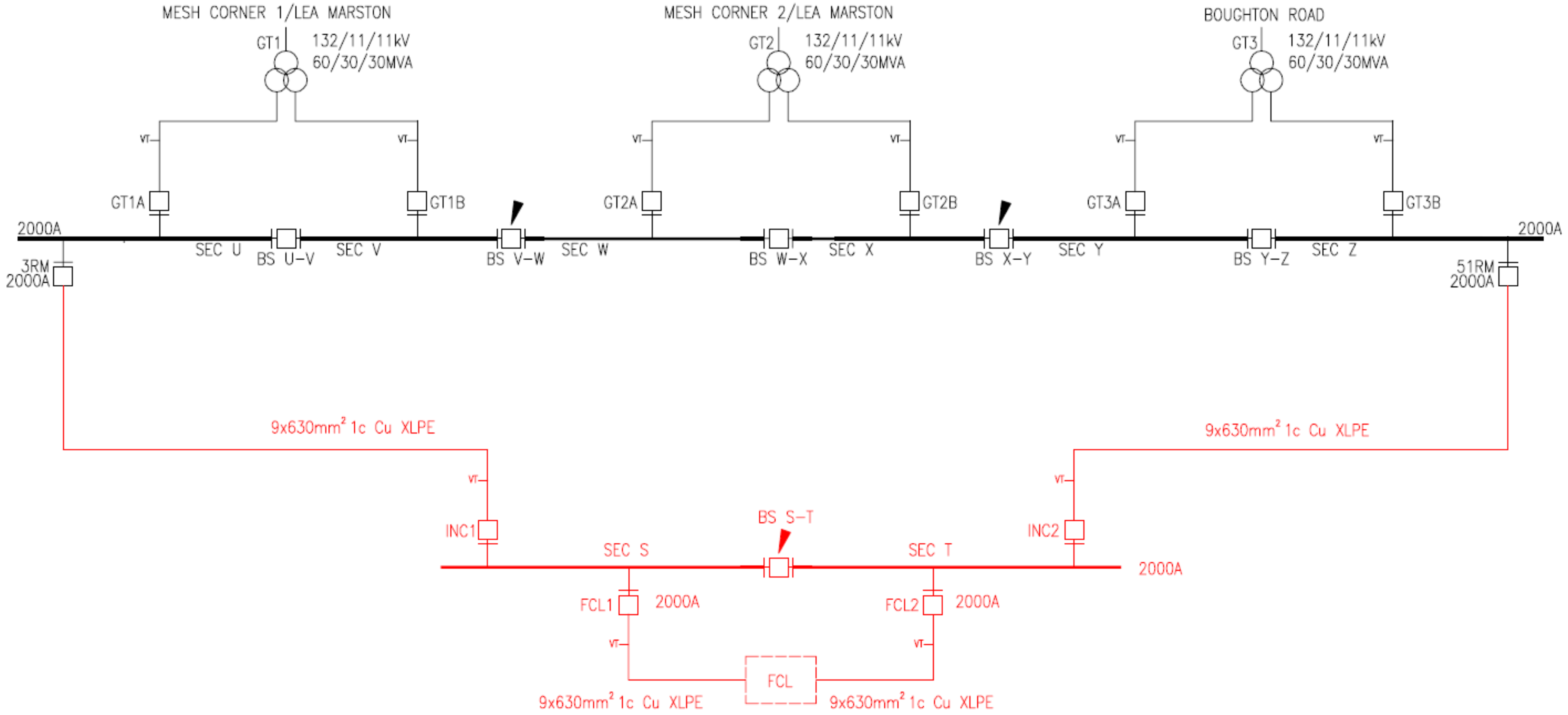
Proposals for FlexDGrid

- Kitts Green
- Castle Bromwich
- Chester Street
- Bournville
- Sparkbrook

Kitts Green 132/11kV

- 3 no. 132/11/11kV transformers
- When operating in parallel at 11kV, 3ph break FL is 15.7kA
- Target 3ph break FL is 9.4kA with FCL
- FCL to be connected into 11kV interconnector
- Spare land is available within the substation compound

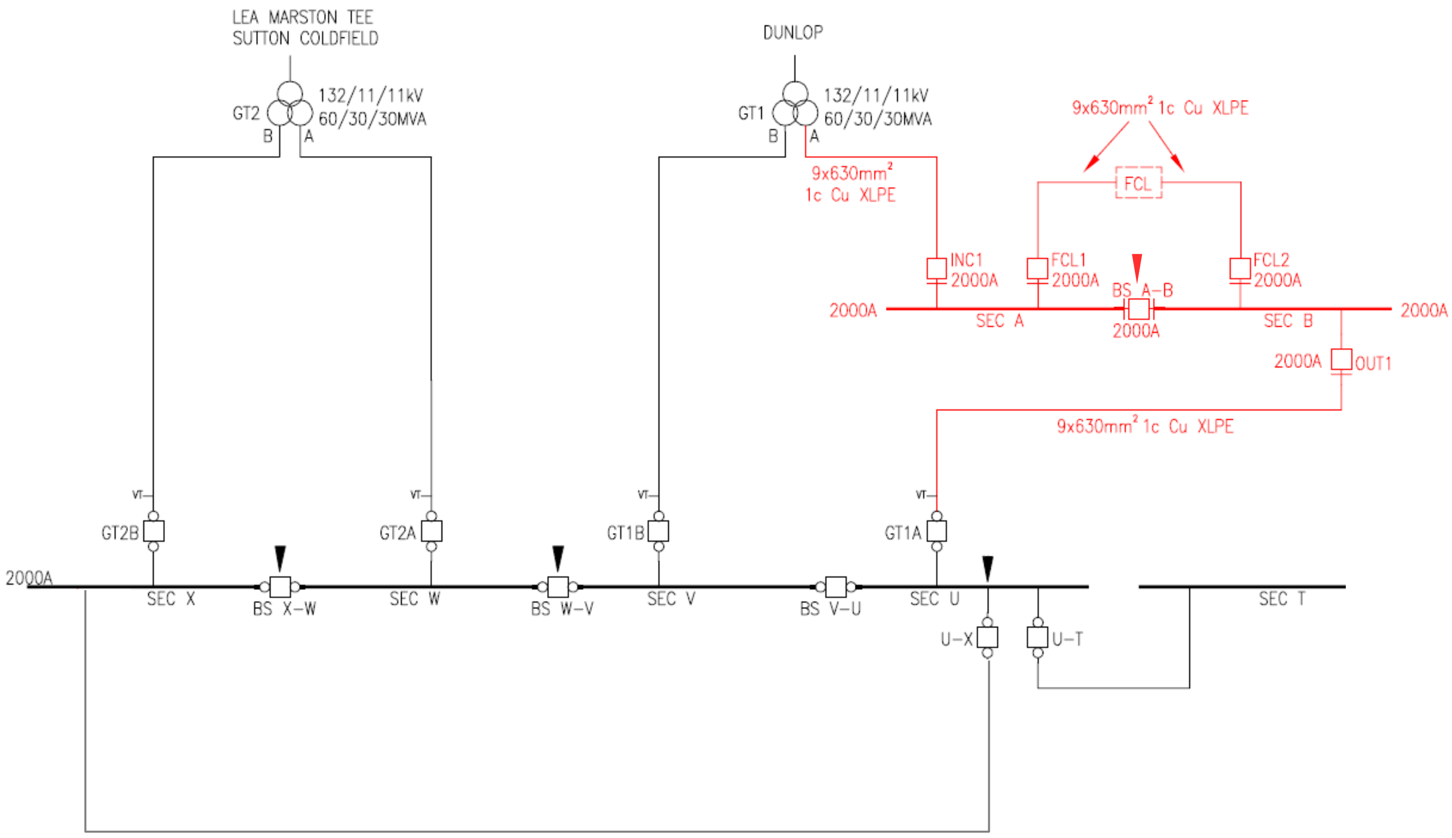
Kitts Green 132/11kV



Castle Bromwich 132/11kV

- 2 no. 132/11/11kV transformers supplied from separate Grid Supply Points
- When operating in parallel at 11kV, 3ph break FL is 13.7kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected into 11kV transformer ‘tails’

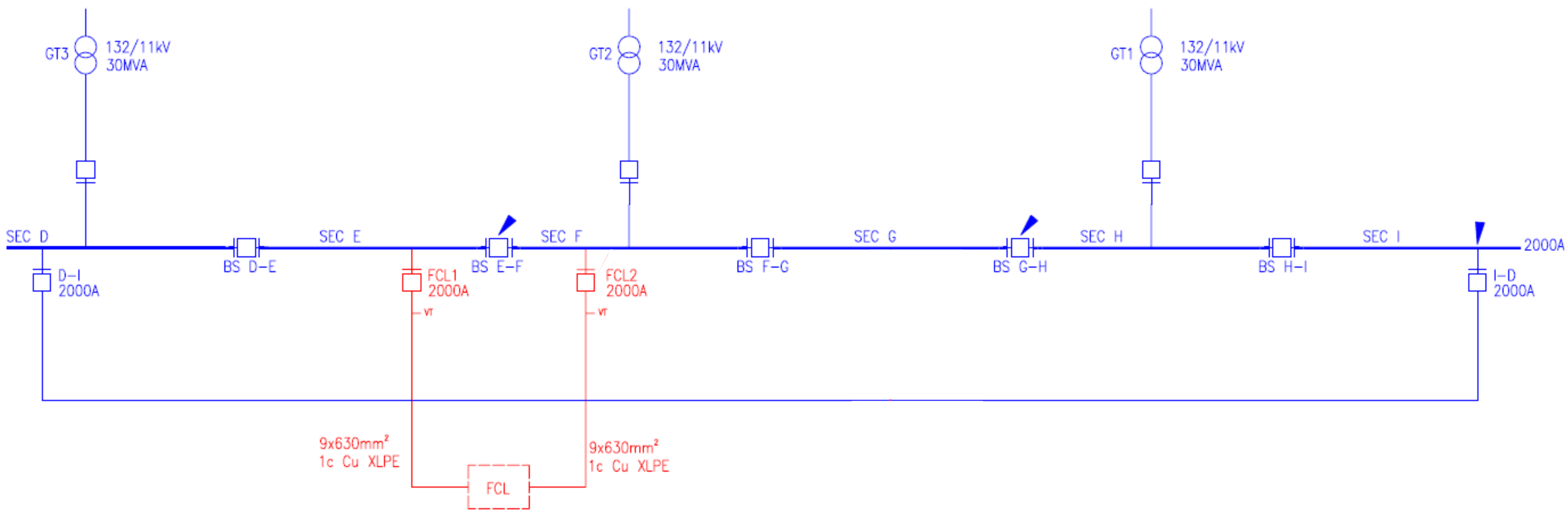
Castle Bromwich 132/11kV



Chester Street 132/11kV

- 3 no. 132/11kV transformers, one supplied from separate Grid Supply Point
- 11kV switchgear is being replaced under DPCR5
- When operating in parallel at 11kV, 3ph break FL is 14.1kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected across bus-section

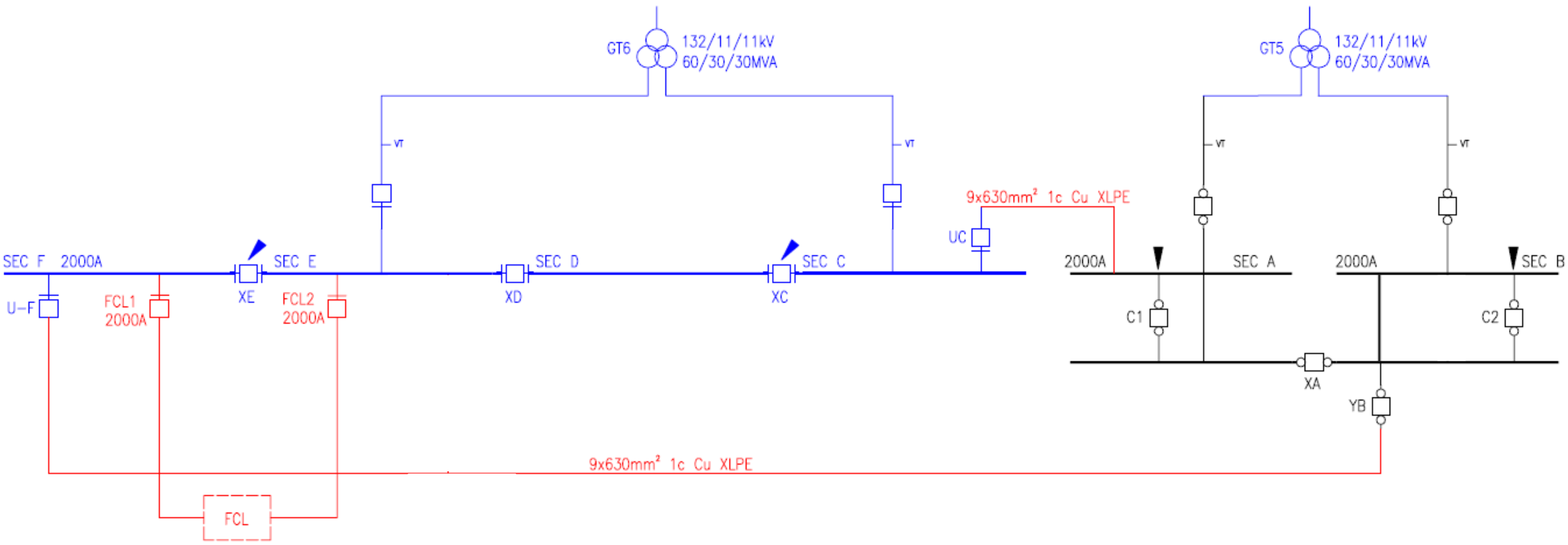
Chester Street 132/11kV



Bournville 132/11kV

- 4 no. 132/11kV transformers
- Transformers and 11kV switchgear are scheduled for replacement
- When operating in parallel at 11kV, 3ph break FL is 15.3kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected across bus-section

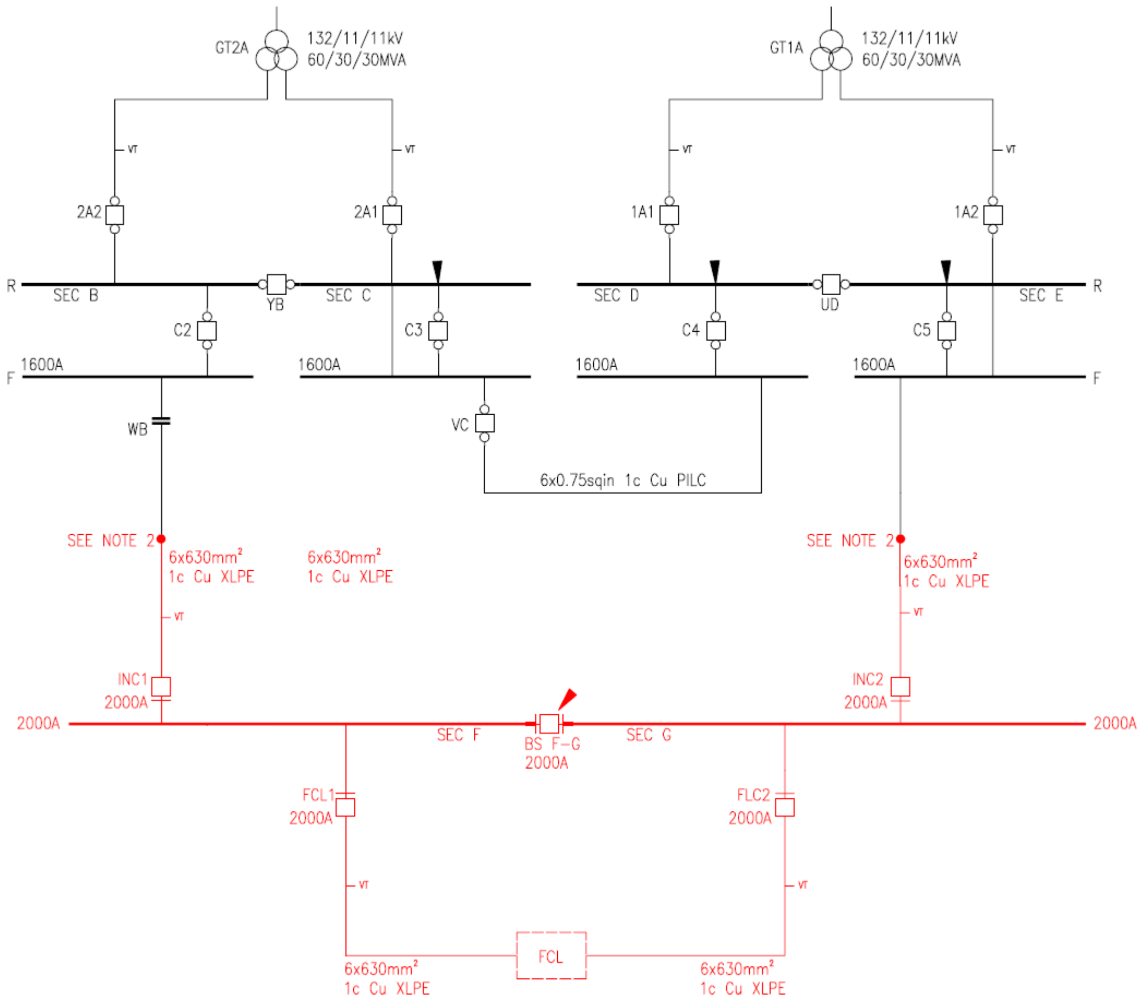
Bournville 132/11kV



Sparkbrook 132/11kV

- 2 no. 132/11/11kV transformers
- When operating in parallel at 11kV, 3ph break FL is 16.1kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected into 11kV interconnector
- Spare land is available within the substation compound

Sparkbrook 132/11kV



Summary

- Principle of Method Gamma
- Existing and emerging methods for fault level mitigation
- Substation Selection Process
- Connection Options for Technologies
- Proposals for FlexDGrid substations

Questions

Lunch and networking

Lodge Room 3

45 minutes

Discussion on FCL installation and implementation

Round table discussion led by:

Jonathan Berry

Break

Sharing best practice options

Round table discussion led by:

Jonathan Berry

Summary of workshop results and next steps

Jonathan Berry

Thank you for joining us

Please complete your feedback form and leave this with us

Have a safe journey home

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

DNO Workshop on the Implementation of Enhanced Fault Level Assessment Processes

Wednesday 23rd October 2013

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Introduction

- House-keeping
- Agenda
- Round table introductions
- Workshop aims

Agenda

10:00 – 10:30	**Arrival – Refreshments and Networking**
10:30 – 10:50	Round table introductions to include delegates' background in fault level modelling
10:50 – 11:00	Overview of FlexDGrid and the purpose of the workshop
11:00 – 11:30	Presentation 1 – Topic Focus: Dissemination of SDRC-1 (Enhanced fault level assessment processes)
11:30 – 12:05	Presentation 2 – Topic Focus: Monitoring and mitigation of fault level
12:05 – 12:30	Q&A session
12:30 – 13:15	Lunch and Networking
13:15 – 14:10	Discussion session 1: Monitoring of fault level and impact on connection applications
14:10 – 14:20	Break
14:20 – 15:15	Discussion session 2: Modelling of fault current limiters and impact on connection applications
15:15 – 15:30	Summary of workshop results and next steps
15:30	Close

Round Table Introductions

DNO	Name	Job Title
WPD	Jonathan Berry	Innovation Engineer
WPD (Parsons Brinckerhoff)	Ali Kazerooni	FlexDGrid Modelling Lead
WPD (Parsons Brinckerhoff)	Neil Murdoch	FlexDGrid Distribution Lead
WPD (Parsons Brinckerhoff)	Samuel Jupe	FlexDGrid EFLA Lead
WPD (Parsons Brinckerhoff)	Stewart Urquhart	Assistant Engineer
UKPN	Ian Cooper	Senior Technology Transfer Engineer
UKPN	Bill Reeves	Distribution Planning Engineer
UKPN	Musa Shah	Distribution Planning Engineer
SSE	David Mobsby	Operational Planning Engineer
SSE	Tawanda Chitifa	R&D Project Manager
SSE	Will Monnaie	System Planning Engineer
SPEN	Malcolm Bebbington	Senior Design Engineer
NPG	Dr. Roshan Bhattarai	System Planning Engineer

FlexDGrid – What and Why

What are we doing?

Understanding, Managing and Reducing the Fault Level on an electricity network

Why are we doing it?

Facilitating the early and cost effective integration of Low Carbon generation

Why are we doing it now?

Supporting the Carbon Plan – Connection of generation to the grid and development of heat networks – reducing carbon emissions

FlexDGrid - Overview

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional generation

FlexDGrid Explained – Method Alpha

The Enhanced Fault Level Assessment Method will provide refined Fault Level analysis techniques to understand the areas of the network that are likely to exhibit Fault Level issues. This will be used to provide customers with more accurate and refined network connection offers

Problem

- Existing models built on lots of network assumptions
- Modelling uncertainty providing reserved outputs

Solution

- Provide greater network model detail and granularity
- Feed in up-to-date network arrangement and connection data

Benefit

- Increased certainty of network model accuracy
- Reduced modelling uncertainty
- Release of DG connection capacity

FlexDGrid Explained – Method Beta

The Real-time Management Method will enable accurate Fault Level data to be gathered for various network arrangements. This will be used to verify the Fault Level assessed through the Trial of Enhanced Fault Level Assessment processes

Problem

- Currently no capability to monitor Fault Level
- Essential safety margin applied due to lack of network information

Solution

- Monitor Fault Level using new device
- Feed monitored and measured Fault Level data in to enhanced network model
- Manage network using monitored and modelled data

Benefit

- Increased knowledge of networks' Fault Level
- Reduction of required safety margin
- Release of DG connection capacity

FlexDGrid Explained – Method Gamma

The Fault Level Mitigation Method will install technologies in to substations which currently exhibit Fault Level issues and where new connections are expected to cause an increase in fault currents. This Method adds Fault Level capacity by reducing fault currents

Problem

- Current Fault Level reduction solutions are costly and take a long time
- Existing solutions have limited reduction capability / no reduction but ability to accommodate more Fault Level

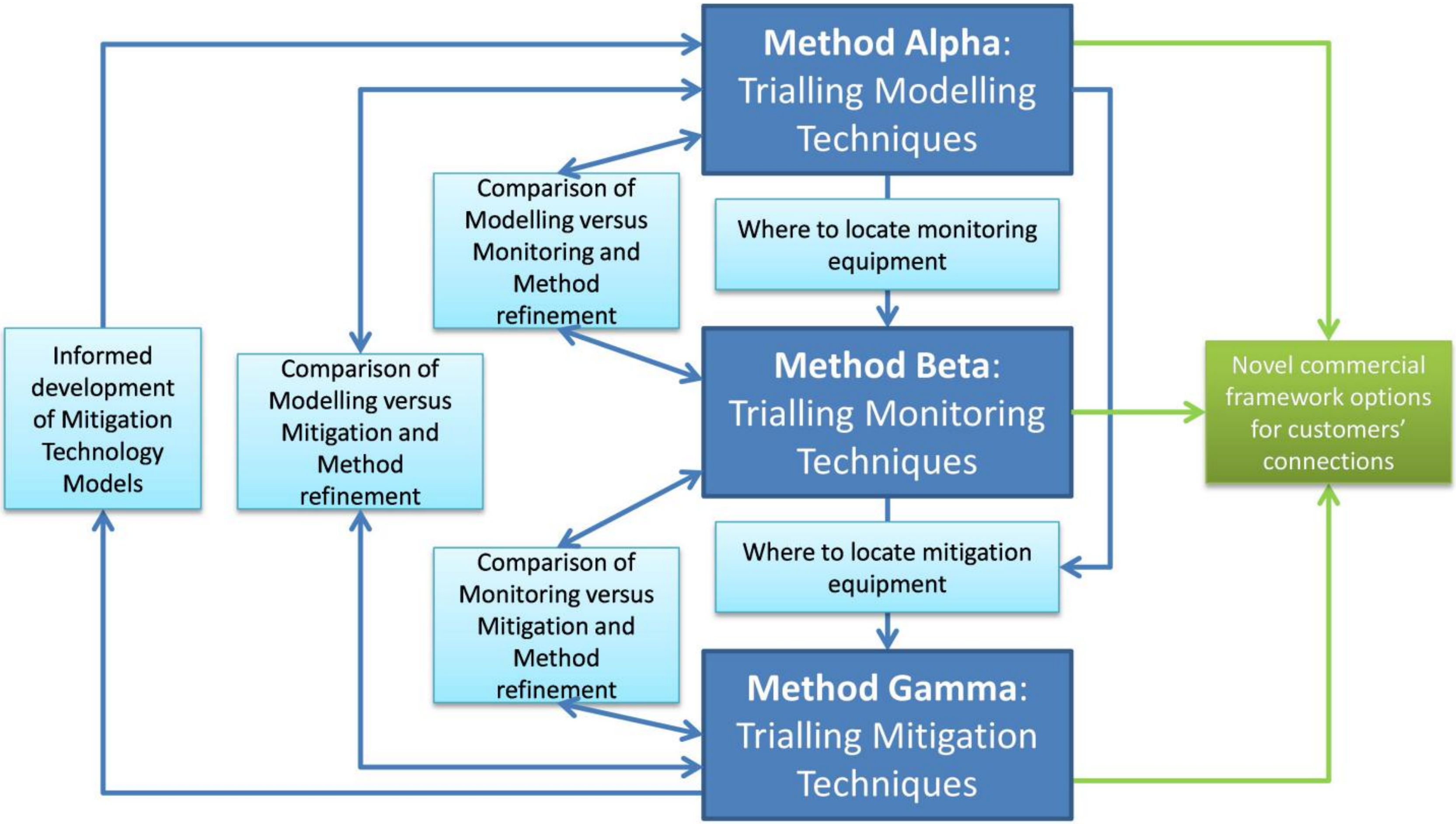
Solution

- Installation of new technologies that have been tested in a laboratory or in network isolation

Benefit

- Reduced cost of connection to all users
- Minimise time to connect generation
- Fault Level headroom is maximised

Integrated Methods and Expected Learning



WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Presentation 1 – Topic Focus:

Method Alpha: Dissemination of SDRC-1 (Specifying enhanced fault level assessment processes)

Samuel Jupe MEng PhD CEng MIET

Senior Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF

FlexDGrid – Method Alpha

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

Method Alpha: Enhanced fault level assessment processes

1. Baseline the consistency of application of present fault level assessment methods
2. Explore assumptions and carry out a sensitivity analysis of standard fault level calculation methods
3. Increasing the frequency and granularity of fault level assessments
4. Design and deployment of fault level measurement and monitoring technologies
5. Design and deployment of fault level mitigation technologies
6. Connection offers based on novel commercial frameworks

Emerging learning: DNO Questionnaire Conclusions

1. Engineering Recommendation G74 requires clarifications on its application:
   a) Guidance on new forms of generation
   b) Modelling of aggregated loads
   c) Validity of general load contribution

2. Sensitivity analysis would provide useful learning

3. Open source database of generation / motor plant types would be beneficial

Emerging learning: DNO Questionnaire Conclusions

4. Open source fault current limiter models would be of benefit to the DNO community

5. Increased frequency and granularity of fault level assessments could be beneficial but would need to outweigh increased modelling effort

6. A move to probabilistic fault level assessments was not deemed to be feasible due to ESQCR and H&S implications

7. There is a need for training processes to be documented

Emerging learning: SDRC-1 Recommendations

1. The 6 process identified and detailed in the SDRC-1 document will be followed

2. A follow-on workshop will be organised with other DNOs to feedback baseline and sensitivity analysis results

3. It is not clear how the values for general load contribution were originally derived:
   a) Load mixes and fault contributions will be investigated
   b) Introduction of fault level monitoring equipment

Emerging learning: SDRC-1 Recommendations

4. An industry-wide review of G74 should be conducted with a focus on the consistent application of G74 to HV networks

5. For training and consistency, DNOs should formally document their connection study process

6. Development of integrated EHV and HV electricity network models

7. Confirm the need to de-rate switchgear in line with CIGRE Recommendation 304

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Presentation 1 – Topic Focus:

Method Alpha:

Progress towards SDRC-4 (Implementing enhanced fault level assessment processes)

Ali Kazerooni PhD MIET

Senior Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks | THE UNIVERSITY OF WARWICK | PARSONS BRINCKERHOFF

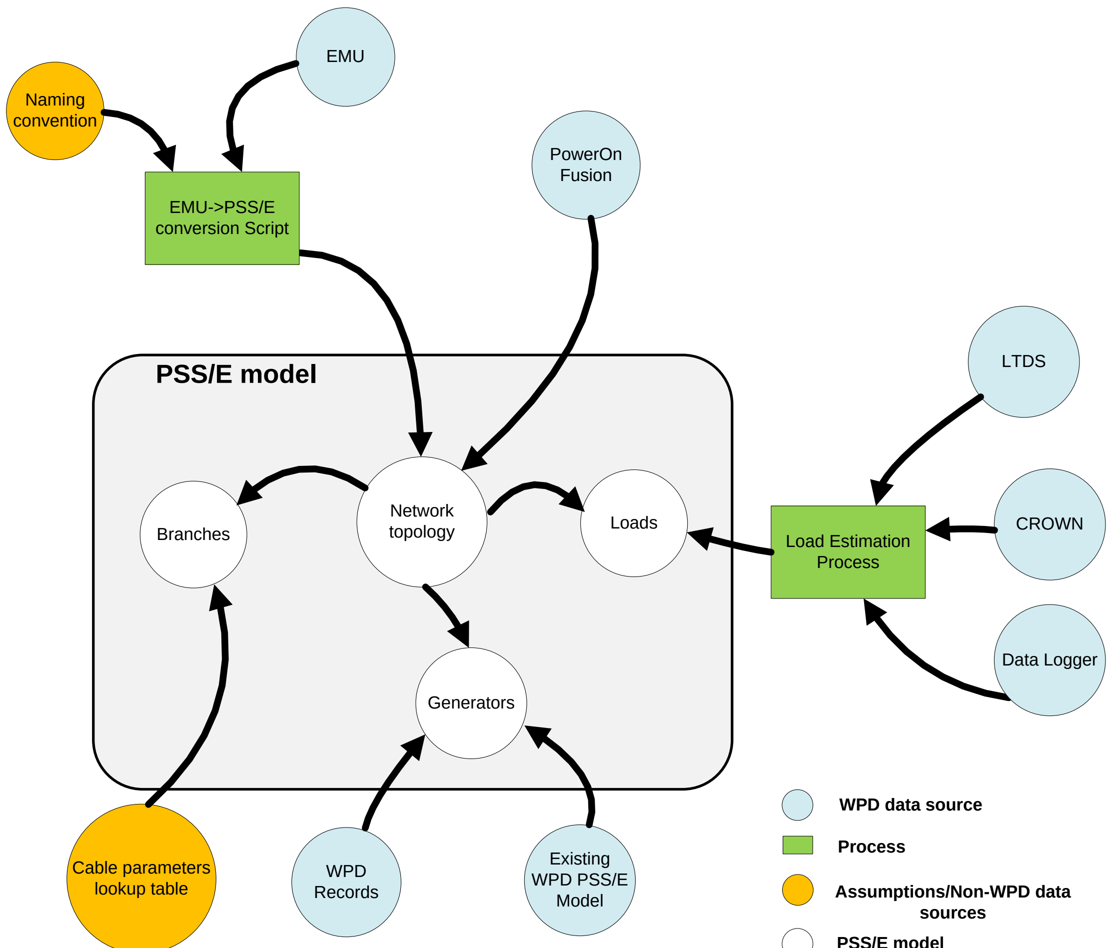
Overview

- **HV network models**
- **Fault level decrements – Heat maps**
- **Fault level sensitivity analysis**

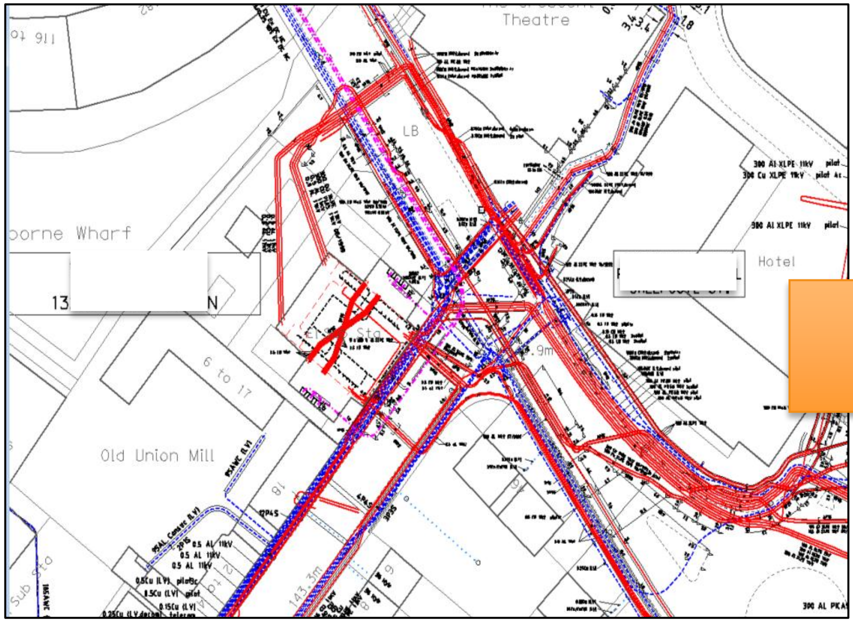
HV networks models

- Developed a methodology for creating computer models of HV networks using BaU WPD databases
- PSS/E models of HV networks of 12 primary substations in Birmingham Central Business district were developed
- Developed HV networks models can be integrated with EHV network model
- EMU (GIS database) –to- PSS/E converter Excel-based tool is developed to automate the modelling process.

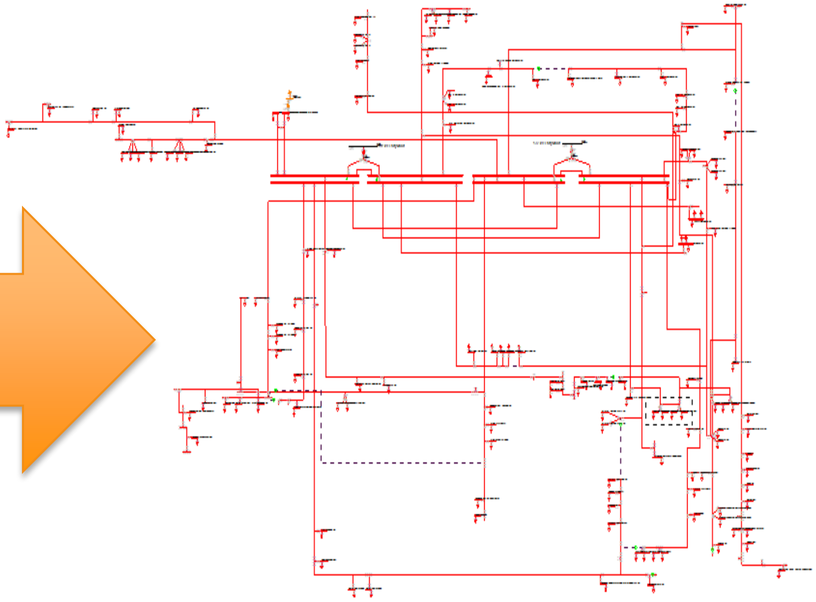
HV network models - Methodology



Modelling of HV networks – EMU to PSSE convertor



EMU

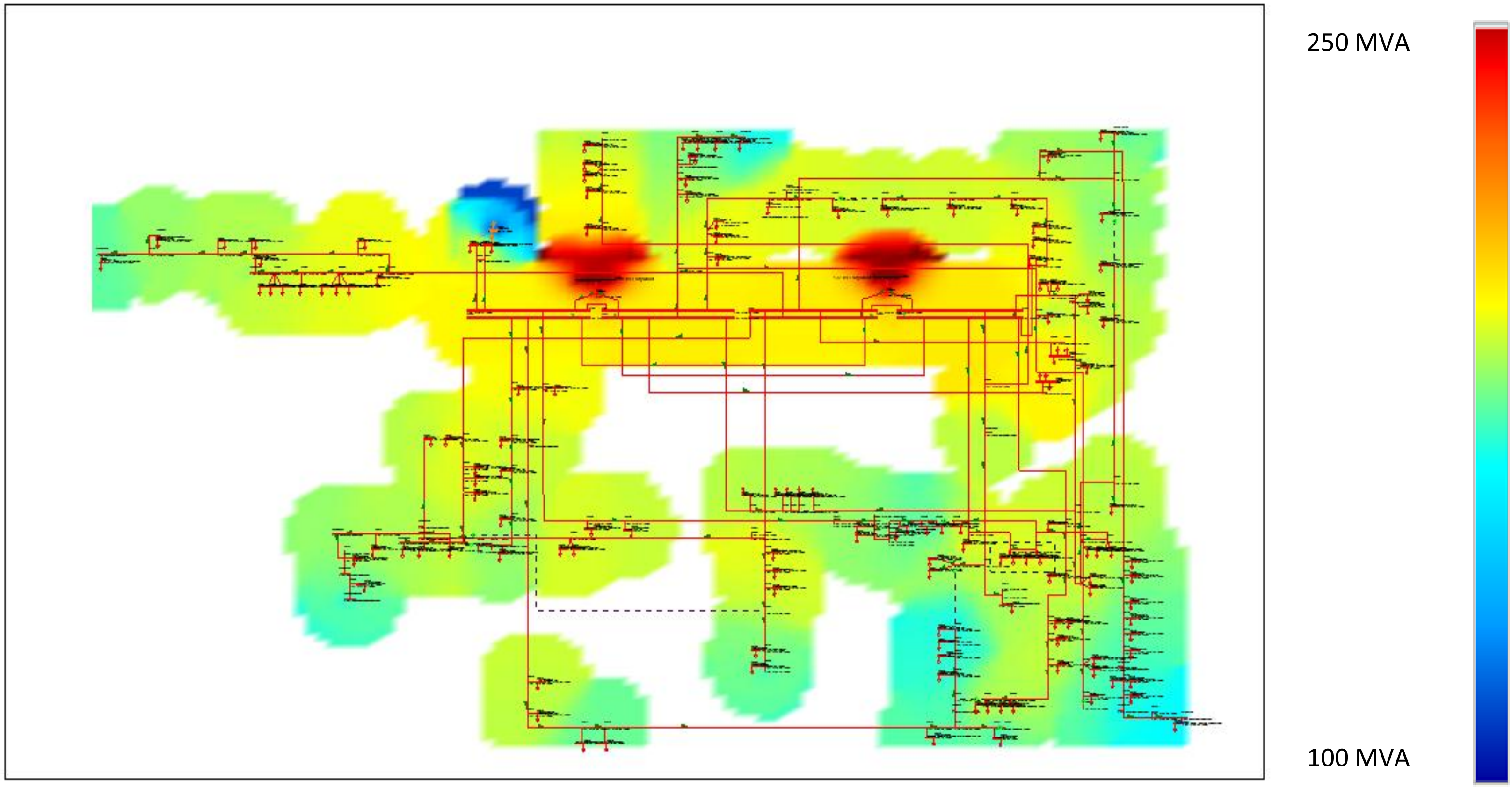


PSS/E

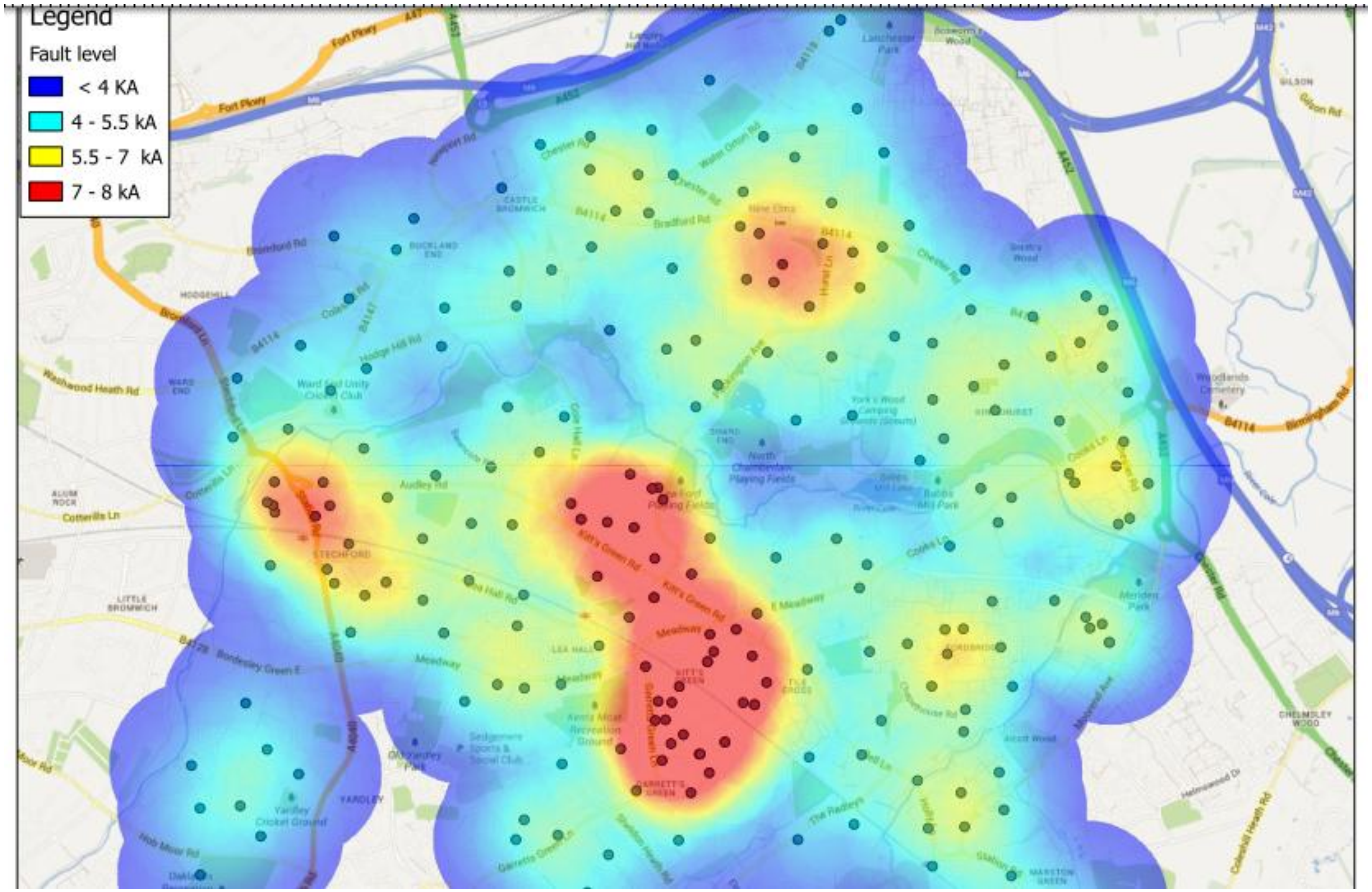
HV networks models - Benefits

- A close-to-reality calculated voltage profile
- Modelling different substation configurations
- Modelling different network arrangements - interconnectors
- Modelling generators in their actual place in the network
- Calculating fault level at distribution substations

Fault level decrement– Heat maps



Fault level decrement– Heat maps



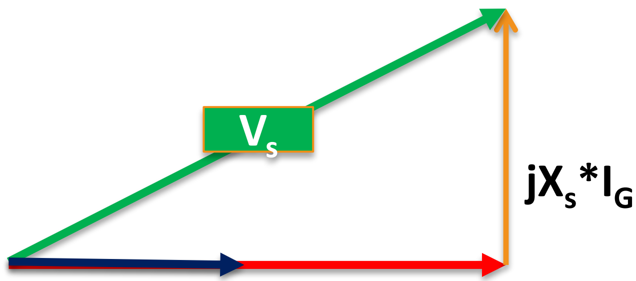
Fault level Sensitivity analysis

Sensitivity of the calculated fault level against different parameters of the electricity network model and assumptions

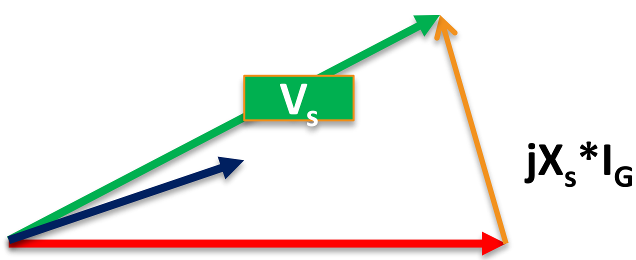
- Cable length
- Demand
- Generation power factor (PF)
- Tap position at primary substation
- General load fault infeed

FL sensitivity analysis – Generator PF

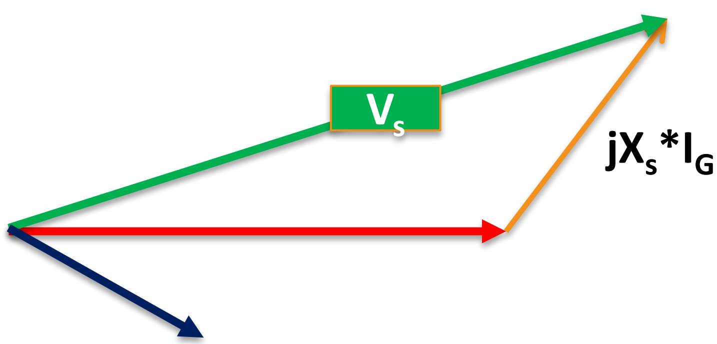
Unity PF

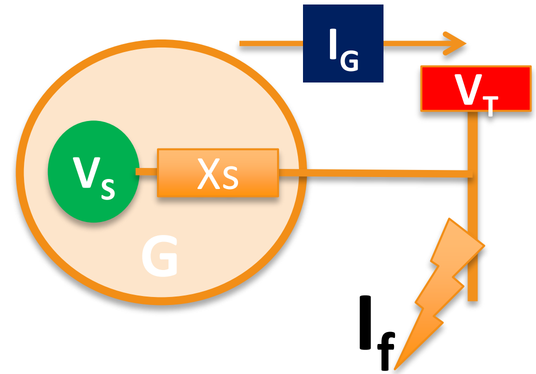


Leading PF



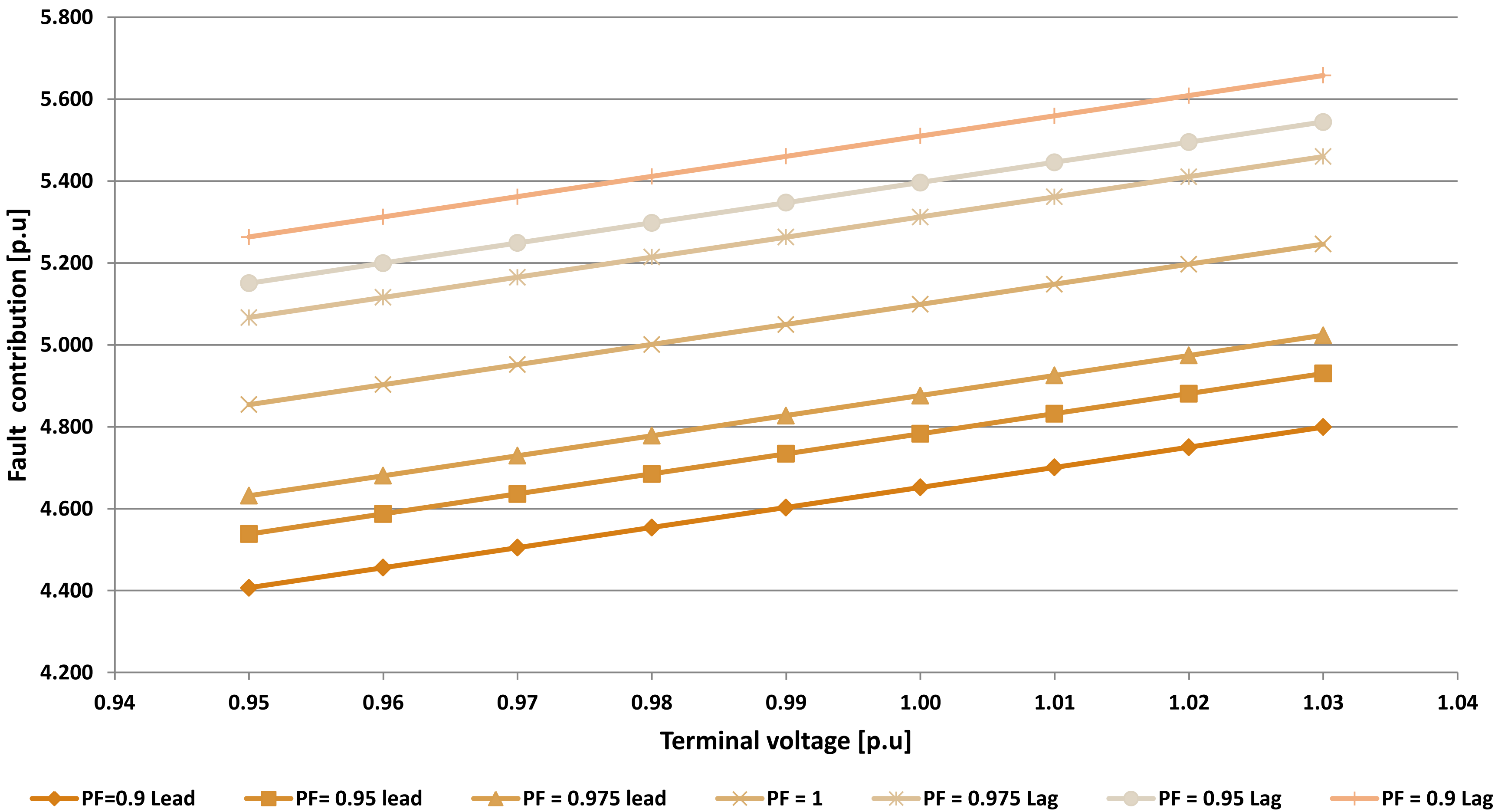
Lagging PF



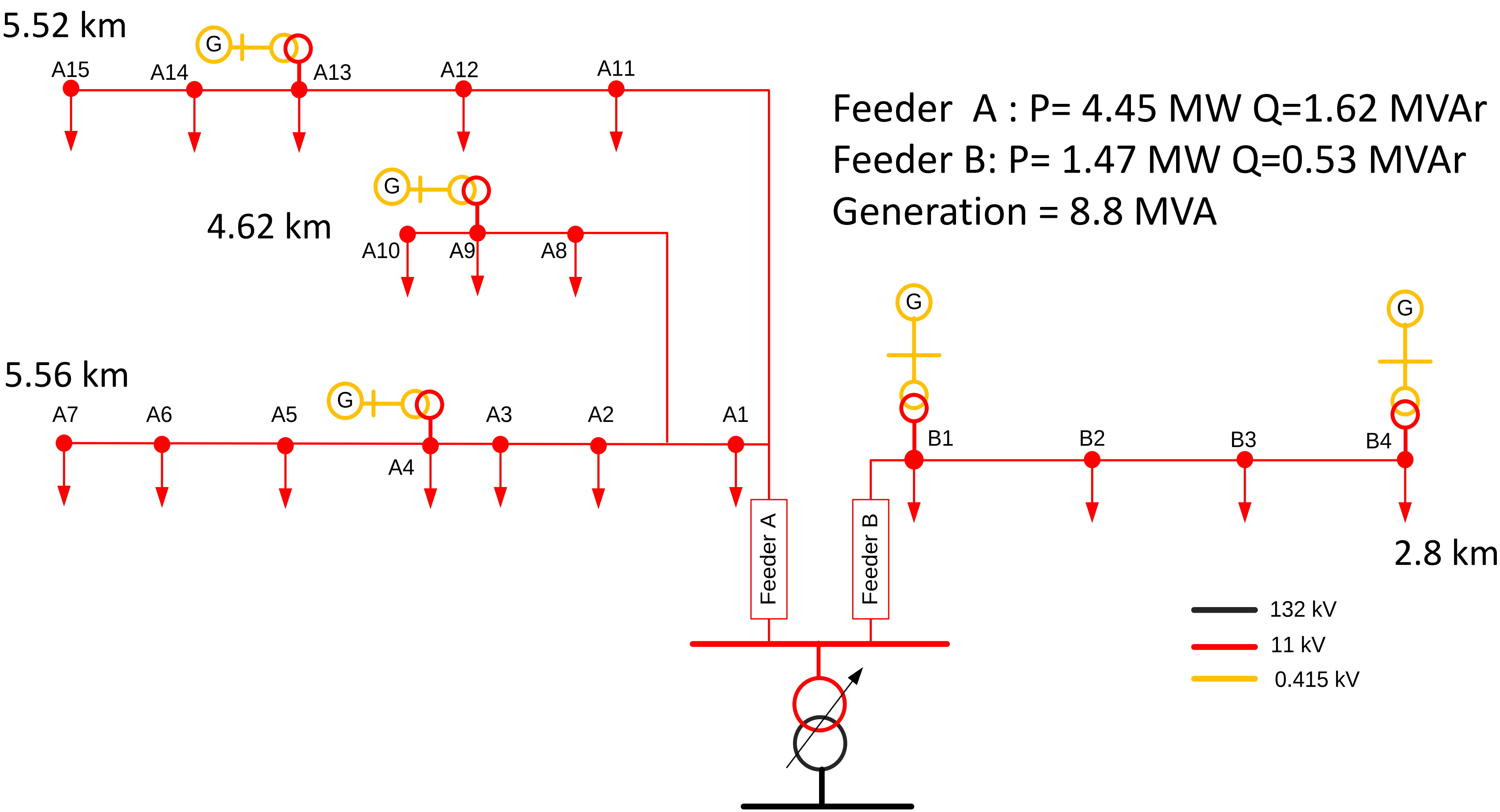


$$I_f = V_s / X_s$$

FL sensitivity analysis – Generation PF

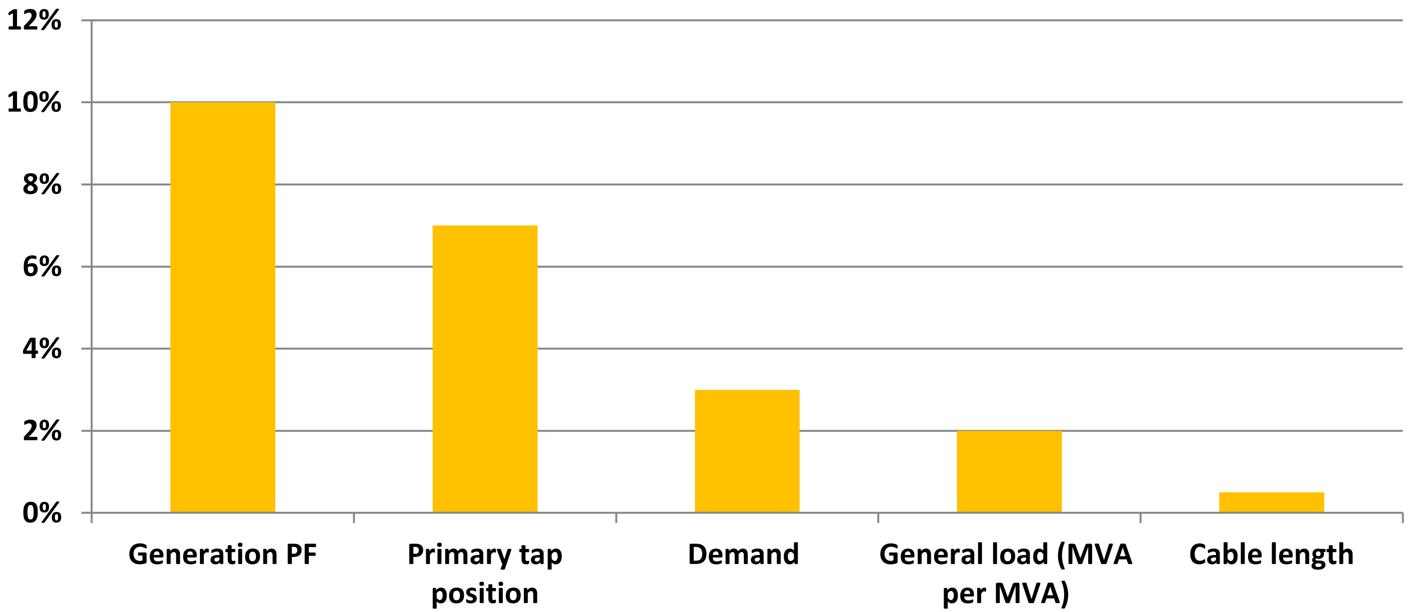


FL Sensitivity analysis – Sample model



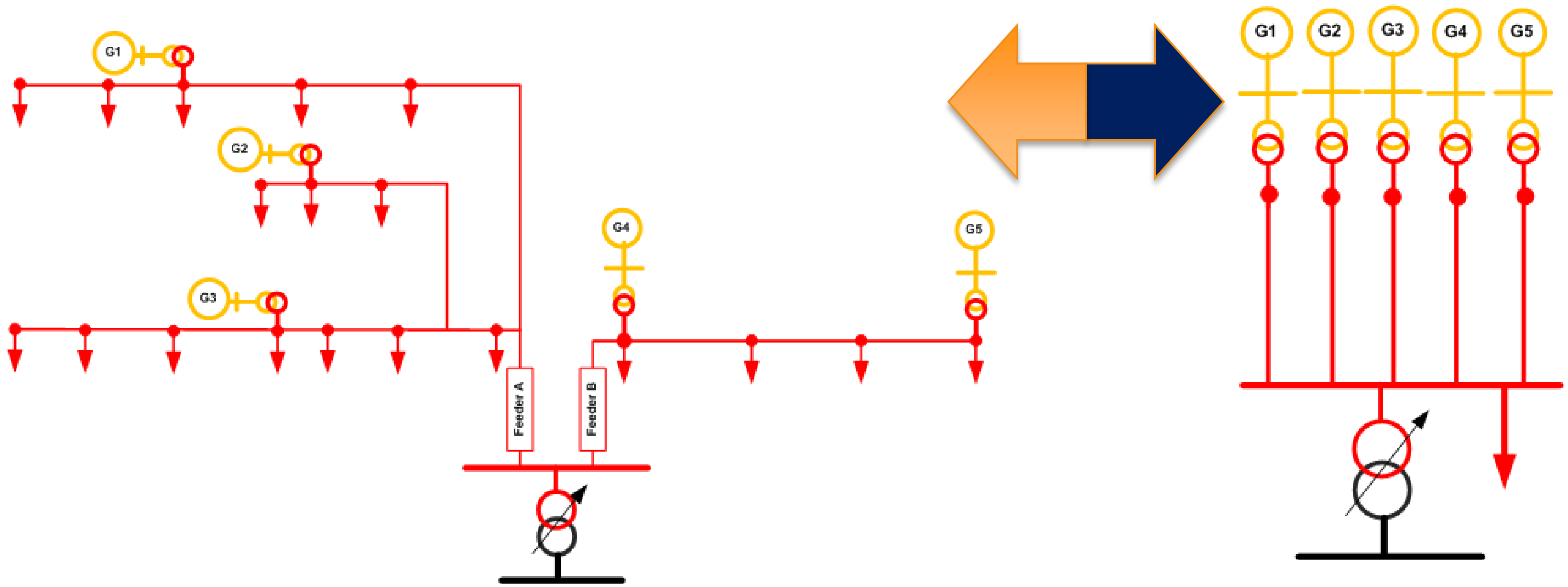
Feeder A : P= 4.45 MW Q=1.62 MVAr
Feeder B: P= 1.47 MW Q=0.53 MVAr
Generation = 8.8 MVA

FL Sensitivity analysis - Results



	Variation range	
Cable length	-5%	5%
Demand	-10%	10%
Generation PF	Unity, 0.95 leading, 0.95 lagging, Vset=1	
General load (MVA per MVA)	0	2
Primary tap position (voltage at HV busbars)	0.95 pu to 1.03 p.u	

FL sensitivity analysis – connection studies



	Unity PF		0.95 leading PF		Unity PF		0.95 leading PF		Gout=0	
	Make	Break	Make	Break	Make	Break	Make	Break	Make	Break
[kA]	6.76	2.50	6.26	2.23	7.13	2.60	6.71	2.43	7.05	2.57
[MVA]	128.8	47.6	119.3	42.5	135.8	49.5	127.8	46.3	134.3	49.0
Difference (%)					5.5	4.0	7.2	9.0	-	-

Conclusions

- Modelling HV network of 12 primary substations allows a close-to-reality pre-fault voltage calculation

- Heat maps enable HV planners to have a better overview of the fault level decrement in the HV networks.

- Sensitivity analysis shows that generators' operating power factor has the largest effect on calculated fault level

- For connection studies, it is recommended that generators are modelled in their actual connection point in the HV network.

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Presentation 2 – Topic Focus:

Method Beta:

Fault level monitoring and management

Samuel Jupe MEng PhD CEng MIET

Senior Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

FlexDGrid – Method Beta

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

Fault level profile analysis methodology

Step 1
- Data analysis of operational configurations

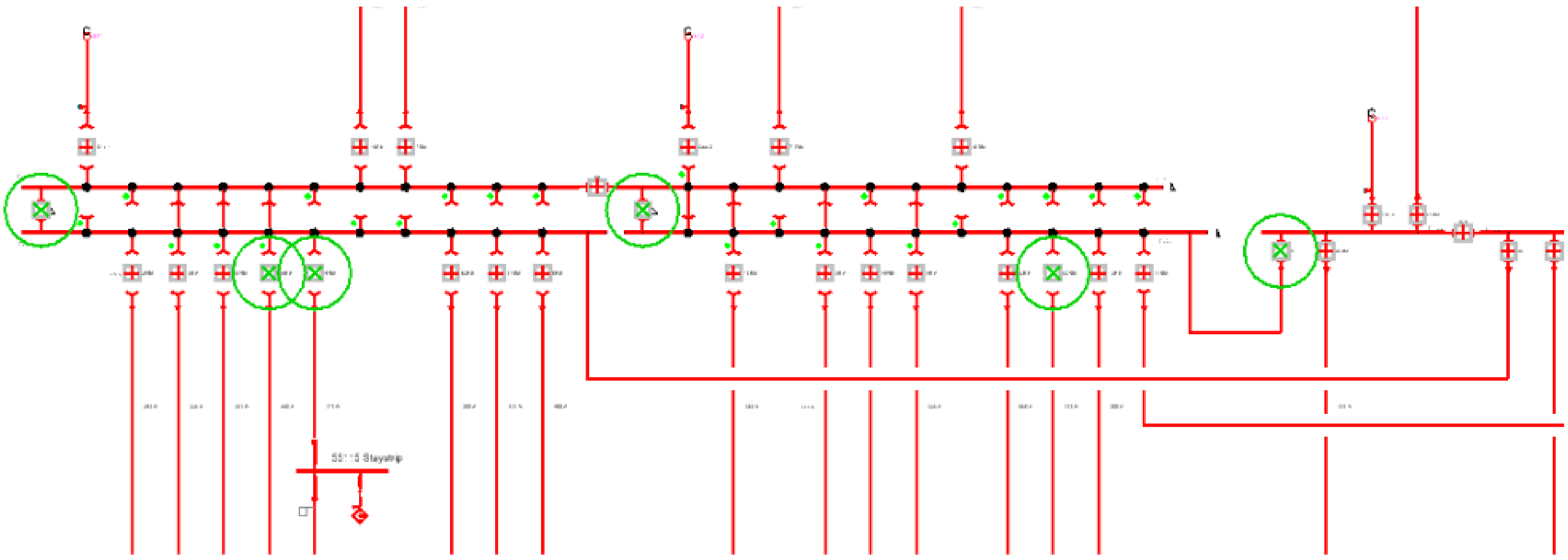
Step 2
- Run fault level studies for operational configurations
- Collate configuration states and corresponding fault level values

Step 3
- Generate time-series graph to display real-time fault level profile

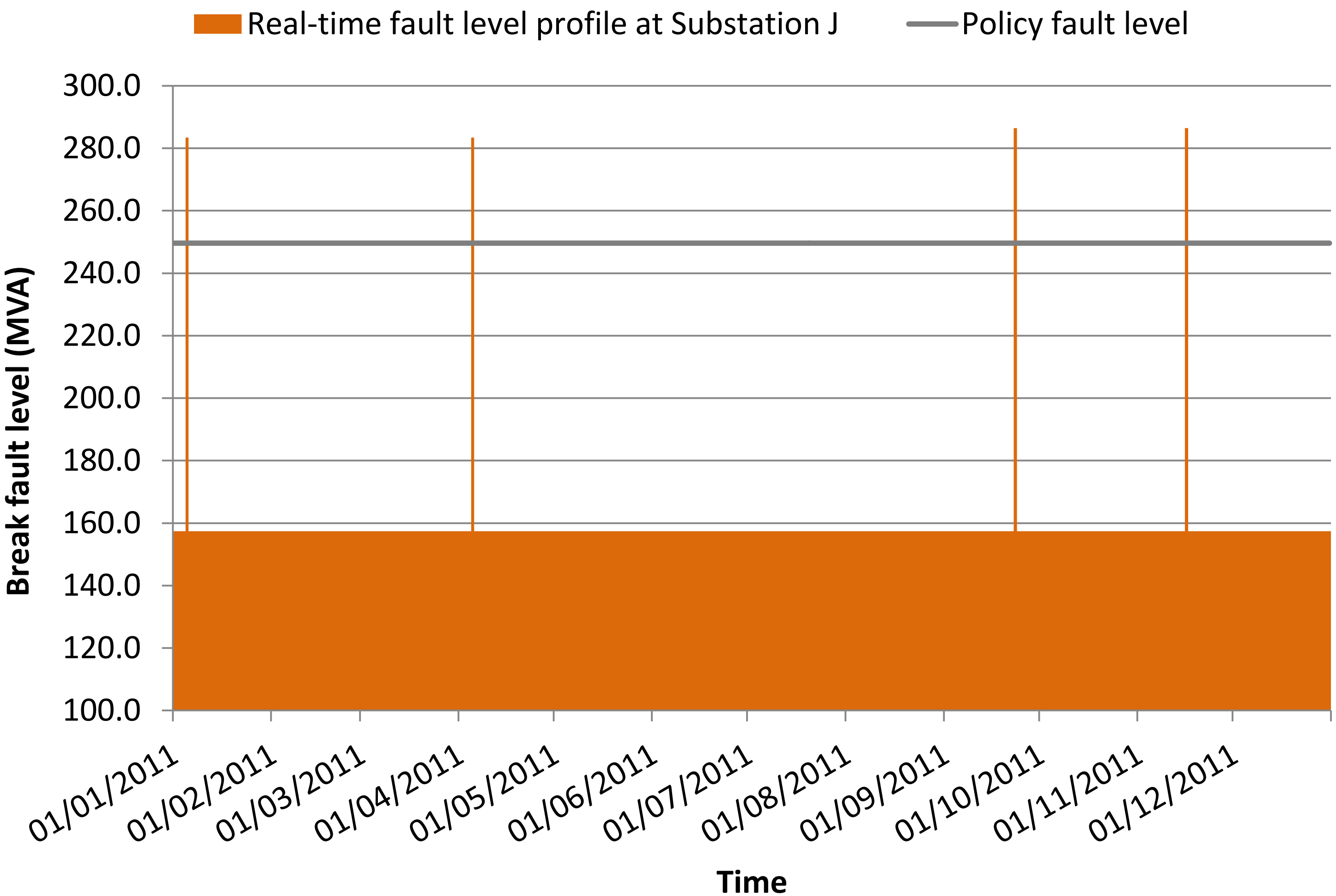
‘Connect and manage’ assumptions / caveats:

- **Generation integration into a ‘split’ network configuration**
- **Infrastructure in place to disconnect generation prior to parallel operation**
- **Commercial arrangements in place to support ‘connect and manage’**

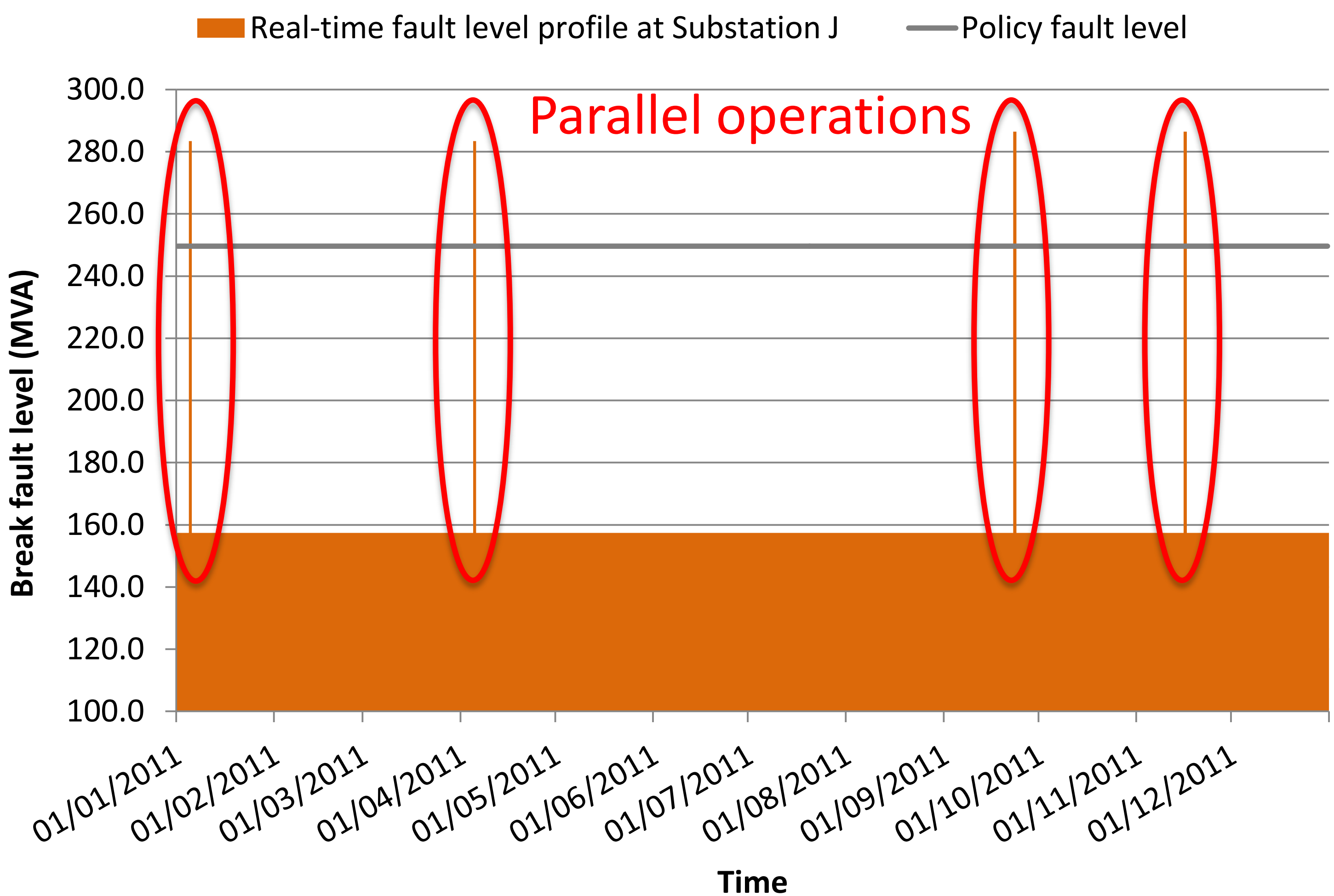
Operational configurations: Substation J



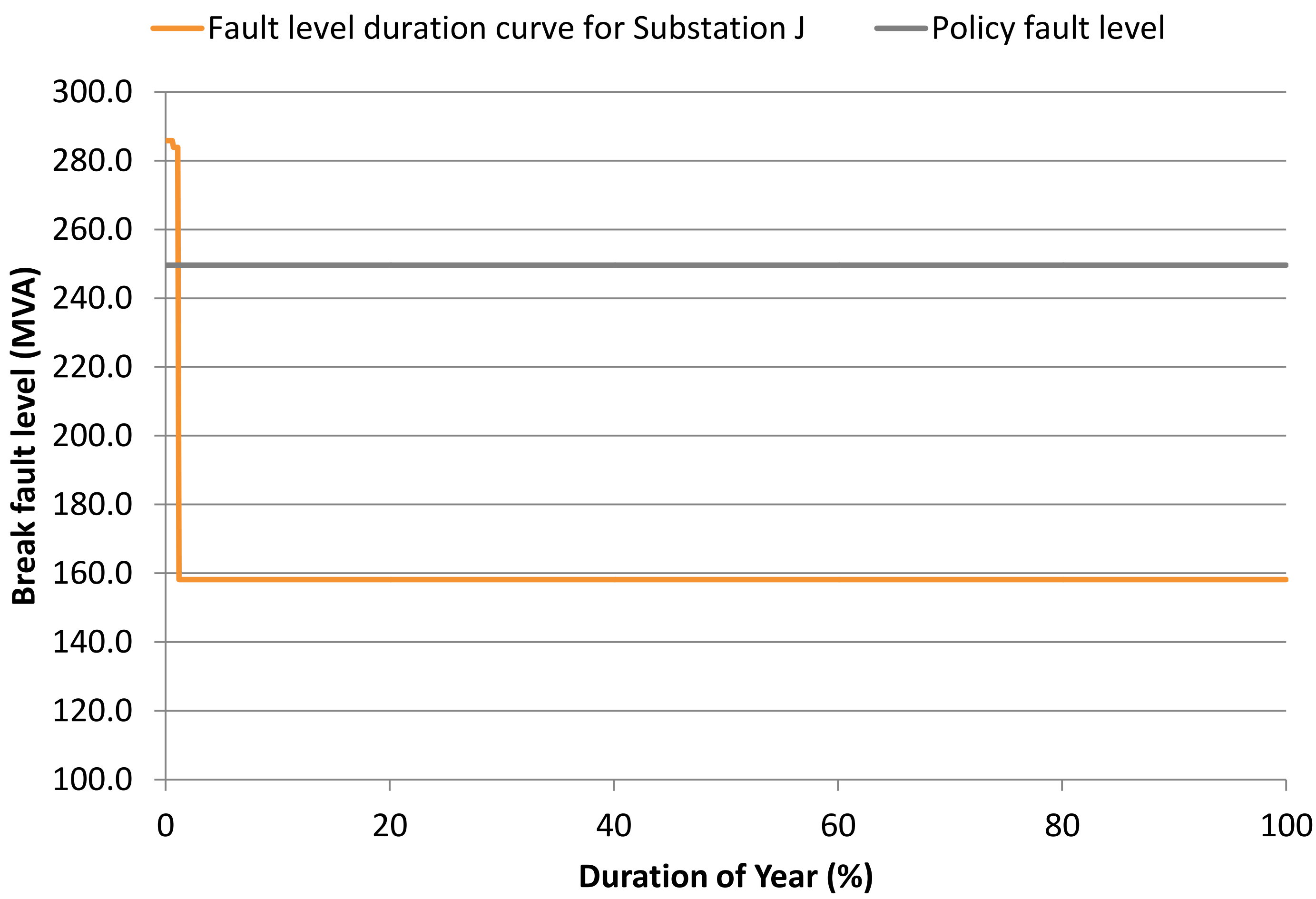
Time-series fault level profile



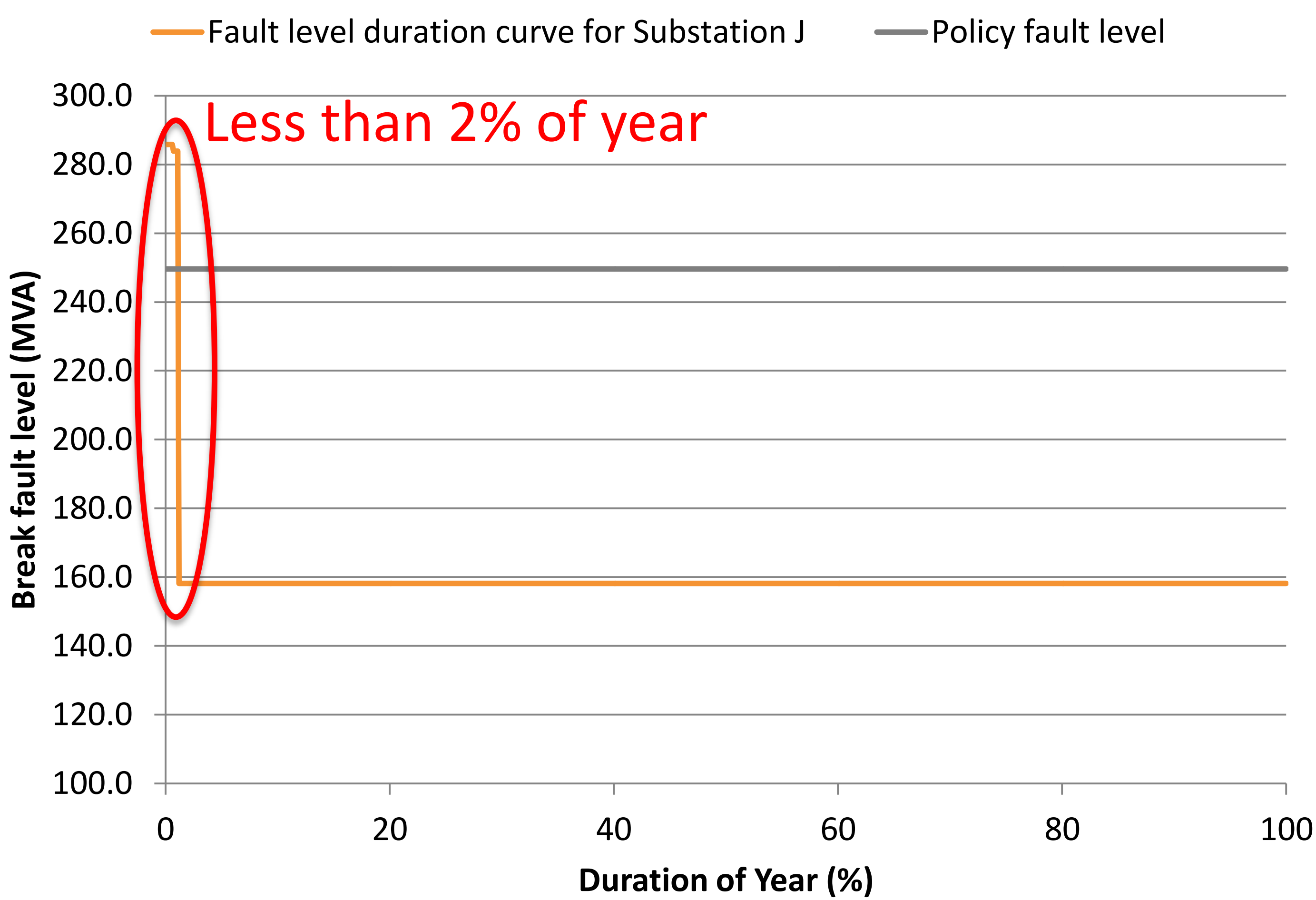
Time-series fault level profile



Fault level duration curve



Fault level duration curve



Generation headroom analysis methodology

Step 1
- Quantify the MVA headroom between 'split' network fault level and policy fault level value
- Convert to MW headroom using MVA / MW factor

Step 2
- Quantify unconstrained energy yield, constrained energy yield, net energy yield
- Perform cost-benefit analysis through £/MWh conversion

Step 3
- Technical basis of 'connect and manage' contract

Assumptions / caveats:

- **Safety margin on policy fault level value**
- **MVA / MW factor and generation capacity factor**
- **£/MWh and financial assumptions related to cost-benefit analysis**

Example results

Substation ID	Cumulative duration of parallels (%)	Parallel Fault Levels (kA) 3ph Break (rms)	Split Fault Levels (kA) 3ph Break (rms)	Switchgear rating (kA) 3ph Break (rms)	FL Headroom (kA)	FL Headroom (MVA)	Gen headroom (MW)
A	4.94%	15.7	8.5	13.1	4.6	87.6	19.5
B	0.05%	18.9	11.4	13.1	1.7	32.4	7.2
C	2.14%	14.6	7.8	13.1	5.3	101.0	22.4
D	0.09%	16.3	8.9	13.1	4.2	80.0	17.8
E	0.07%	16.1	8.7	13.1	4.4	83.8	18.6
F	0.03%	15.0	8.2	13.1	4.9	93.4	20.7
G	0.60%	14.2	11.6	13.1	1.5	28.6	6.4
H	0.12%	16.7	9.0	13.1	4.1	78.1	17.4
I	0.01%	15.9	8.4	13.1	4.7	89.5	19.9
J	2.01%	15.0	8.2	13.1	4.9	93.4	20.7

Analysis:

- **Each substation has a fault level issue when parallel operations take place**
- **Due to space availabilities, some substations are more suitable for fault current limiter technologies and some substations are more suitable for fault level management**

Evaluation

Pros:

- Avoids network reinforcement
- Readily integrate generation with limited network reconfiguration
- Potentially quicker and cheaper customer connections
- Can use present fault level values or 'enhanced' assessment values

Cons:

- Additional communications infrastructure to control generation connection, additional risk
- Limited impact on CI / CML improvement

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Presentation 2 – Topic Focus:

Method Gamma: Fault level mitigation

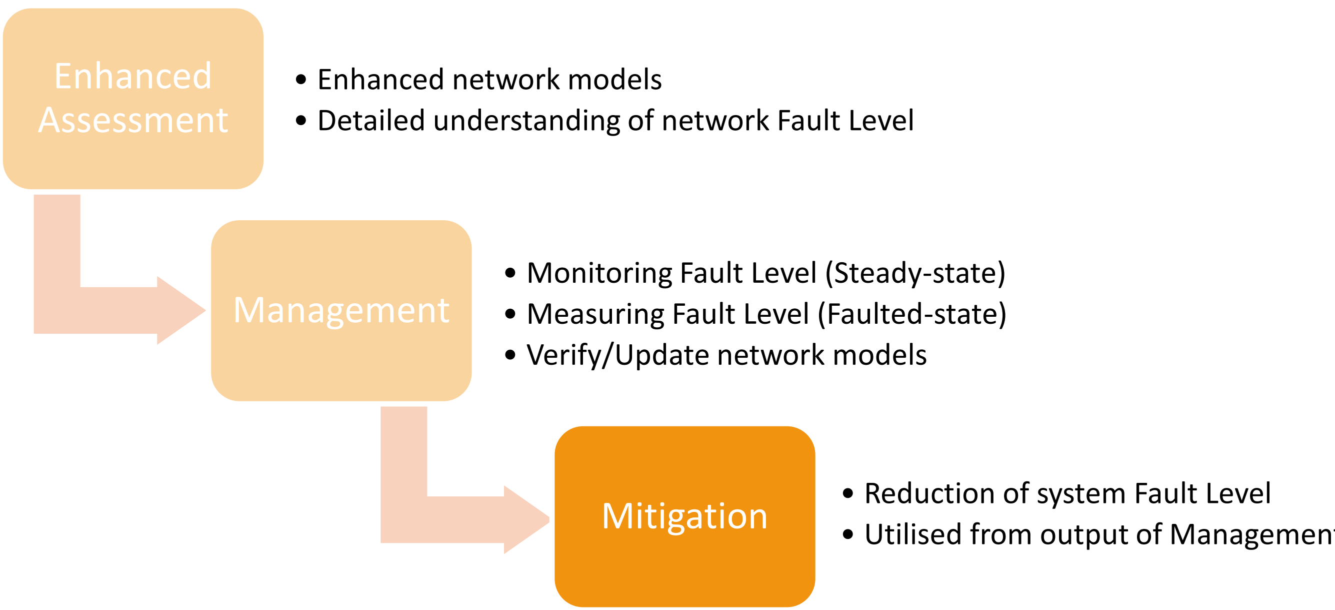
Neil Murdoch

Senior Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks | THE UNIVERSITY OF WARWICK | PARSONS BRINCKERHOFF

FlexDGrid – Method Gamma

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level



Introduction

- Update on Method Gamma
- Specifying FCLs
- Considerations for FlexDGrid sites
- Summary

Method Gamma Update

- Method Gamma: Fault Level Mitigation Technologies
  - Build on knowledge learned through IFI, ETI and LCNF Projects
  - Install 5 FL mitigation technologies in 5 separate WPD substations
  - Test & trial emerging technologies to quantify performance and network benefits

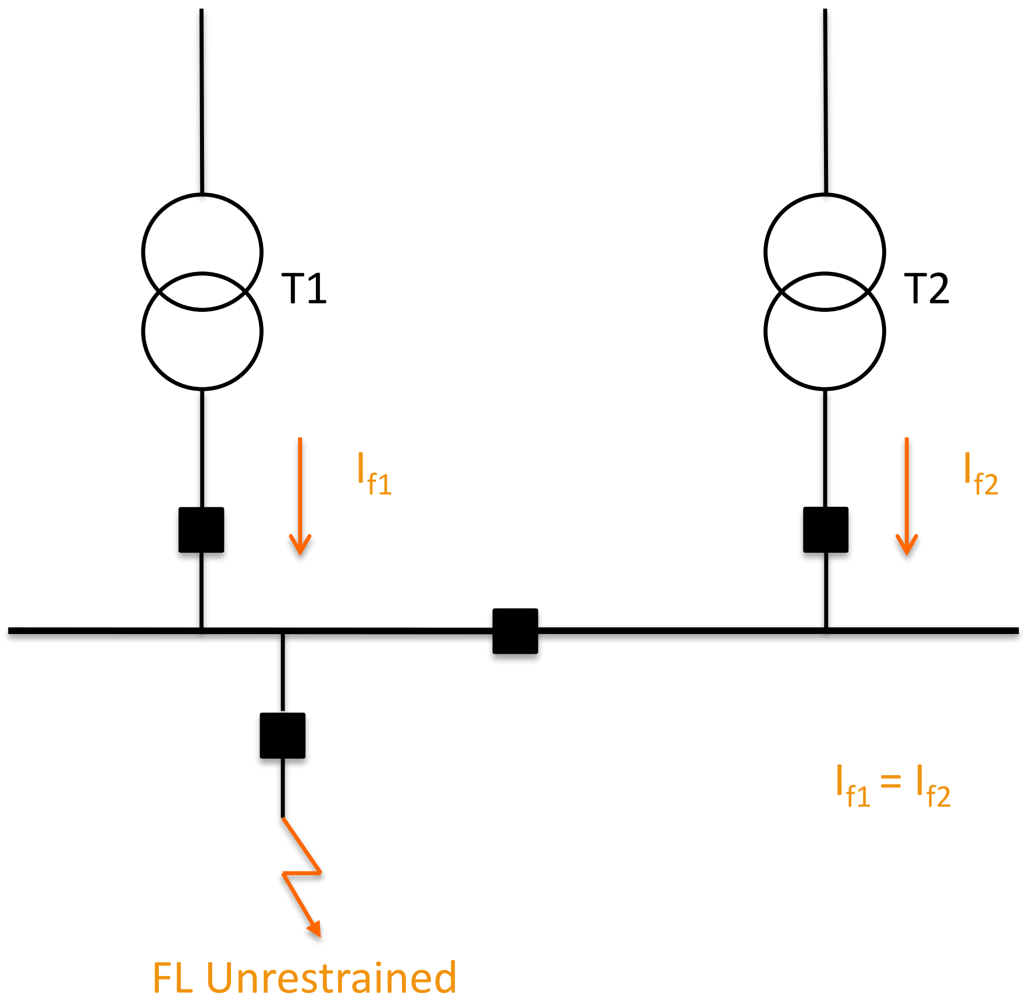
Method Gamma Update

- Specified requirements for FCLs at each substation
- ITT released in June 2013
- Post Tender Negotiations Complete
- SDRC-6 submitted to Ofgem for approval
- Contract awards December 2013 (provisional)
- Conceptual designs underway

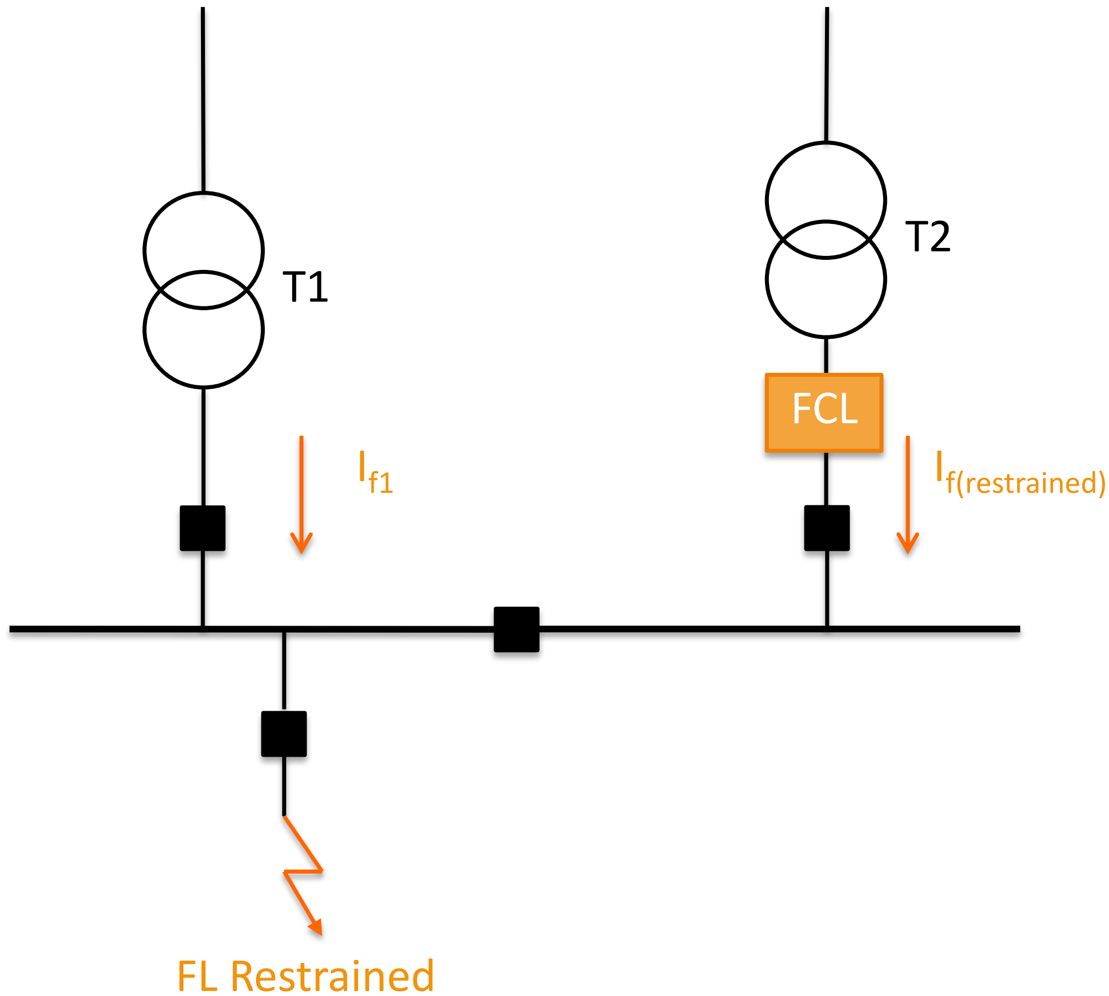
Specifying FCLs

- As part of the ITT a range of functional requirements were provided to the Tenderers:
  - **Voltage (normal and withstand)**
  - **Rating (continuous current)**
  - **Typical specifications (IEC, BS and ENA – where applicable)**
- In addition, it was critical to specify the prospective fault levels and level of reduction required
  - **This can be expressed in two ways: Overall and through the source**

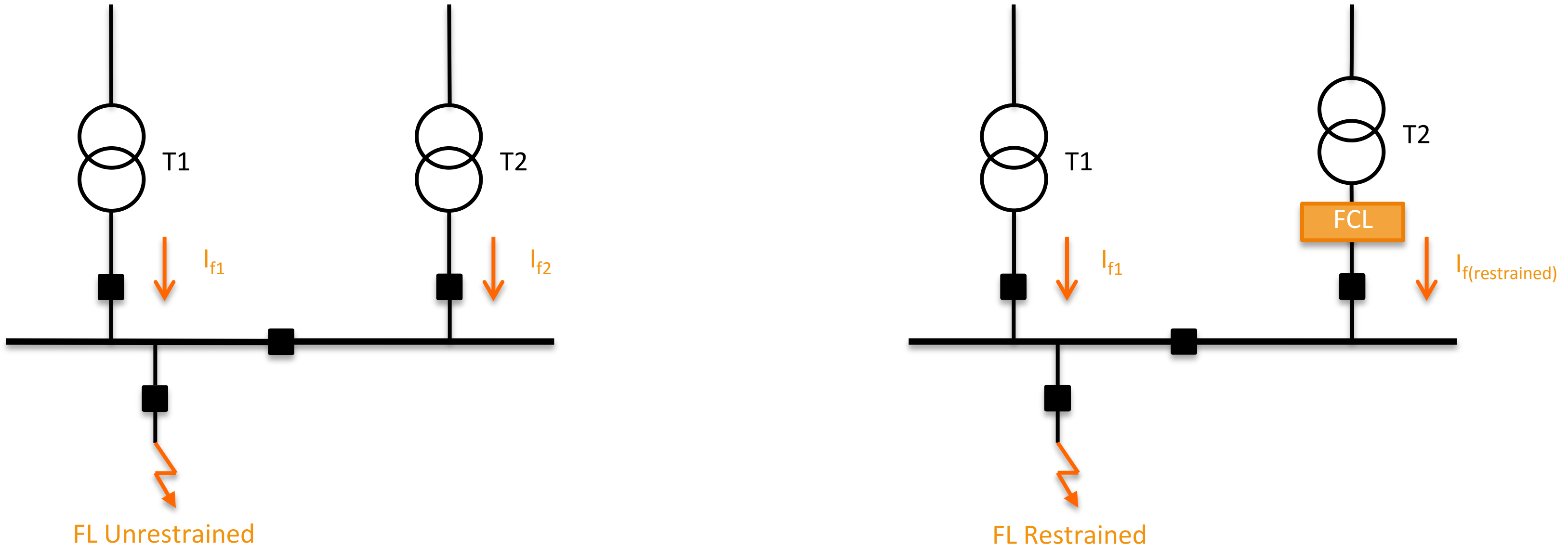
Example: Existing Parallel Fault Level



Example: With FCL added



Example: Calculation of reduction



FCL Requirements:

Overall Reduction = $(FL_{Unrestrained} - FL_{Restrained})/FL_{Unrestrained}$ X 100 = XX %

T2 Reduction = $(I_{f2} - I_{f(restrained)})/I_{f2}$ X 100 = YY %

Specifying FCLs

- Following information was requested from manufacturers to aid with the FCL evaluation:
  - General operation and maintenance requirements
  - Proposed dimensions and mass
  - Recovery / reset times
  - H&S implications (potential EMFs, non standard equipment)
  - Previous experience / installations
  - Costs, lead-times, T&Cs etc…

Specifying FCLs

- Proposals were evaluated individually per substation
  - **Does it meet the required FL reduction requirements?**
  - **Physical size of the proposed solution – can it be accommodated?**
  - **Are there any deviations from the functional specification?**

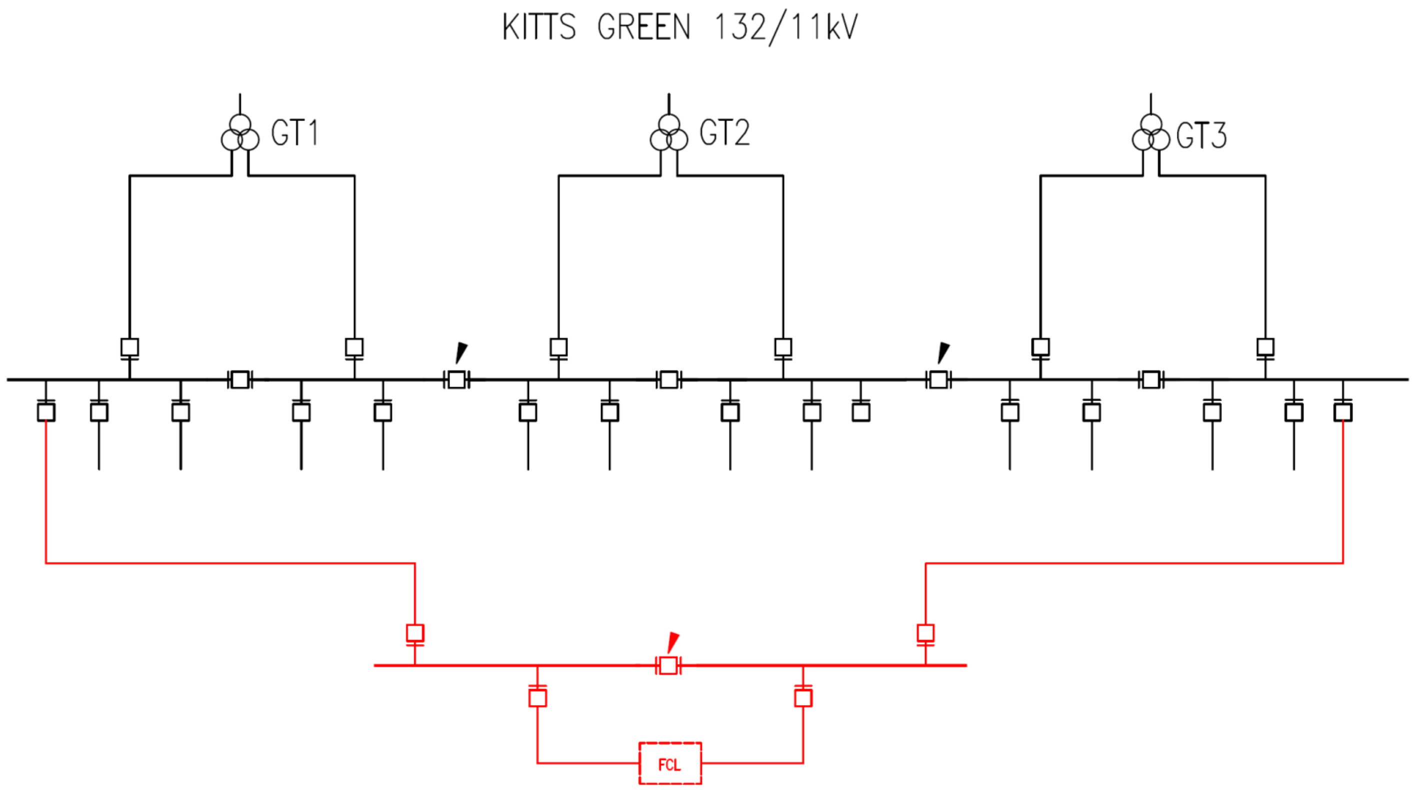
FCLs for FlexDGrid

- Kitts Green
- Castle Bromwich
- Chester Street
- Bournville
- Sparkbrook

Kitts Green 132/11kV

- 3 no. 132/11/11kV transformers
- When operating in parallel at 11kV, 3ph break FL is 15.7kA
- Target 3ph break FL is 9.4kA with FCL
- FCL to be connected into 11kV interconnector

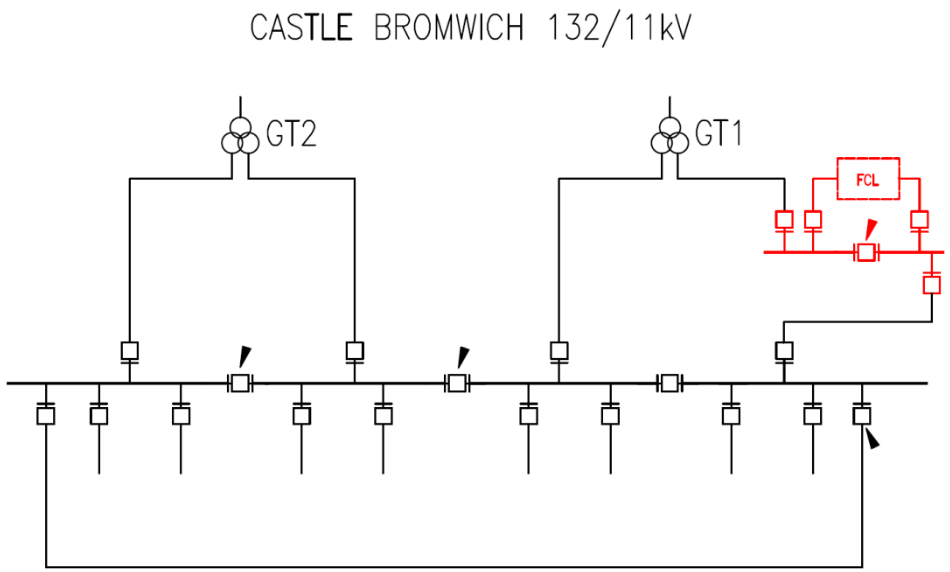
Kitts Green 132/11kV



Castle Bromwich 132/11kV

- 2 no. 132/11/11kV transformers supplied from separate Grid Supply Points
- When operating in parallel at 11kV, 3ph break FL is 13.7kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected into 11kV transformer ‘tails’

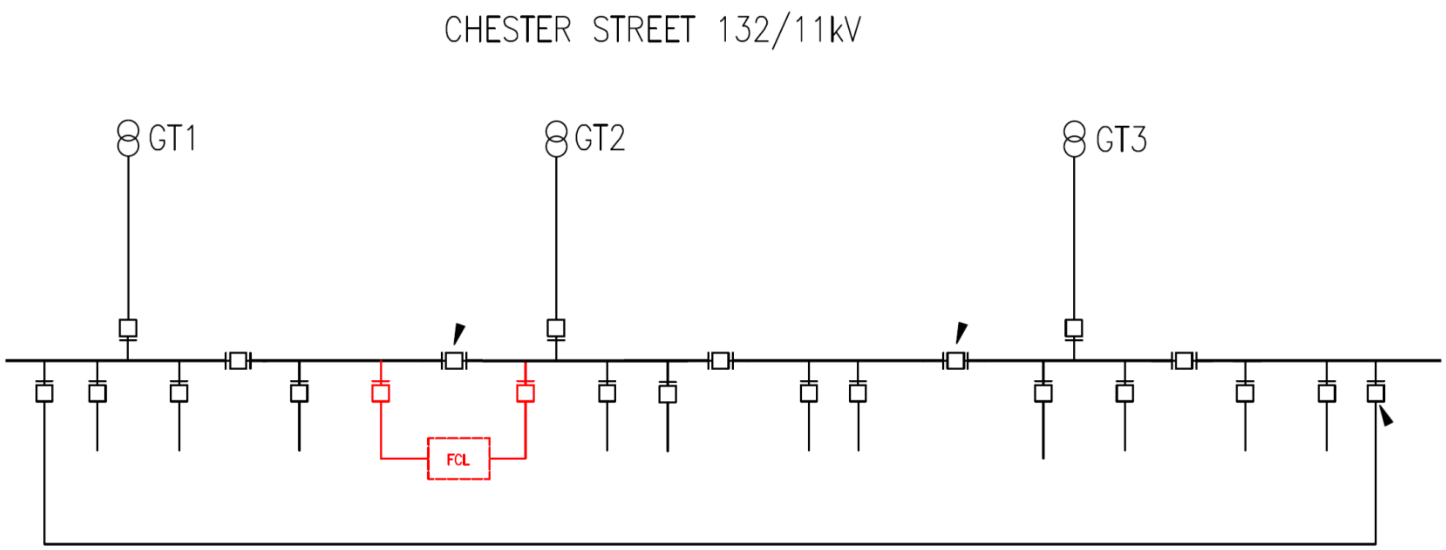
Castle Bromwich 132/11kV



Chester Street 132/11kV

- 3 no. 132/11kV transformers, one supplied from separate Grid Supply Point
- 11kV switchgear is being replaced under DPCR5
- When operating in parallel at 11kV, 3ph break FL is 14.1kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected across bus-section

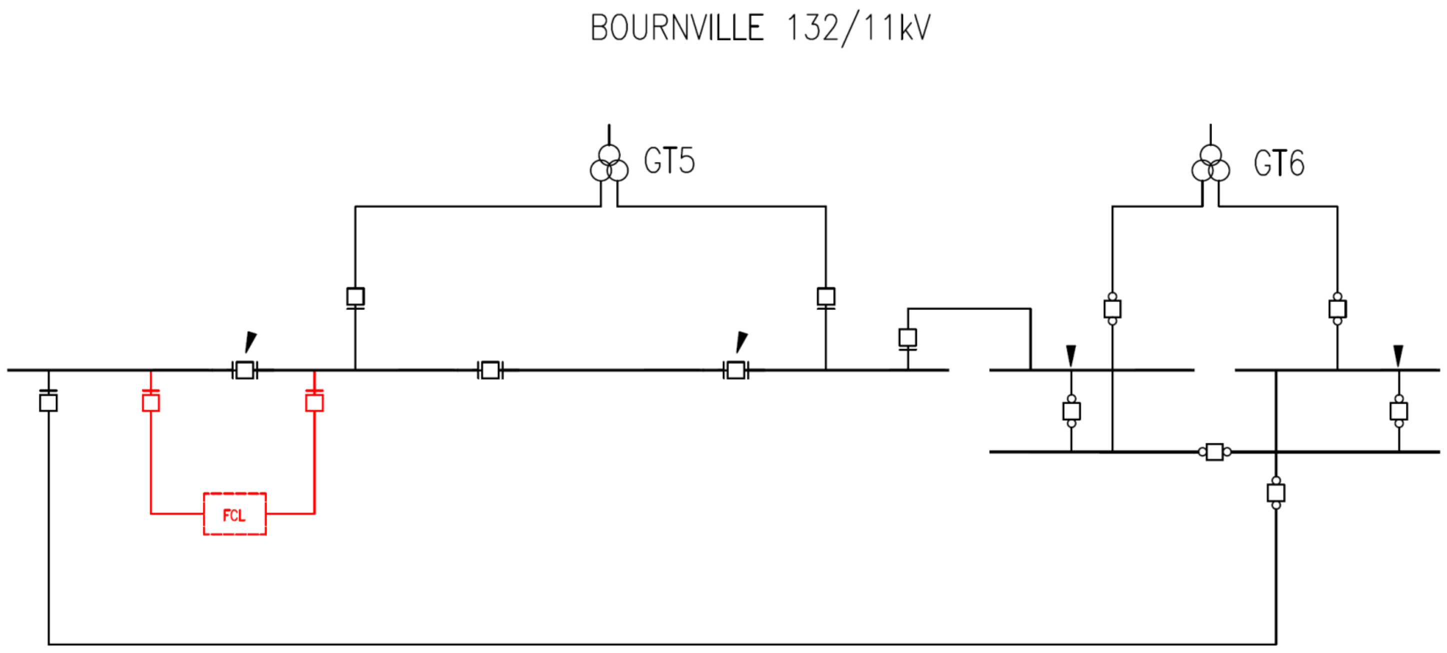
Chester Street 132/11kV



Bournville 132/11kV

- 4 no. 132/11kV transformers
- Transformers and 11kV switchgear are scheduled for replacement
- When operating in parallel at 11kV, 3ph break FL is 15.3kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected across bus-section

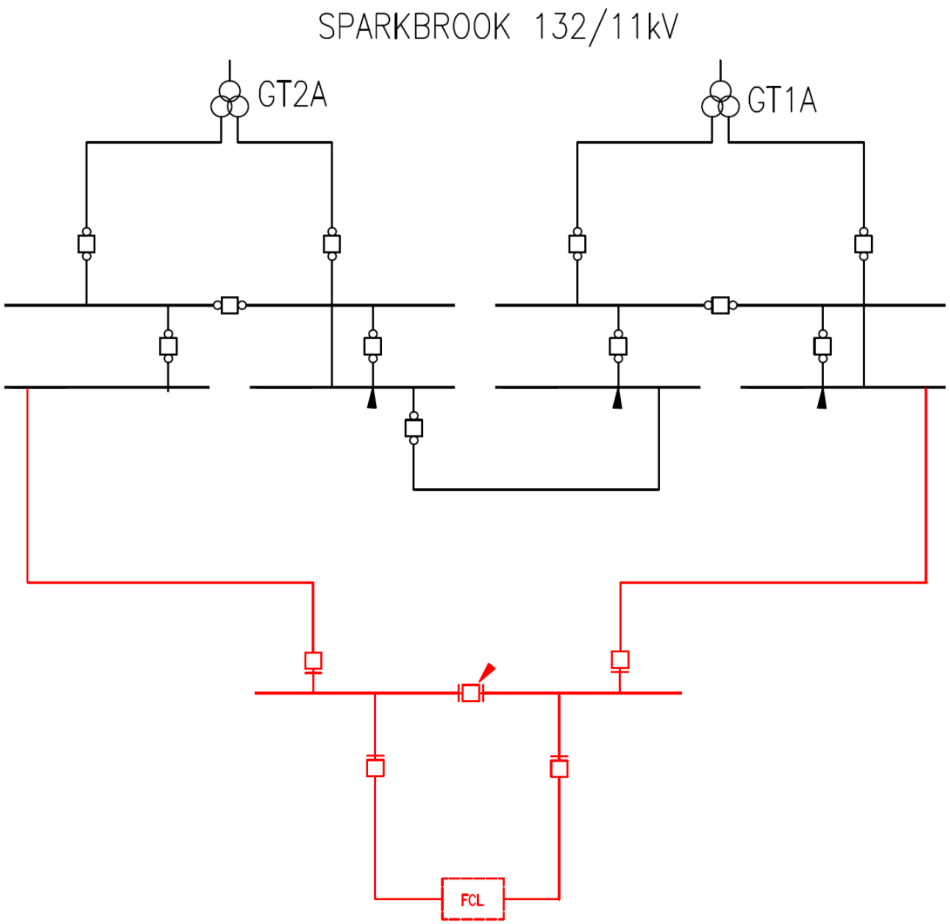
Bournville 132/11kV



Sparkbrook 132/11kV

- 2 no. 132/11/11kV transformers
- When operating in parallel at 11kV, 3ph break FL is 16.1kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected into 11kV interconnector

Sparkbrook 132/11kV



Summary

- Any technologies that could not meet the fundamental requirements were rejected
- Remaining technologies were scored in line with the method explained in the ITT
- As the aim of FlexDGrid is to install and trial emerging technologies, a maximum of two of the same type of FCLs were considered across the five sites
- Contract awards December 2013 (provisional)

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions and Answers

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Lunch and Networking

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Agenda

10:00 – 10:30	**Arrival – Refreshments and Networking**
10:30 – 10:50	Round table introductions to include delegates' background in fault level modelling
10:50 – 11:00	Overview of FlexDGrid and the purpose of the workshop
11:00 – 11:30	Presentation 1 – Topic Focus: Dissemination of SDRC-1 (Enhanced fault level assessment processes)
11:30 – 12:05	Presentation 2 – Topic Focus: Monitoring and mitigation of fault level
12:05 – 12:30	Q&A session
12:30 – 13:15	Lunch and Networking
13:15 – 14:10	Discussion session 1: Monitoring of fault level and impact on connection applications
14:10 – 14:20	Break
14:20 – 15:15	Discussion session 2: Modelling of fault current limiters and impact on connection applications
15:15 – 15:30	Summary of workshop results and next steps
15:30	Close

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Discussion Session 1:

Monitoring of fault level and impact on connection applications

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF

Monitoring of fault level and impact on connection applications

1. What needs to be in place for fault level monitoring systems to be adopted?
    - From the DNO perspective / from the customer perspective

2. How would the network model and connection application process be modified if DNOs were able to access monitored fault level data?

3. What updates to G74 and Policy documents are needed and how should these documents be modified?

4. Any other discussions related to monitoring of fault level

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Discussion Session 2:

Modelling of fault current limiters and impact on connection applications

LCN Fund Low Carbon Networks
THE UNIVERSITY OF WARWICK
PARSONS BRINCKERHOFF

Modelling of fault current limiters and impact on connection applications

1. What parameters should be modelled and what studies carried out to understand the behaviour of fault current limiters?

2. How should power system analysis packages be modified to accommodate fault current limiter models? (Define user requirements)

3. How should the connection application process and connection offers be modified to incorporate FCLs?
   a) Who should pay for what?
   b) How should connection charges be quantified?

4. Any other discussions related to modelling of fault current limiters

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Summary

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Thank you for joining us

Please complete your feedback form and have a safe journey home

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

DNO Workshop on Fault Level Mitigation Technologies

Wednesday 14th May 2014

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Introduction

- House-keeping
- Agenda
- Round table introductions
- Workshop aims

Agenda

10:00 – 10:30	**Arrival – Refreshments and Networking**
10:30 – 11:10	Round Table Introductions to include delegates background in FCL
11:10 – 11:30	Update on progress of FlexDGrid and purpose of the workshop
11:30 – 12:15	Session 1 – Detailed overview of chosen technologies for FlexDGrid
12:15 – 13:00	Lunch and Networking
13:00 – 14:30	Session 2 – Installing technologies in to FlexDGrid sites
14:30 – 14:45	Open Session – Other DNOs on-going experiences of FCLs on their system
14:45 – 15:15	Turning trials in to BaU – Policies, operational and maintenance procedures
15:15 – 15:30	Summary of workshop results and next steps
15:30	**Close**

Round Table Introductions

DNO	Name	Job Title
WPD	Jonathan Berry	Innovation Engineer
WPD (Parsons Brinckerhoff)	Ali Kazerooni	FlexDGrid Modelling Lead
WPD (Parsons Brinckerhoff)	Samuel Jupe	FlexDGrid EFLA Lead
WPD (Parsons Brinckerhoff)	Neil Murdoch	FlexDGrid Distribution Lead
ENWL	Dan Randles	Network Innovation and Performance Manager
NPG	Dr. Roshan Bhattarai	System Planning Engineer
SPEN	Stephen Peacock	Engineering Development Manager
SSE	Hui Yi Heng	System Planning Engineer
UKPN	Ian Cooper	Senior Technology Transfer Engineer
UKPN	Paul Dyer	Transformer and Switchgear Specialist

FlexDGrid – What and Why

What are we doing?

Understanding, Managing and Reducing the Fault Level on an electricity network

Why are we doing it?

Facilitating the early and cost effective integration of Low Carbon generation

Why are we doing it now?

Supporting the Carbon Plan – Connection of generation to the grid and development of heat networks – reducing carbon emissions

What is FlexDGrid?

Three integrated Methods leading to quicker and cost effective customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network Fault Level.

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

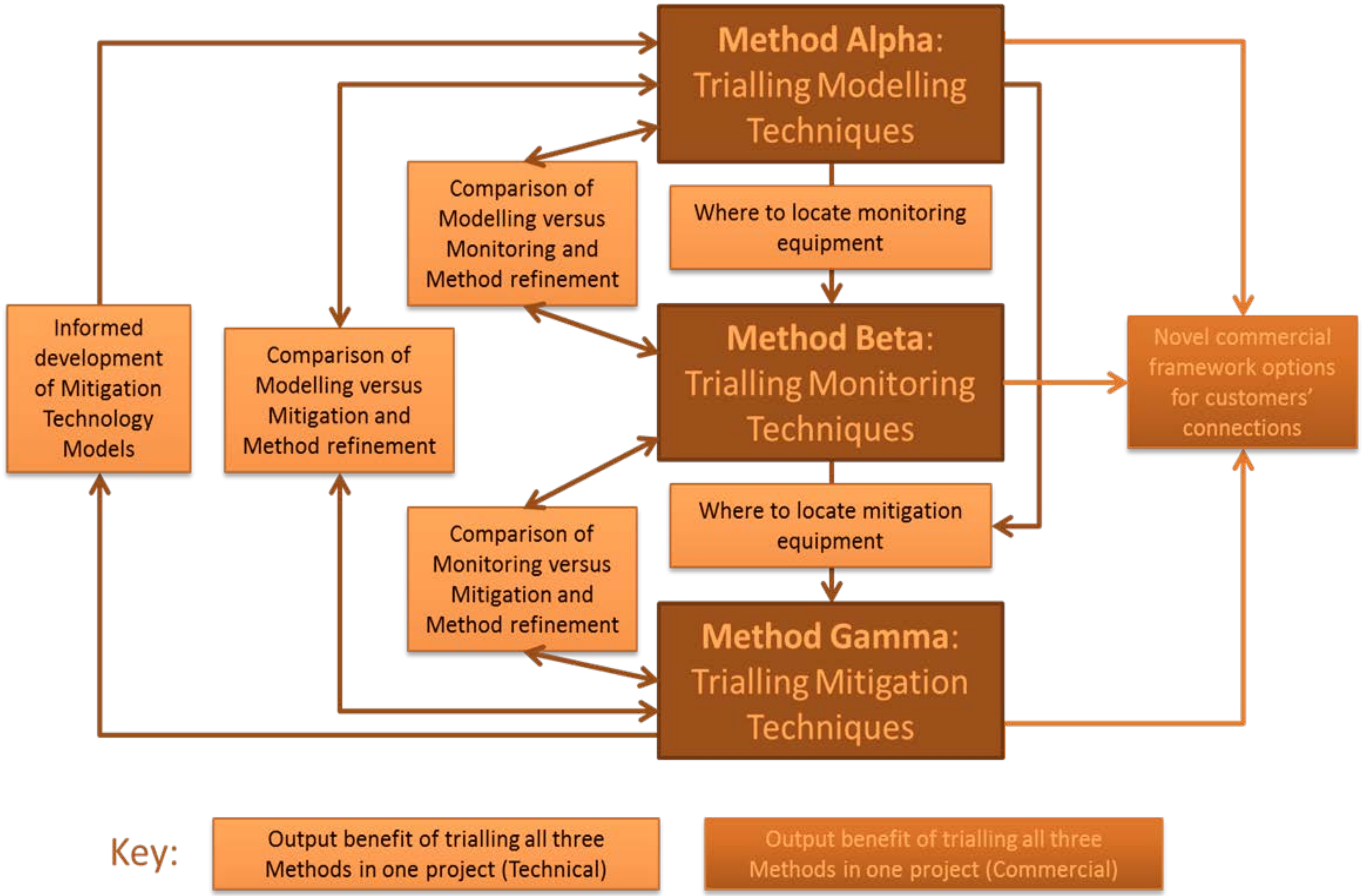
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional Generation.

An Integrated Method Approach



FlexDGrid Explained – Method Alpha

The Enhanced Fault Level Assessment Method will provide refined Fault Level analysis techniques to understand the areas of the network that are likely to exhibit Fault Level issues. This will be used to provide customers with more accurate and refined network connection offers.

Problem

- Existing models built on lots of network assumptions
- Modelling uncertainty providing reserved outputs

Solution

- Provide greater network model detail and granularity
- Feed in up-to-date network arrangement and connection data

Benefit

- Increased certainty of network model accuracy
- Reduced modelling uncertainty
- Release of DG connection capacity

FlexDGrid Explained – Method Beta

The Real-time Management Method will enable accurate Fault Level data to be gathered for various network arrangements. This will be used to verify the Fault Level assessed through the Trial of Enhanced Fault Level Assessment processes.

Problem

- Currently no capability to monitor Fault Level
- Essential safety margin applied due to lack of network information

Solution

- Monitor Fault Level using new device
- Feed monitored and measured Fault Level data in to enhanced network model
- Manage network using monitored and modelled data

Benefit

- Increased knowledge of networks’ Fault Level
- Reduction of required safety margin
- Release of DG connection capacity

FlexDGrid Explained – Method Gamma

The Fault Level Mitigation Method will install technologies in to substations which currently exhibit Fault Level issues and where new connections are expected to cause an increase in fault currents. This Method adds Fault Level capacity by reducing fault currents.

Problem

- Current Fault Level reduction solutions are costly and take a long time
- Existing solutions have limited reduction capability / no reduction but ability to accommodate more Fault Level

Solution

- Installation of new technologies that have been tested in a laboratory or in network isolation

Benefit

- Reduced cost of connection to all users
- Minimise time to connect generation
- Fault Level headroom is maximised

Selected Substations

Ref:	Substation	
A	Kitts Green	FCL & FLM
B	Castle Bromwich	FCL & FLM
C	Chester Street	FCL & FLM
D	Bournville	FCL & FLM
E	Sparkbrook	FCL & FLM
F	Hall Green	FLM Only
G	Elmdon	FLM Only
H	Chad Valley	FLM Only
I	Perry Barr	FLM Only
J	Winson Green	FLM Only

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Session 1 – Topic Focus:

Detailed overview of technologies chosen for FlexDGrid

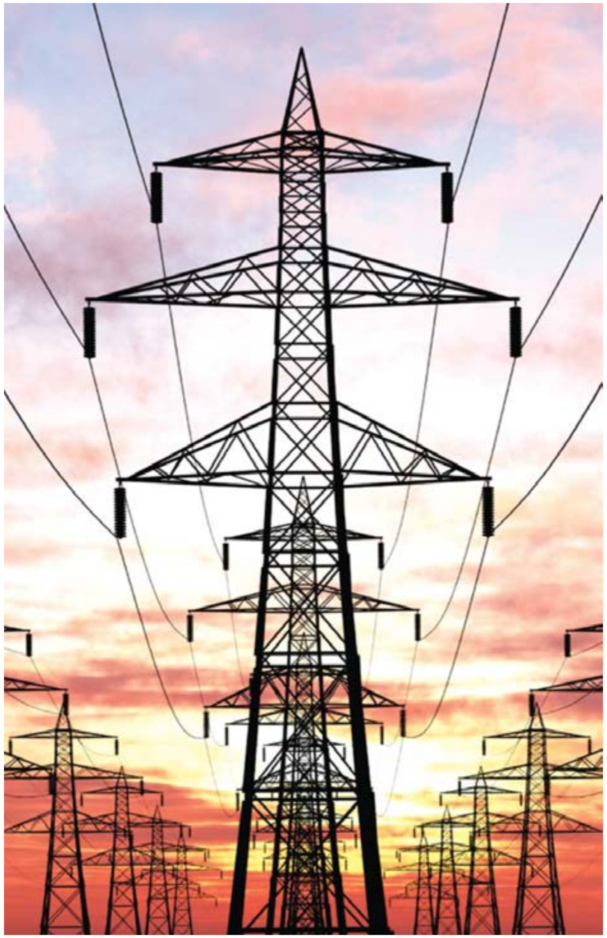
Neil Murdoch

Distribution Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF

Introduction

- Update on Method Gamma
- Summary of technologies
- Description of:
  - Pre-Saturated Core FCL
  - Resistive Superconducting FCL
  - Power Electronic FCL
- Overview of Engineering Specification for FCLs



FlexDGrid – Method Gamma

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

FlexDGrid – Method Gamma

- Method Gamma: Fault Level Mitigation Technologies
  - Build on knowledge learned through IFI, ETI and LCNF Projects
  - Install 5 FL mitigation technologies in 5 separate WPD substations
  - Test & trial emerging technologies to quantify performance and network benefits

Summary of Technologies

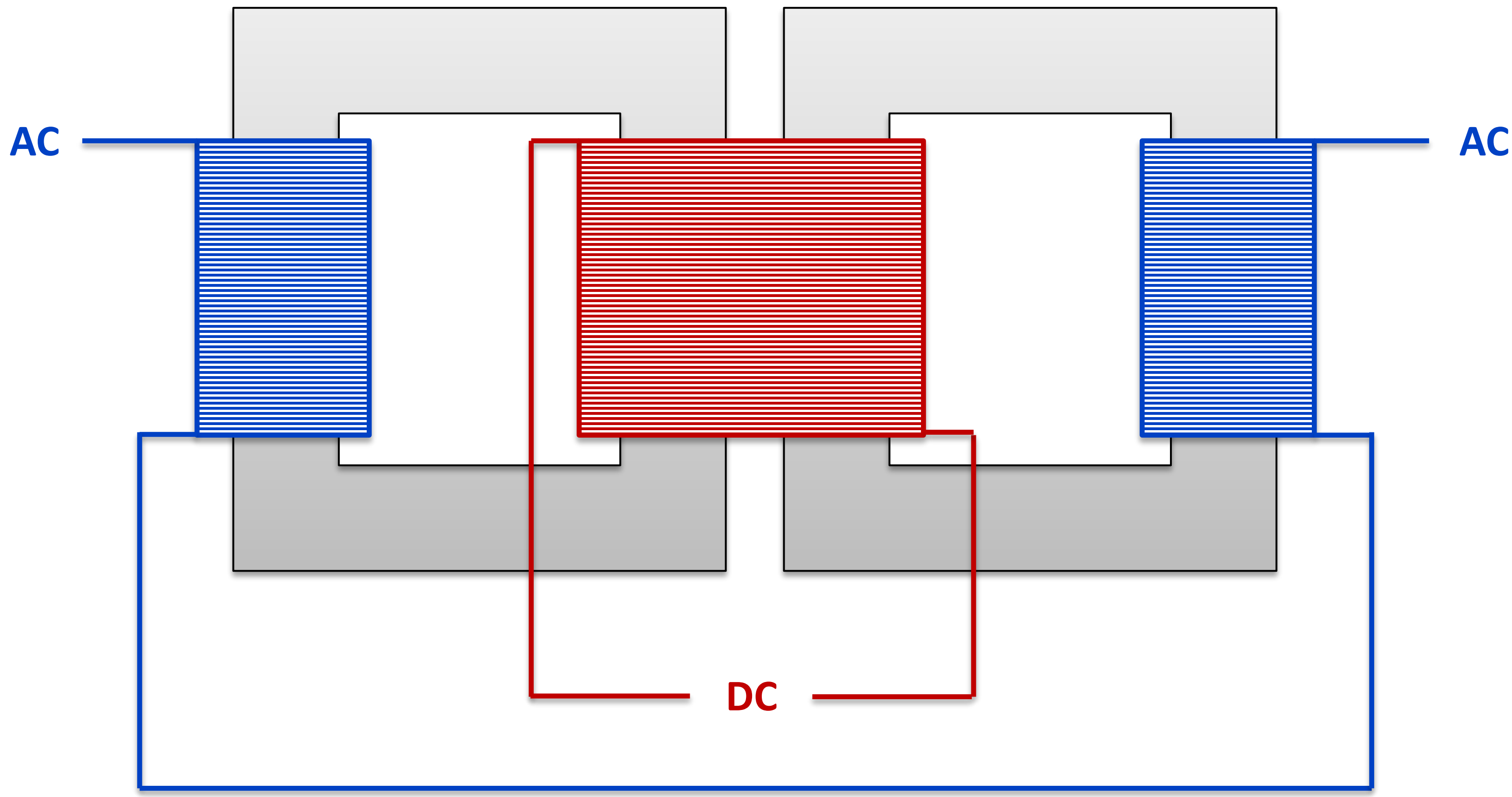
– Signed Contracts now in place for 5 FlexDGrid substations:

Substation	Technology	Manufacturer	Delivery Date
Castle Bromwich	Pre-Saturated Core FCL	GridON	Q4 2014
Chester Street	Resistive Superconducting FCL	Nexans	Q2 2015
Bournville	Resistive Superconducting FCL	Nexans	Q3 2015
Kitts Green	Power Electronic FCL	Alstom	Q4 2015
Sparkbrook	Power Electronic FCL	Alstom	Q1 2016

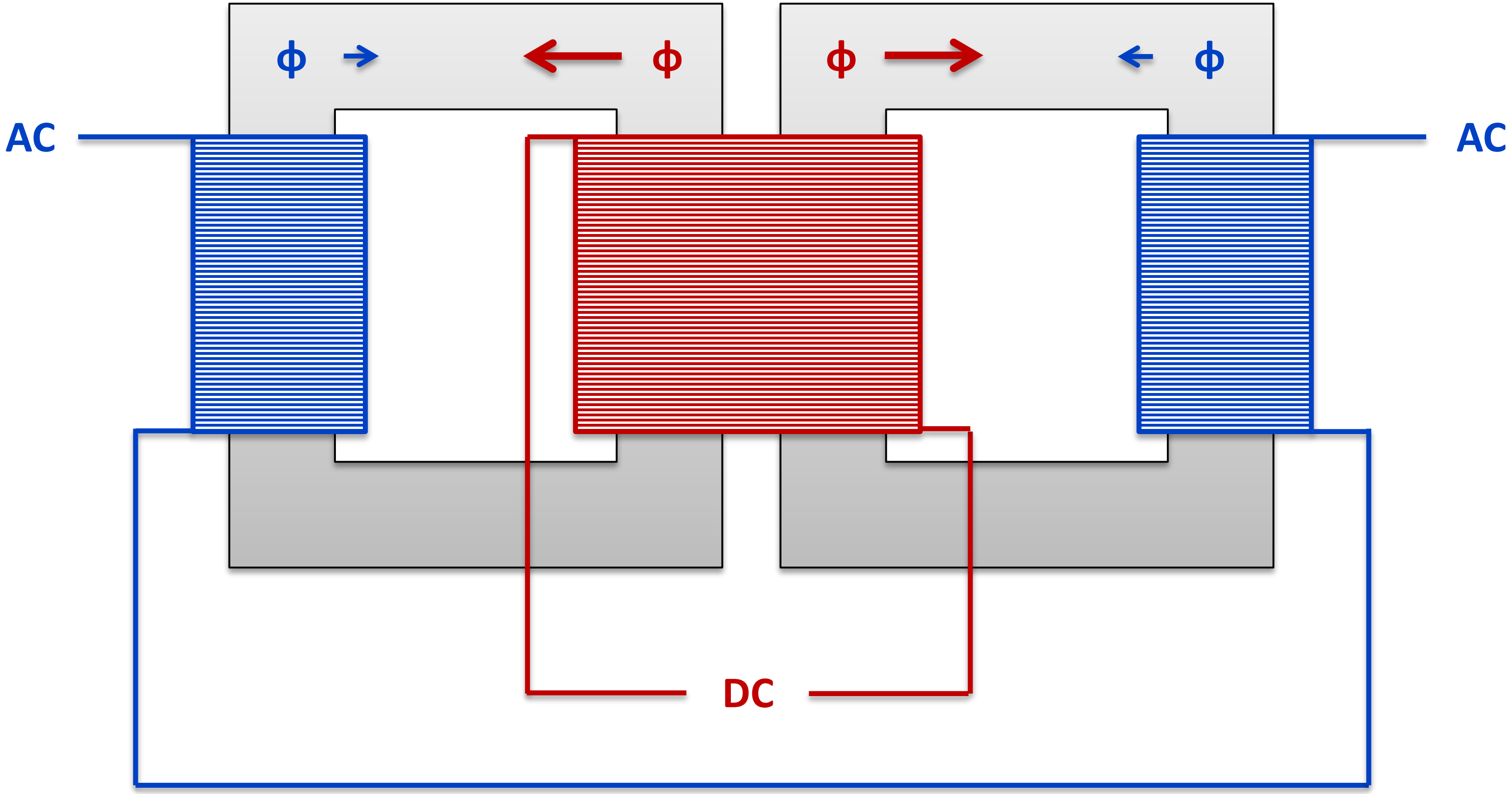
Pre-Saturated Core Fault Current Limiter

- Also known as an "Inductive FCL" the PSCFCL uses the principles of magnetisation in a core to create a variable inductor
- The device comprises:
  - Laminated Cores (similar to that of a reactor)
  - AC Coils (connected in series with the 11kV network)
  - DC Coils (supplied from a local source)

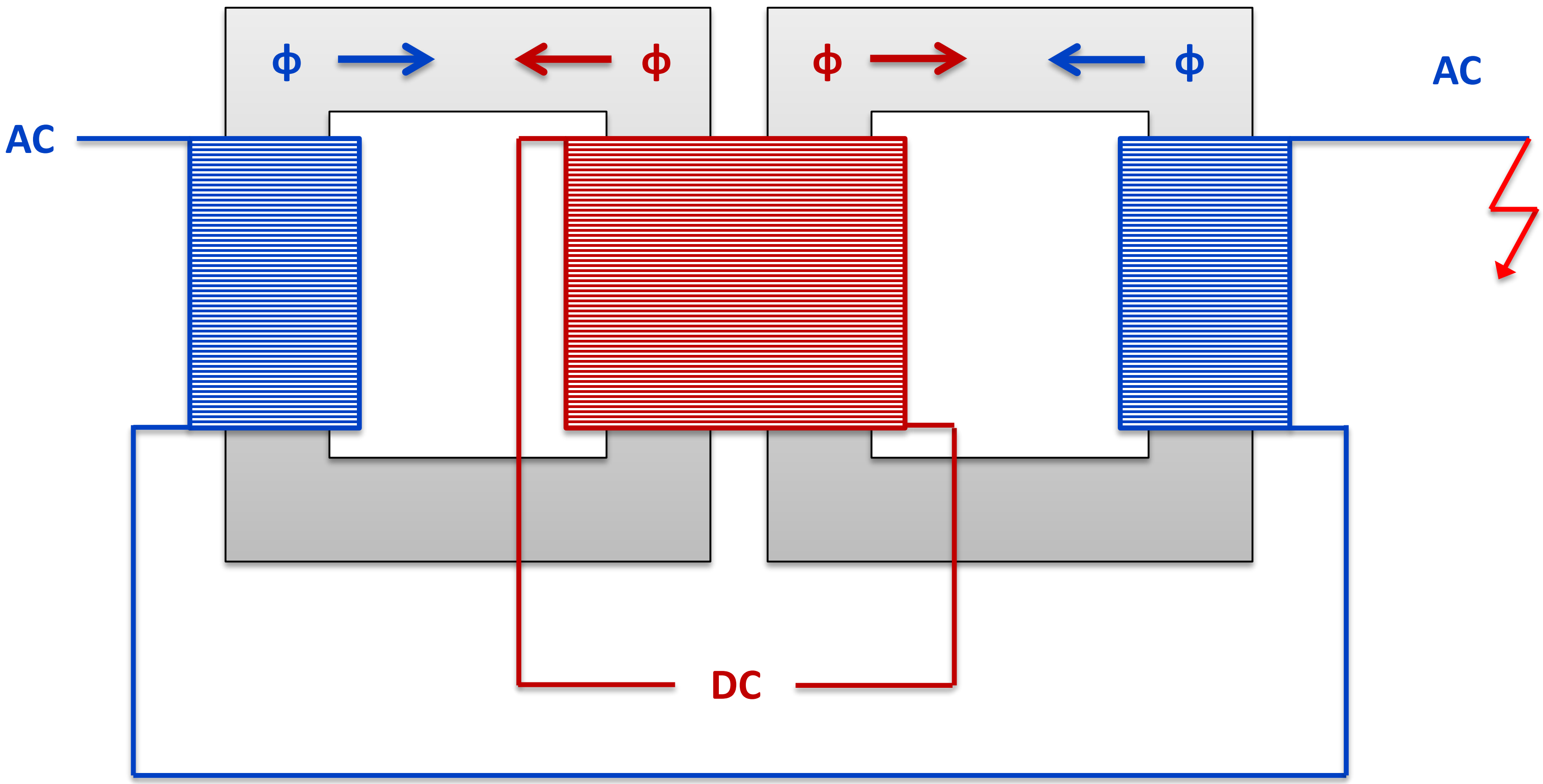
Diagram of PSCFCL



Normal Operation of PSCFCL



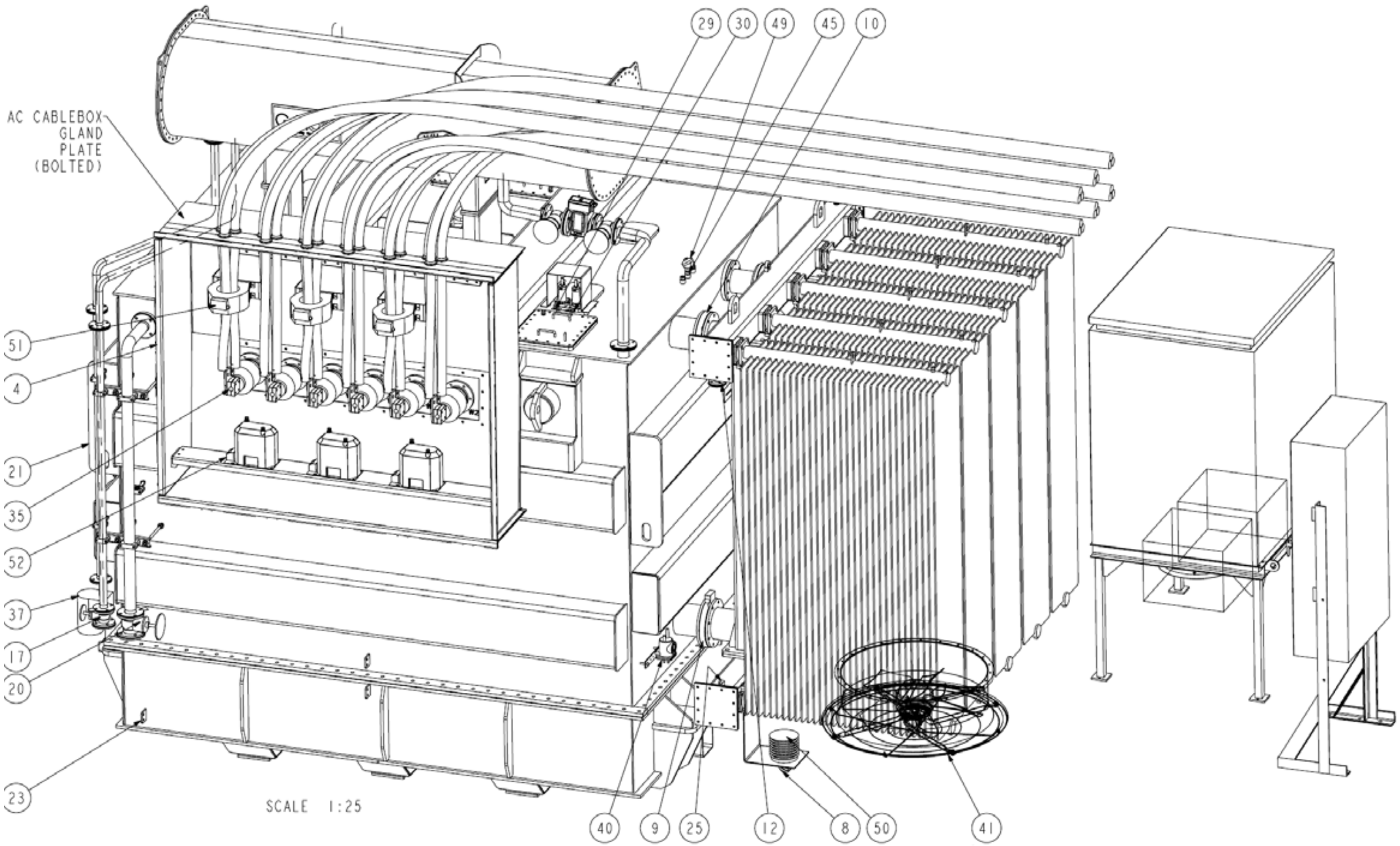
Operation of PSCFCL during a fault



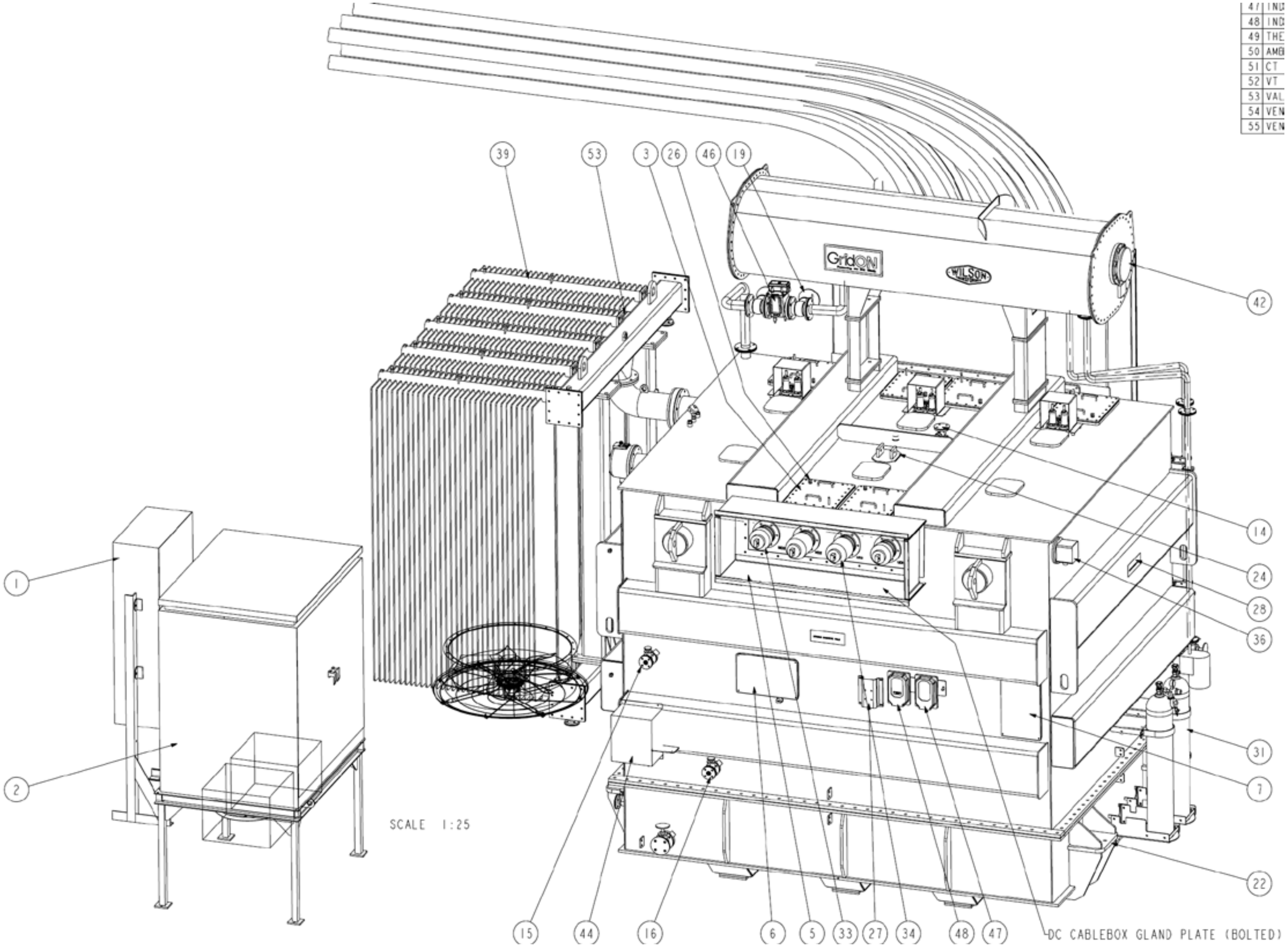
Details for GridON PSCFCL for Castle Bromwich

- Rating: 30MVA ONAN, 38MVA ONAF
- Break fault level reduction required: 44%
- Peak fault level reduction required: 53%
- Mass: 170 Tonnes
- Dimensions (LxWxH): 6.4 x 4.5 x 5.3 m

GA for GridON PSCFCL for Castle Bromwich



GA for GridON PSCFCL for Castle Bromwich



DC bias current during operation

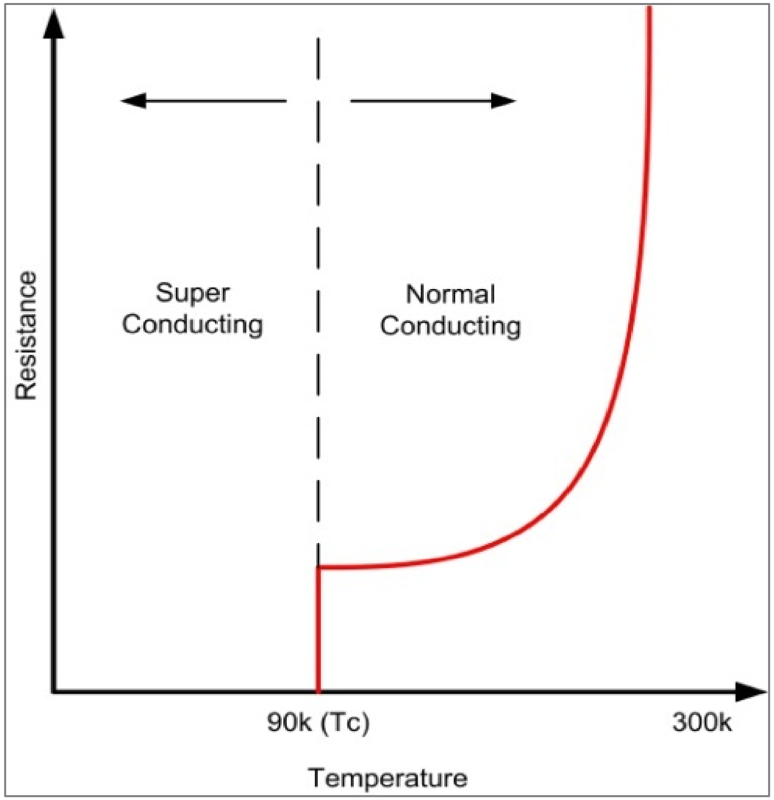
- The level of DC current required to saturate the core sufficiently is proportional to the level of AC current
- For Castle Bromwich the DC supplies shall be switched to control the level of DC bias

AC Load current RMS [A]	DC bias current [A]
400	130
800	220
1000	270
1250	320
1575	390
2000	490

Resistive Superconducting Fault Current Limiter

- Uses the inherent properties of a High Temperature Superconductor (HTS) to provide high insertion impedance to limit fault current
- During normal operation the RSFCL operates below the critical current in the superconducting region
- In a fault situation, the current rises in the HTS and subsequently the device begins to operate in the non-superconducting region

Resistive Superconducting Fault Current Limiter



Resistive Superconducting Fault Current Limiter

– In the non-superconducting region, the impedance of the device will rise dramatically. This is known as "quenching" and will result in tripping of the device.

Details for Nexans RSFCL for Chester Street

- Rating: 1600A
- Break fault level reduction required: 48%
- Peak fault level reduction required: 55%
- Mass: 30 Tonnes (including enclosure)
- Dimensions (LxWxH): 8 x 3 x 4 m

Details for Nexans RSFCL for Bournville

- Rating: 1050A
- Break fault level reduction required: 65%
- Peak fault level reduction required: 60%
- Mass: 6 Tonnes (components only)
- Dimensions (LxWxH): 8 x 3 x 4 m

Resistive Superconducting Fault Current Limiter

Resistive Superconducting Fault Current Limiter

– Power Consumption for cooling systems of RSFCLs

Chester Street	
Current (A)	Power (kW)
0	18.0
300	24.0
910	32.0
1160	39.5
1350	47.0
1490	53.5
1600	53.5

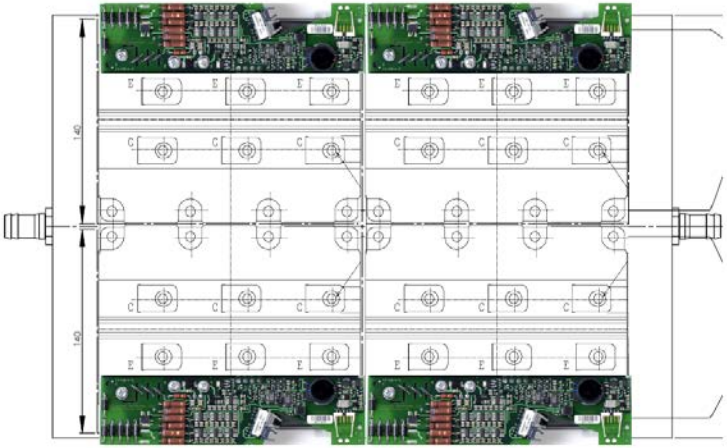
Bournville	
Current (A)	Power (kW)
0	18.0
240	18.0
300	24.0
850	24.0
910	32.0
1050	32.0

Power Electronic Fault Current Limiter

- The PEFCL comprises of power semiconductor devices which can be controlled to break the flow of fault current
- Due to the type of devices used in the PEFCL, in the instance where the control system fails the PEFCL will open
- Unlike other FCLs, after installation the PEFCL can be adjusted to reduce fault level of different magnitudes

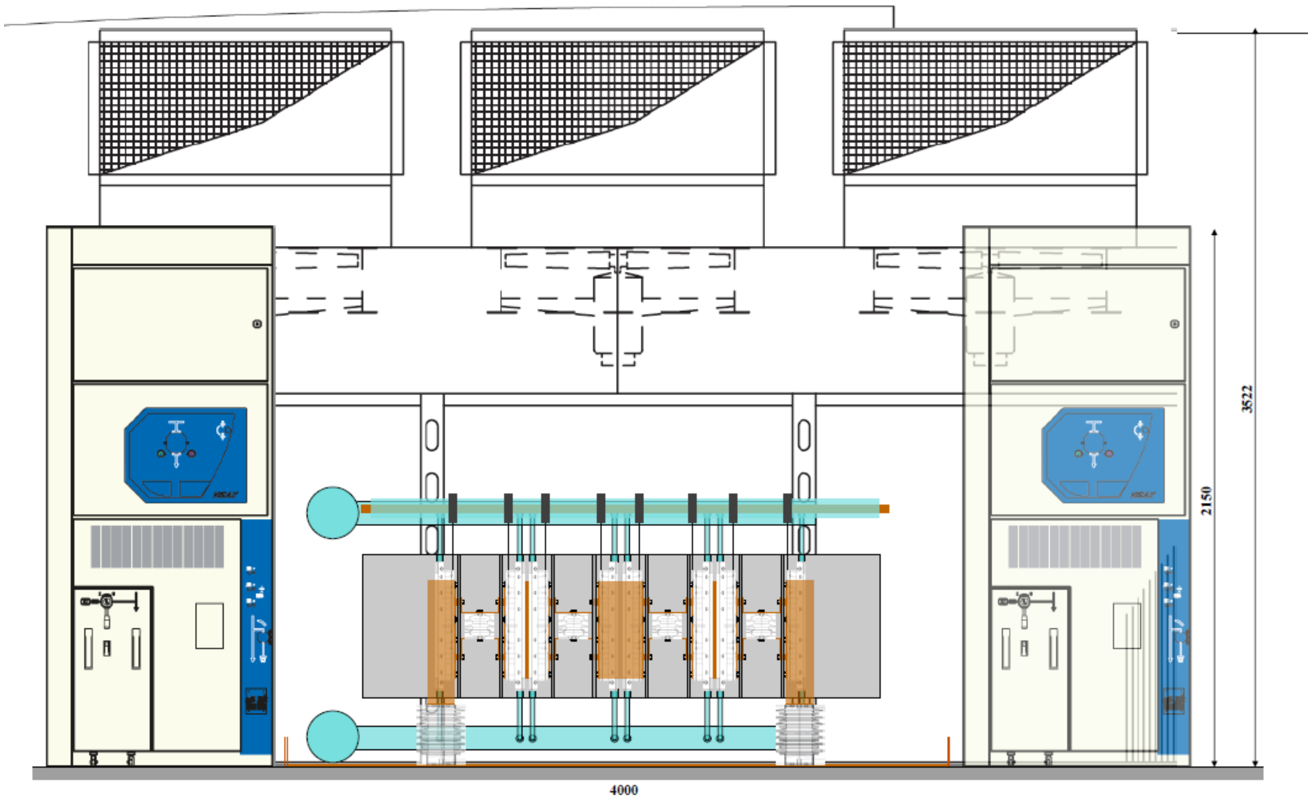
Power Electronic Fault Current Limiter

- IGBT and IGBT modules similar to those that will be used in the PEFCL



Power Electronic Fault Current Limiter

Full installation shown with switchgear



Details for Alstom PEFCL for Kitts Green

- Rating: 2000A
- Break fault level reduction required:82%
- Peak fault level reduction required: 86%
- Mass: 6 Tonnes
- Dimensions (LxWxH): 6 x 2.3 x 2.3 m

Details for Alstom PEFCL for Sparkbrook

- Rating: 2000A
- Break fault level reduction required:76%
- Peak fault level reduction required: 67%
- Mass: 6 Tonnes
- Dimensions (LxWxH): 6 x 2.3 x 2.3 m

Power Electronic Fault Current Limiter

– Power Consumption for PEFCL Cooling System

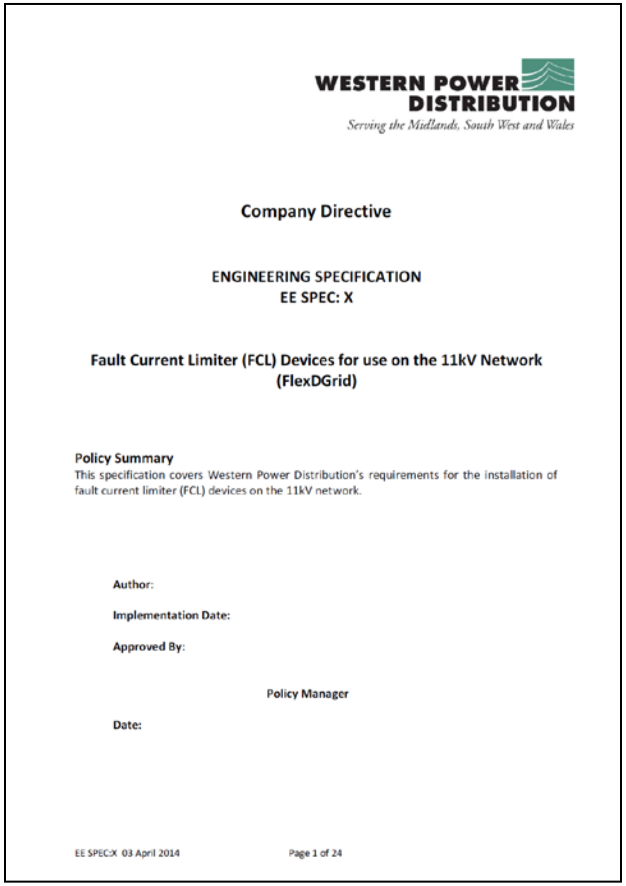
Current [A]	Power [A]
0	0.0
200	15.0
400	30.0
800	65.0
1200	110.0
1600	170.0
2000	250.0

Engineering Specification for Fault Current Limiters

- WPD have a suite of Engineering Specifications for equipment such as switchgear, transformers, cables etc.
- Using the structure of these existing documents as a template, an Engineering Specification for FCLs was produced
- The specification encompasses the three FCL technologies used for FlexDGrid

Engineering Specification

- Structure:
  - General Requirements
    - International standards
    - Service conditions
    - System parameters
  - Design
    - Common components
    - Earthing
    - Wiring
    - General construction requirements
    - Site works etc.



WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

ENGINEERING SPECIFICATION
EE SPEC: X

Fault Current Limiter (FCL) Devices for use on the 11kV Network (FlexDGrid)

Policy Summary
This specification covers Western Power Distribution's requirements for the installation of fault current limiter (FCL) devices on the 11kV network.

Author:

Implementation Date:

Approved By:

Policy Manager

Date:

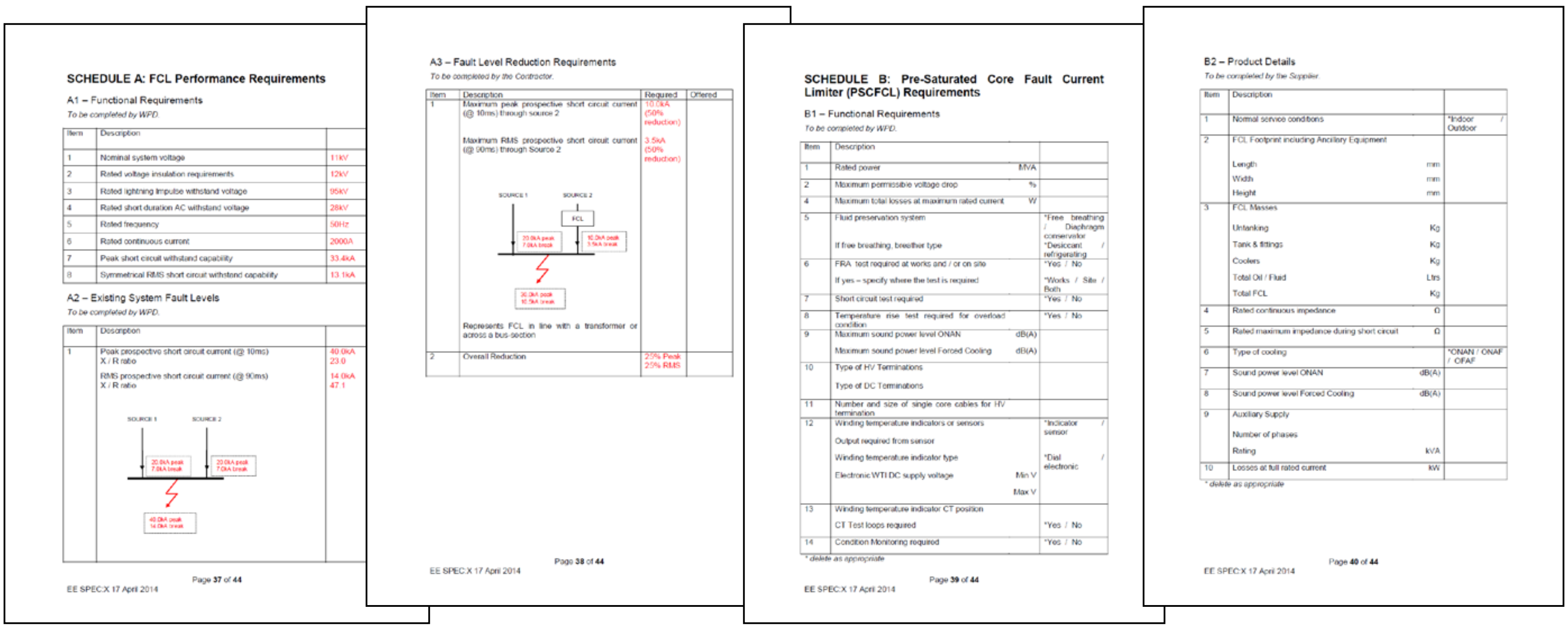
EE SPEC:X 03 April 2014 Page 1 of 24

Engineering Specification

- Structure:
  - Technology Specific
    - General expectations for PSCFCL, RSFCL and PEFCL
    - Requirement for all devices to be fail-safe
    - Magnetic shielding/protection (PSCFCL)
    - Pressure relief (PSCFCL/RSFCL)
    - Enclosures (RSFCL/PEFCL)
    - Control system redundancy (PEFCL)

Engineering Specification

- Schedules
  - FCL Performance Requirements
  - Functional requirements and product details for each technology



WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions and Answers

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Lunch and Networking

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Agenda

12:15 – 13:00	**Lunch and Networking**
13:00 – 14:30	Session 2 – Installing technologies in to FlexDGrid sites
14:30 – 14:45	Open Session – Other DNOs on-going experiences of FCLs on their system
14:45 – 15:15	Turning trials in to BaU – Policies, operational and maintenance procedures
15:15 – 15:30	Summary of workshop results and next steps
15:30	**Close**

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

DNO Workshop on Fault Level Mitigation Technologies

Wednesday 14th May 2014

Fault level monitoring

Samuel Jupe

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Overview

Summary of Method Beta aims

Output from SDRC-4, demonstrating potential value of monitoring

Comparison of modelled and monitored fault level results

Next steps

FlexDGrid – Method Beta

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

Fault level profile analysis methodology

Step 1
- Data analysis of operational configurations

Step 2
- Run fault level studies for operational configurations
- Collate configuration states and corresponding fault level values

Step 3
- Generate time-series graph to display real-time fault level profile

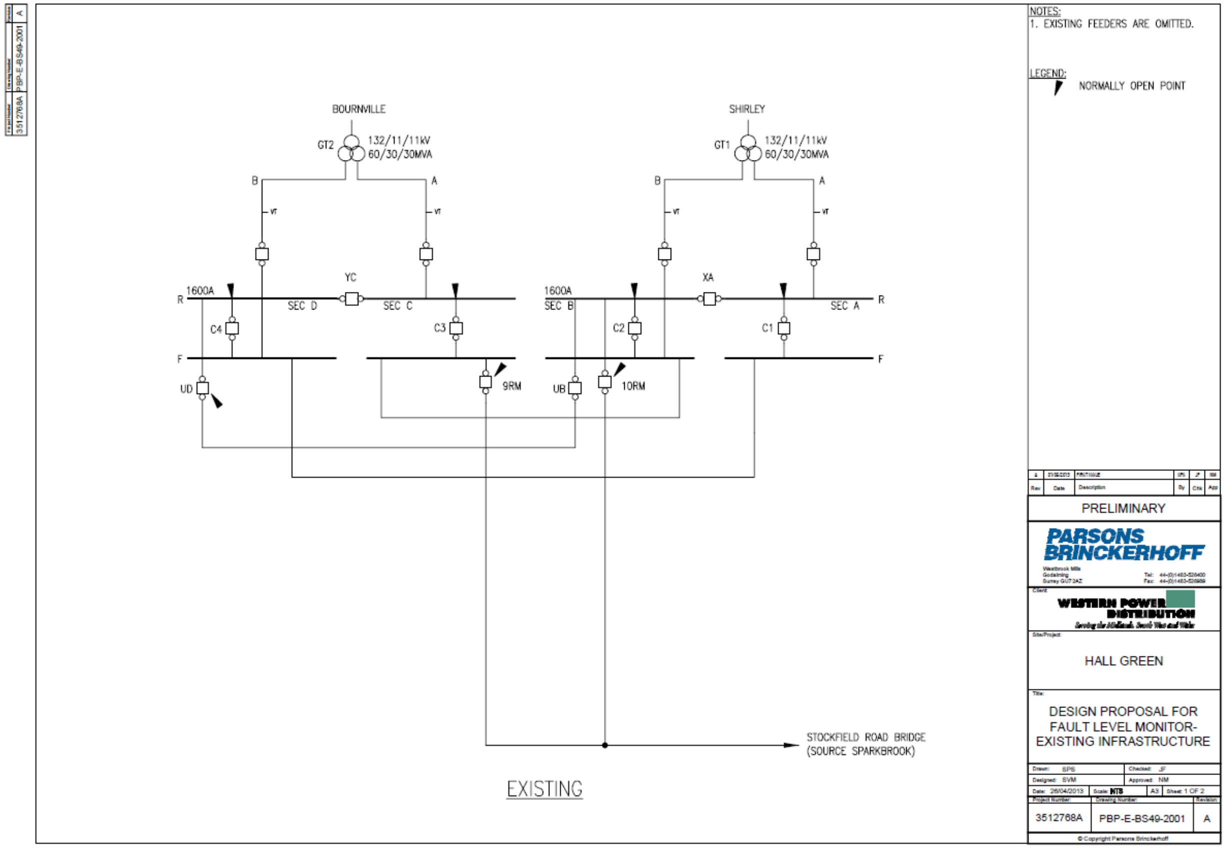
Step 4
- Generate fault level duration curve and quantify the MVA headroom between 'split' network fault level and policy fault level value

Step 5
- Convert to MW headroom using MVA / MW factor

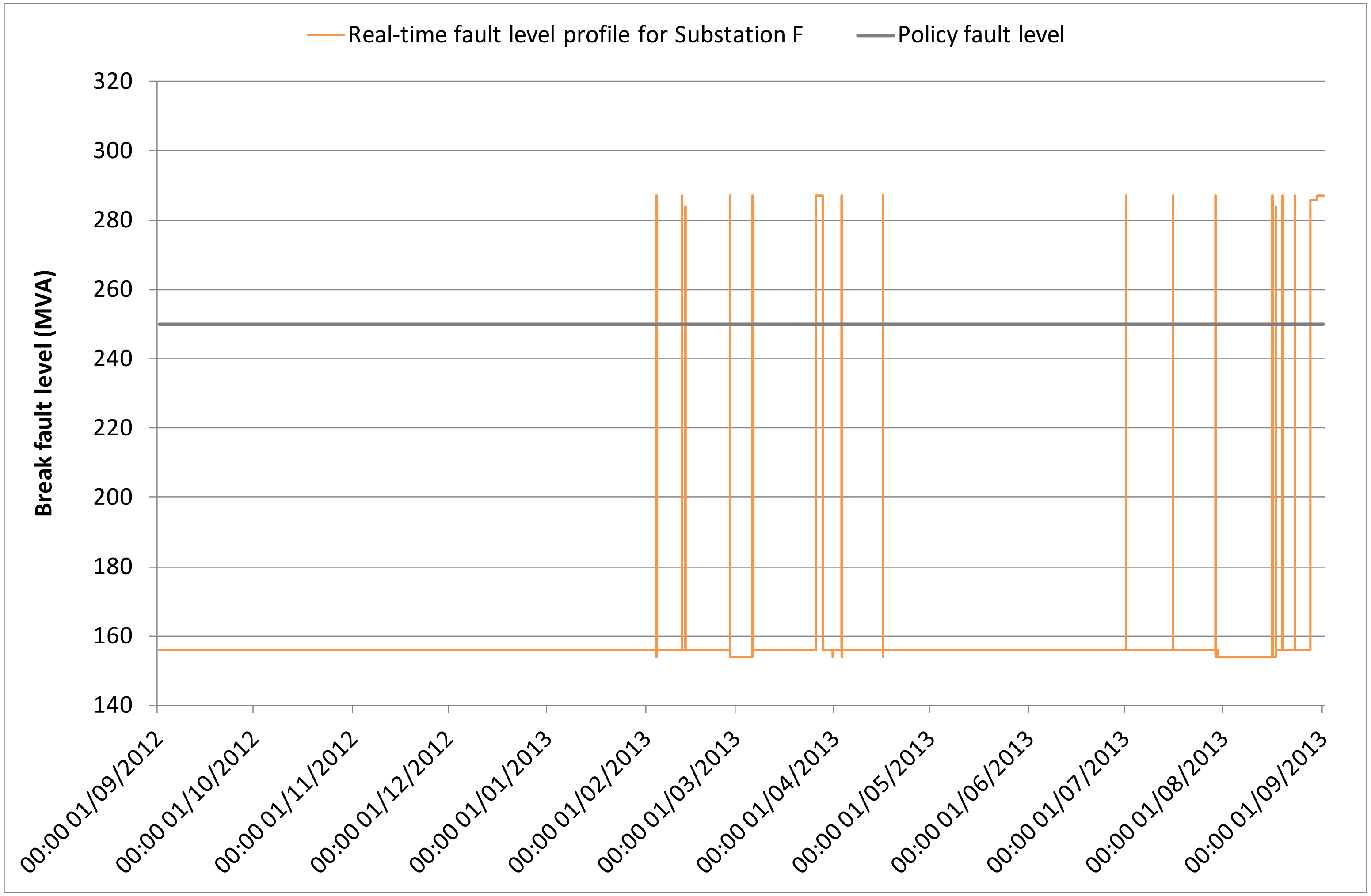
'Connect and manage' assumptions / caveats:

- Generation integration into a 'split' network configuration
- Infrastructure in place to disconnect generation prior to parallel operation
- Commercial arrangements in place to support 'connect and manage'

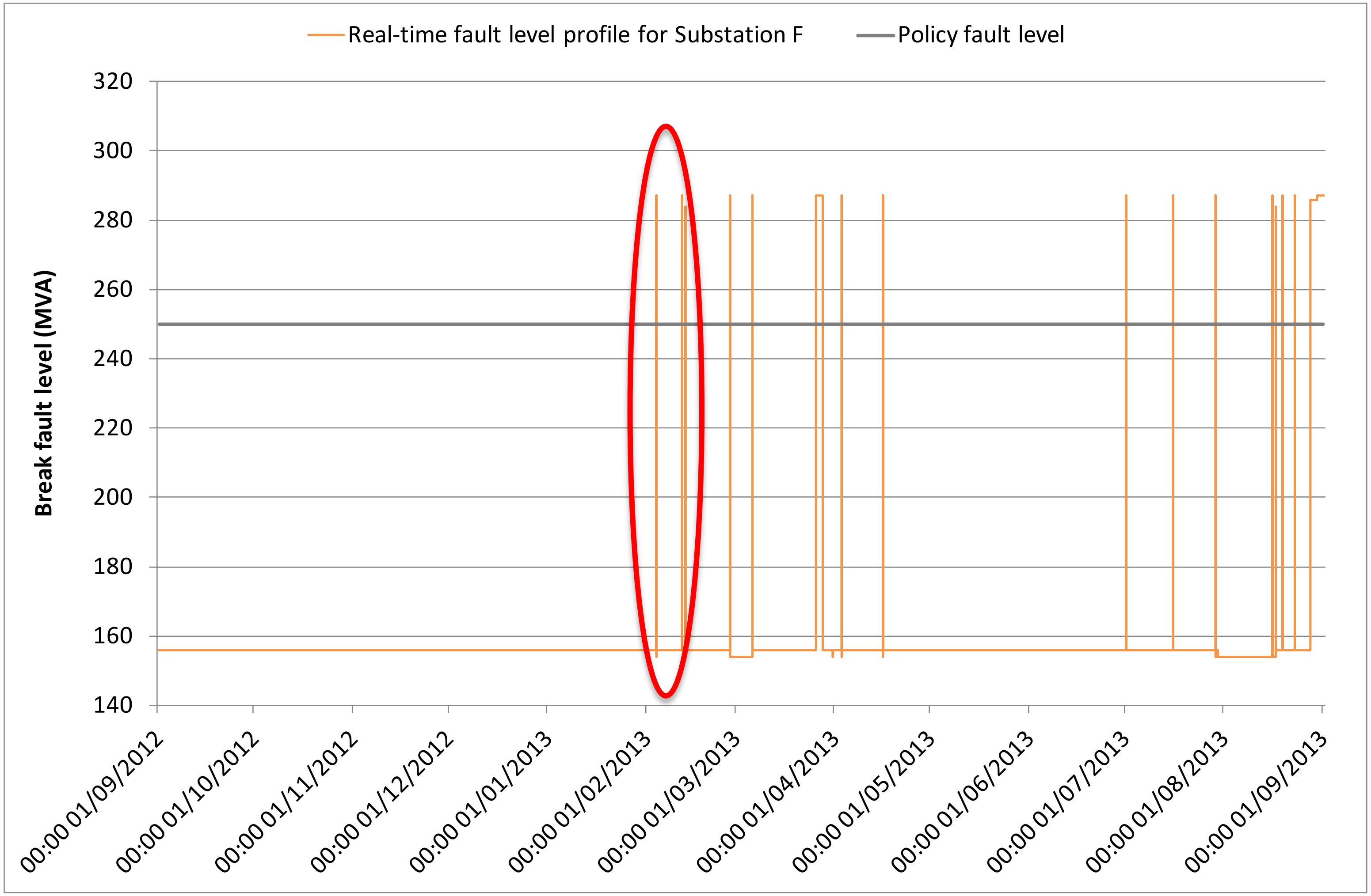
Operational configurations: Hall Green



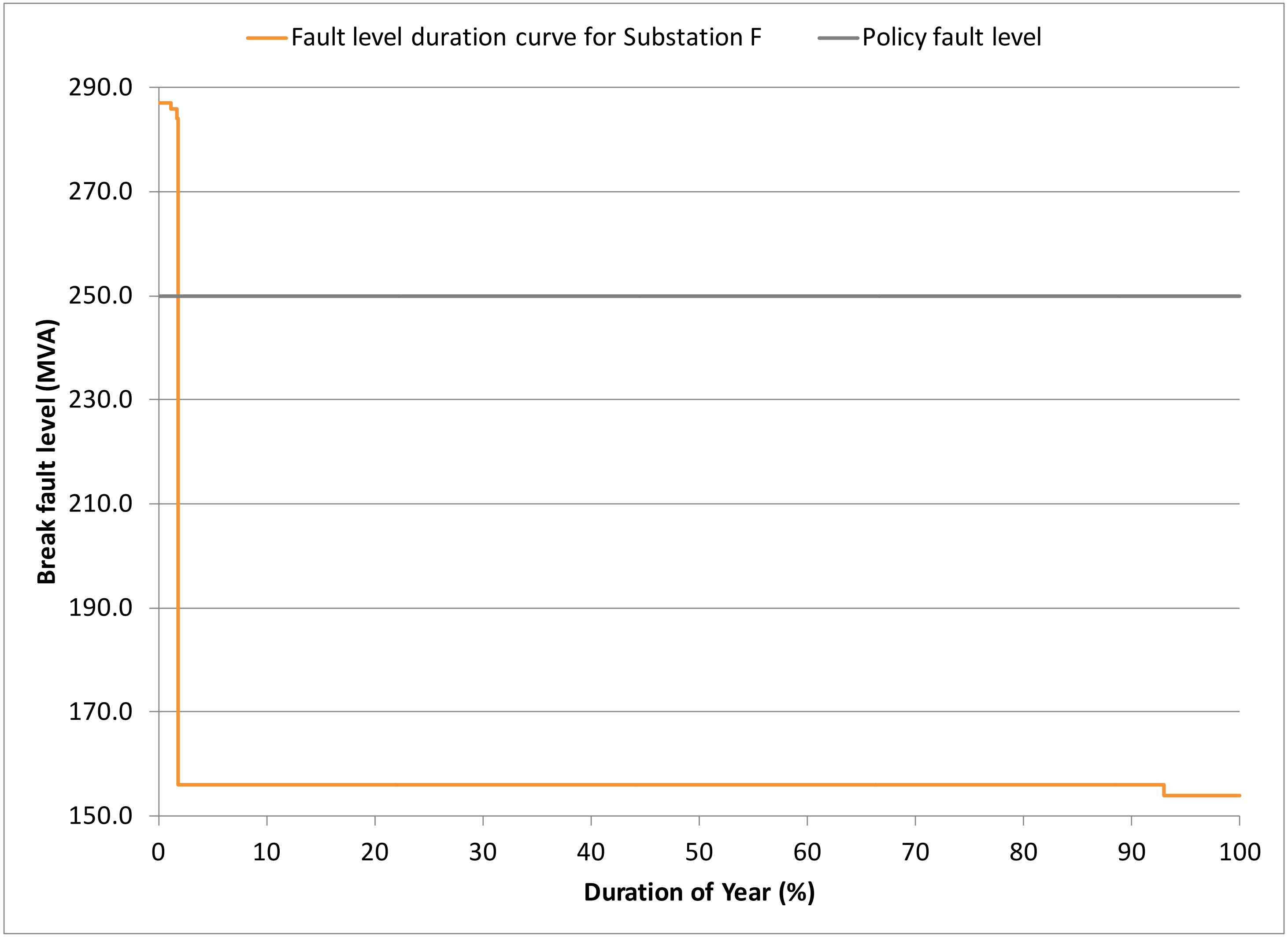
Time-series fault level profile



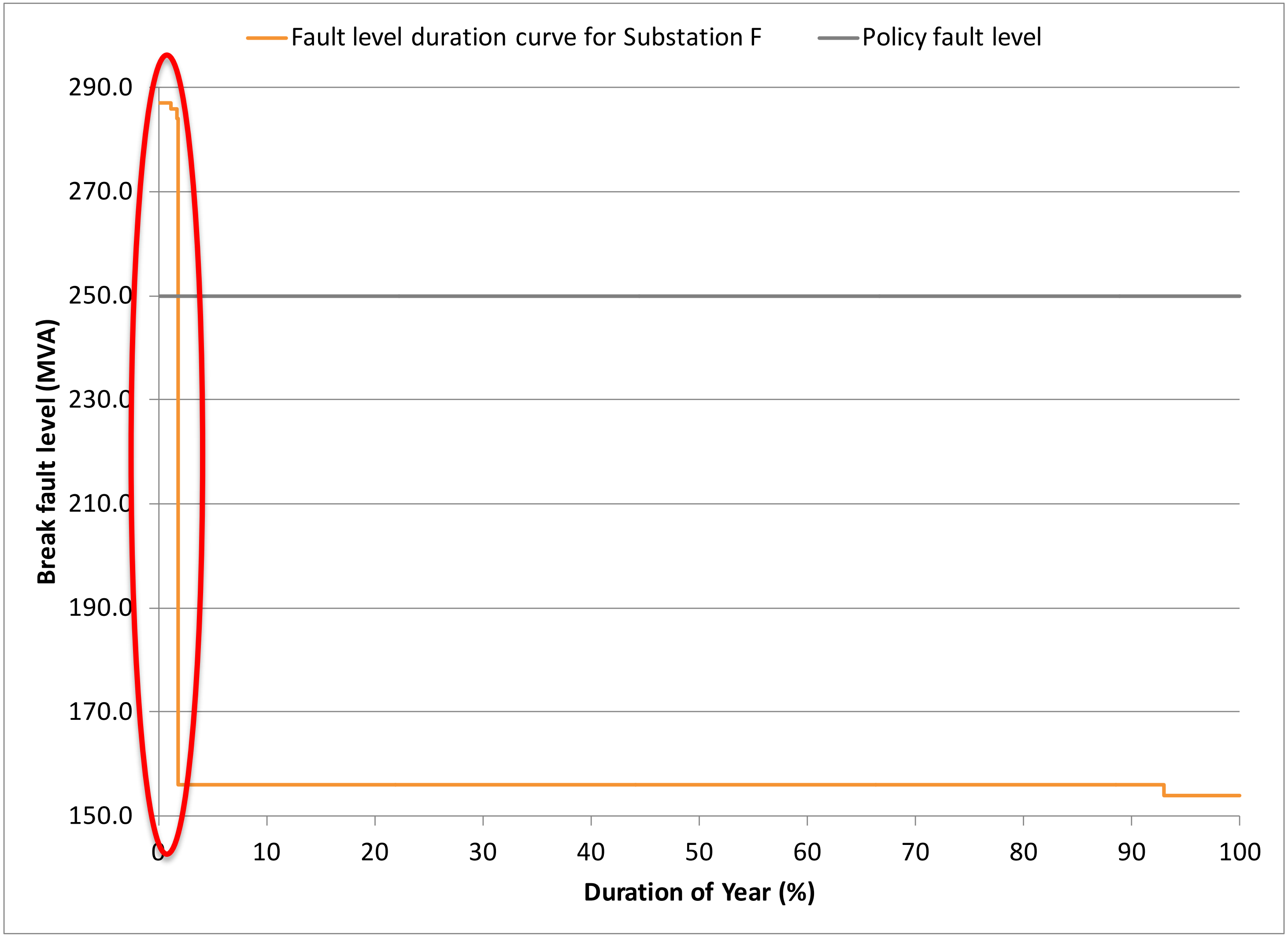
Time-series fault level profile



Fault level duration curve



Fault level duration curve



Generation headroom analysis methodology

Step 1
- Quantify the MVA headroom between operational network fault level and policy fault level value
- Convert to MW headroom using MVA / MW factor

Step 2
- Quantify unconstrained energy yield, constrained energy yield, net energy yield
- Quantification of losses

Step 3
- Perform cost-benefit analysis through £/MWh conversion

Assumptions / caveats:

- Safety margin on policy fault level value
- MVA / MW factor and generation capacity factor
- £/MWh and financial assumptions related to cost-benefit analysis

Generation headroom analysis results

Substation ID	Cumulative duration of parallels	Parallel Fault Levels (MVA)	Split Fault Levels (MVA)	Switchgear rating (MVA)	Fault level headroom	Generation headroom
	(%)	**3ph Break (rms)**	**3ph Break (rms)**	**3ph Break (rms)**	**(MVA)**	**(MW)**
A	0.34%	304	162	250	75.5	16.8
B	3.80%	261	217	250	20.5	4.6
C	2.27%	268	149	250	88.5	19.7
D	0.22%	314	170	250	67.5	15.0
E	0.13%	308	166	250	71.5	15.9
F	1.76%	287	156	250	81.5	18.1
G	0.99%	258	217	250	20.5	4.6
H	0.39%	319	172	250	65.5	14.6
I	2.21%	304	160	250	77.5	17.2
J	1.13%	283	156	250	81.5	18.1

Analysis:

- Each substation has a fault level issue when parallel operations take place
- Due to space availabilities, some substations are more suitable for fault current limiter technologies and some substations are more suitable for fault level management

Energy yield and carbon savings analysis results

Substation ID	Generation headroom (MW)	Indicative cumulative annual connection time (% per year)	Unconstrained Energy Yield (GWh/year)	Constrained Energy Yield (GWh/year)	Net Energy Yield (GWh/year)	CO_2 savings (kt/year)
A	16.8	99.7%	139.6	0.5	139.1	20.6
B	4.6	96.2%	37.9	1.4	36.5	5.4
C	19.7	97.7%	163.7	3.7	160.0	23.6
D	15.0	99.8%	124.8	0.3	124.6	18.4
E	15.9	99.9%	132.2	0.2	132.1	19.5
F	18.1	98.2%	150.7	2.7	148.1	21.8
G	4.6	99.0%	37.9	0.4	37.5	5.6
H	14.6	99.6%	121.1	0.5	120.7	17.9
I	17.2	97.8%	143.3	3.2	140.2	20.7
J	18.1	98.9%	150.7	1.7	149.0	22.0

CO_2 emissions have been calculated using the same methodology, as given in Appendix P of the FlexDGrid Full Submission Pro-forma, to compare emissions savings from CHP with the present UK generation mix for electricity and provision of heating from domestic boilers.

Evaluation

Pros:

- Avoids network reinforcement
- Readily integrate generation with limited network reconfiguration
- Potentially quicker and cheaper customer connections
- Can use present fault level values or ‘enhanced’ assessment values

Cons:

- Additional communications infrastructure to control generation connection, additional risk
- Limited impact on CI / CML improvement

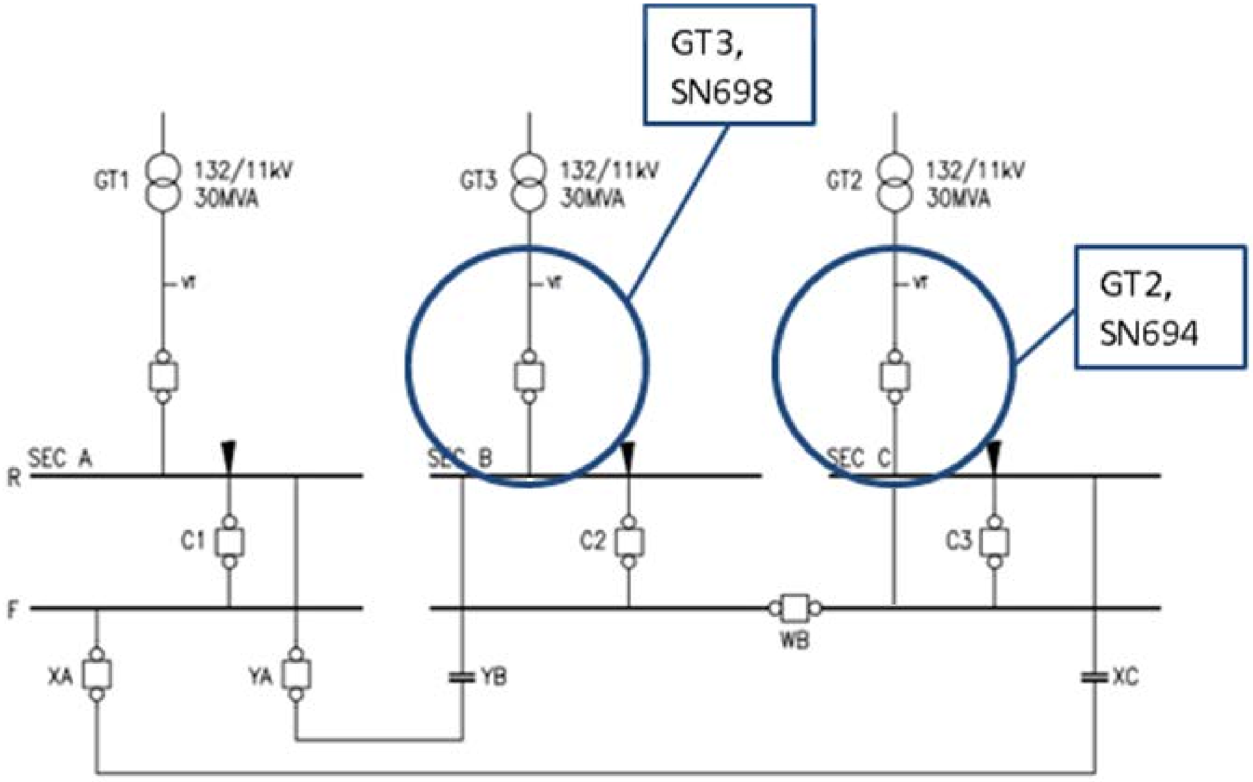
PM7000 locations (monitoring natural disturbances)

Location	Up to end Q3 2013	Up to end Q4 2013	Up to end Q1 2014	Up to end Q2 2014
Kitts Green (s/s)	√ (2 loggers)	√ (2 loggers)	√ (2 loggers)	√ (2 loggers)
Castle Bromwich (s/s)	√ (2 loggers)	√ (2 loggers)	√ (2 loggers)	√ (2 loggers)
Chester Street(s/s)	√ (2 loggers)	√ (2 loggers)	-	-
Bournville (s/s)	-	-	√ (1 logger)*	√ (1 logger)*
Sparkbrook (s/s)	-	-	√ (1 logger)*	√ (1 logger)*
Elmdon (s/s)	-	-	-	-
Hall Green (s/s)	-	-	√ (1 logger)**	√ (1 logger)**
Chad Valley (s/s)	-	-	-	-
Perry Barr (s/s)	-	-	-	-
Shirley (s/s)	-	-	-	-
Bordesley (s/s)	√ (2 loggers)	√ (2 loggers)	√ (2 loggers)	√ (2 loggers)
University of Warwick	-	-	√ (1 logger)**	√ (1 logger)**

* Logger previously located at Ladywood

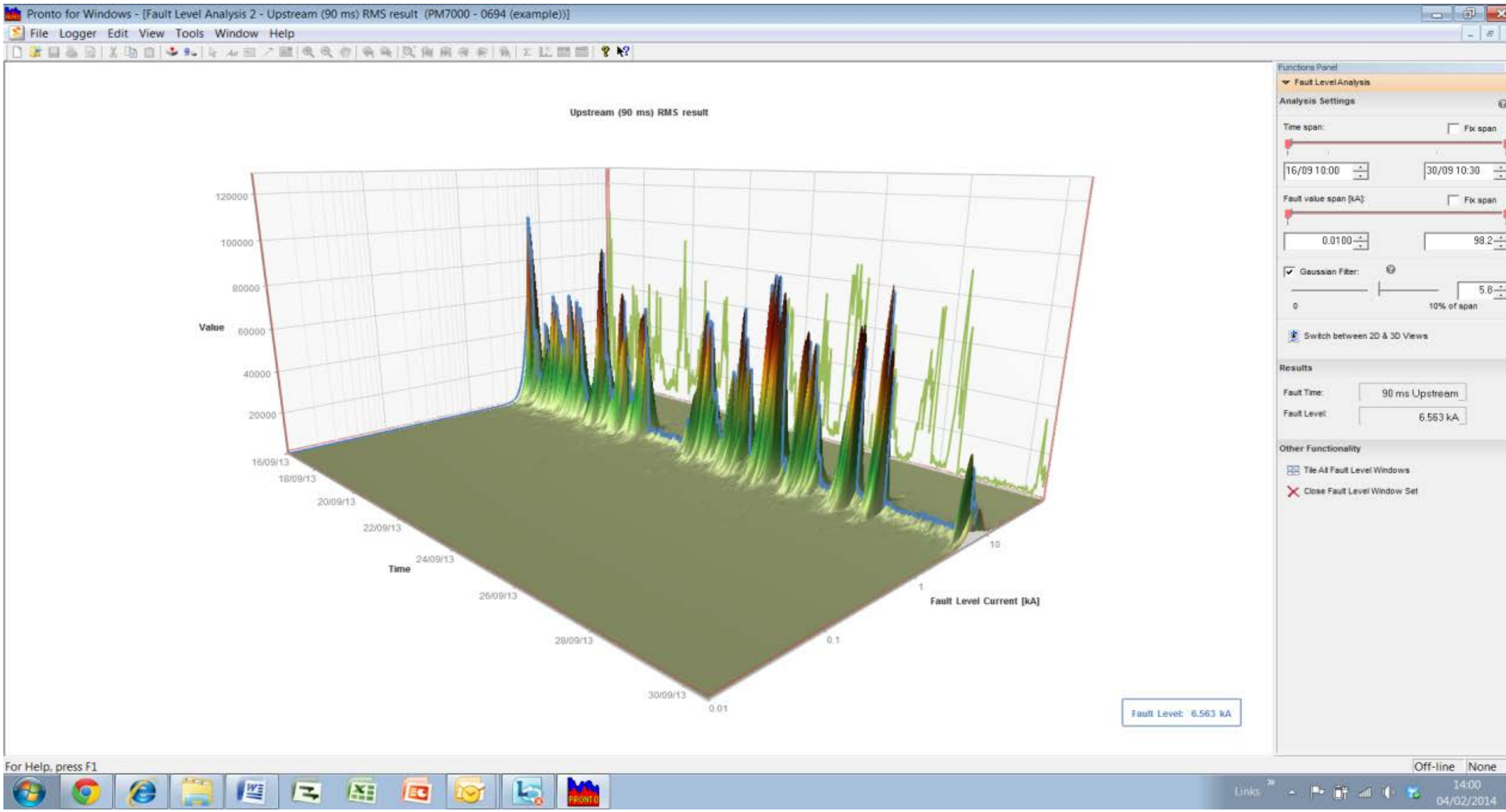
** Logger previously located at Chester Street

Example FLM Results from PM7000 at Chester Street

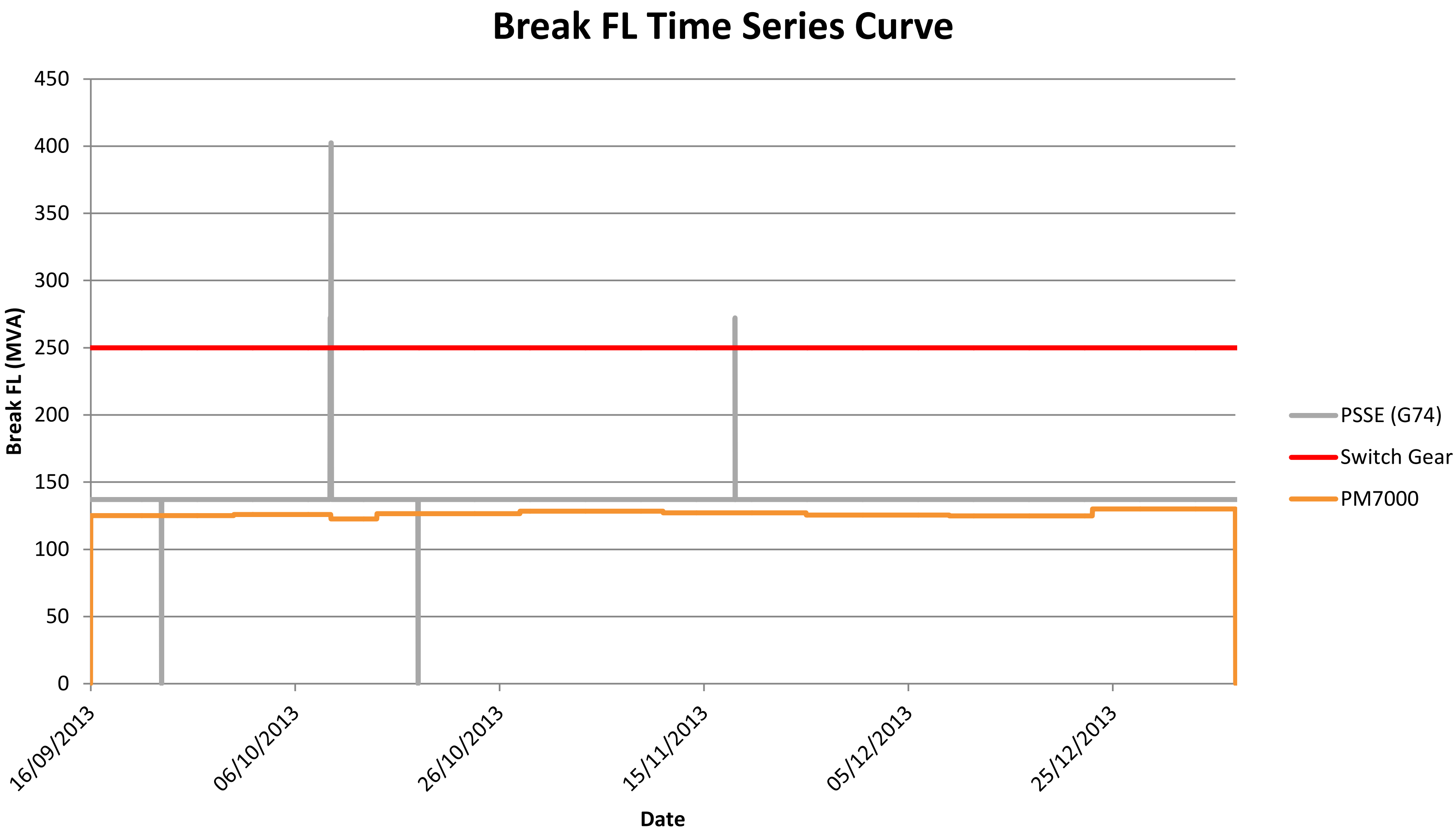


Example FLM Results from PM7000:

(GT2 Upstream 90ms 16/09/13-30/09/13)



GT2 Modelled and Monitored Break Fault Level



Results and Conclusions

Results

Location	Modelled Break fault level (rms at 90ms)	Monitored Break fault level (rms at 90 ms)	Difference (MVA)	Difference (%)
GT2	137.1	126.2	-10.1	-8.0
GT3	150.3	148.0	-2.3	-1.6

Conclusions

- Break monitored FL under predicts modelled value (2 - 8%).
- Make monitored FL – currently under investigation.
- Significant FL headroom could be utilised to accommodate DG in normal split configuration.

Next steps

Analyse Make FL data taking into account the actual variation of FL contribution from general load and integration of FCLs

Further analysis of PM7000 data (make fault level and during parallel operations) to quantify and understand difference in modelled and monitored results

Extend analysis to encompass other substations and include active fault level monitoring results

Development of ‘connect and manage’ systems for new connections

Any questions… ?

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

DNO Workshop on Fault Level Mitigation Technologies

Wednesday 14th May 2014

Fault current limiter Modelling

Ali Kazerooni

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Overview

- FCL modelling - aims and objectives
- Methodology for modelling FCL
- FCL modelling – FCL technologies
  - Pre-saturated core FCL (PCFCL)
  - Resistive superconducting FCL (RSFCL)
  - Power Electronic FCL (PEFCL)
- Platforms
- Next steps

FlexDGrid – Method Alpha

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

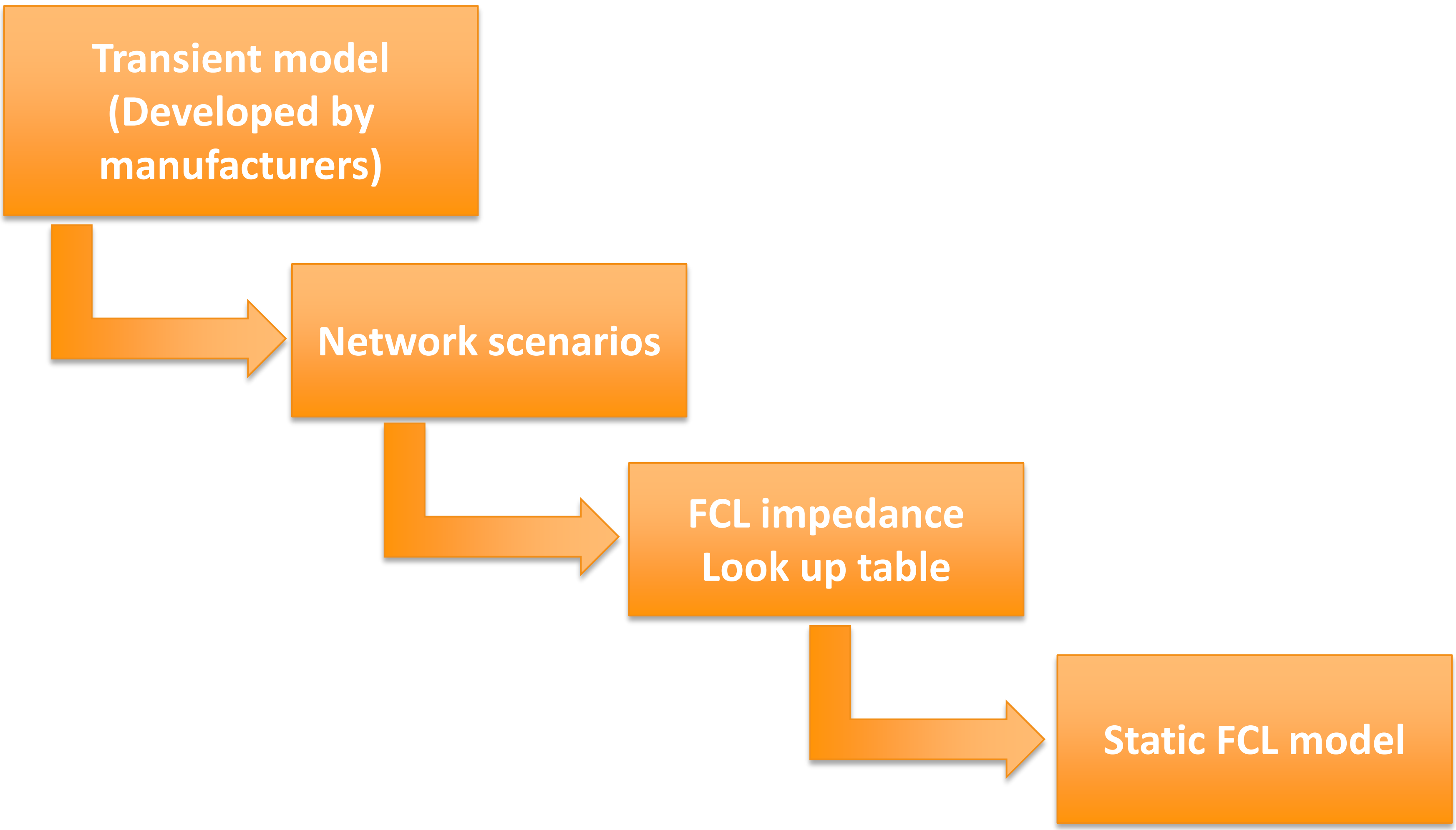
Mitigation

- Reduction of system Fault Level
- Utilised from output of Management

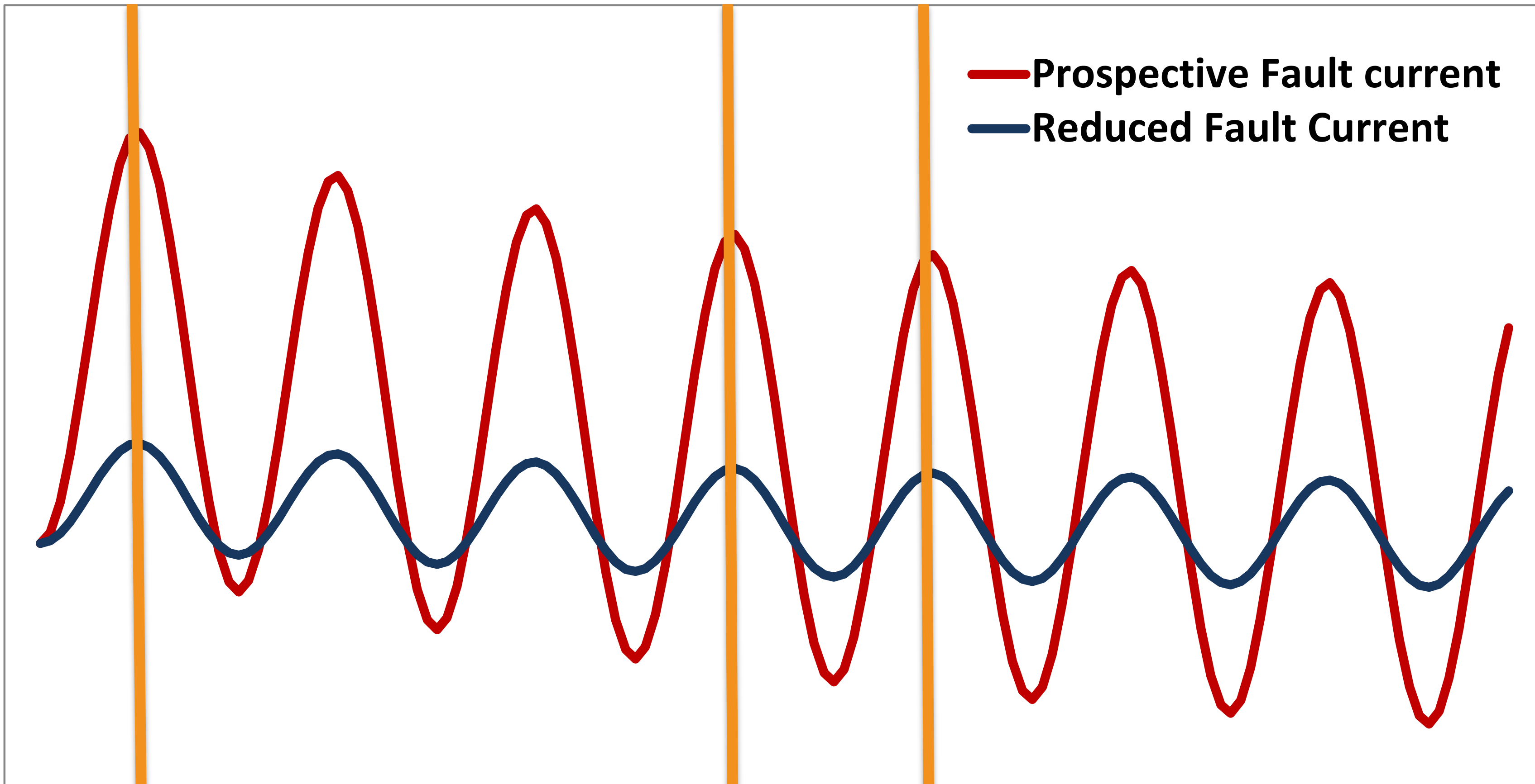
Aims and objectives

- Develop models of FCL technologies trialled in FlexDGrid – PCFCL, RSFCL and PEFCL
- Static model of FCL for calculating making and breaking fault levels
- Develop tools and provide methodologies that FCL model can be deployed by users/non-users of professional power system analysis software (PSS/E)

Methodology



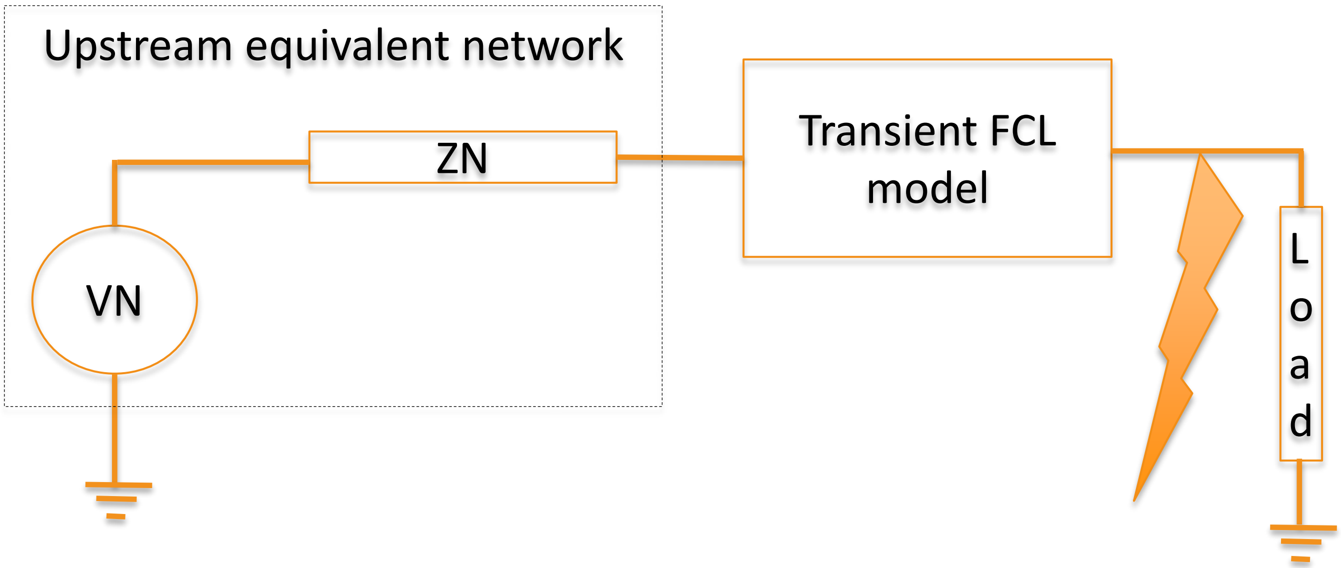
Methodology



Peak time (10ms)

Breaking time (70ms, 90ms)

Methodology



- **Network scenarios include pre-fault, post-fault (making and breaking fault current), X/R ratio network conditions**
- **FCL impedances are calculated at fault peak time (10ms), breaking time (70ms and 90ms)**

FCL modelling- PCFCL

- Pre-saturated core FCL operation
- Network scenarios
  - Pre-fault network conditions - FCL loading

AC Load current RMS [A]	DC bias current [A]
400	130
800	220
1000	270
1250	320
1575	390
2000	490

  - Post-fault network conditions - prospective fault currents
- Electromagnetic model developed by GridOn
- Time-consuming process for simulating the transient behaviour

Data requirement - PCFCL

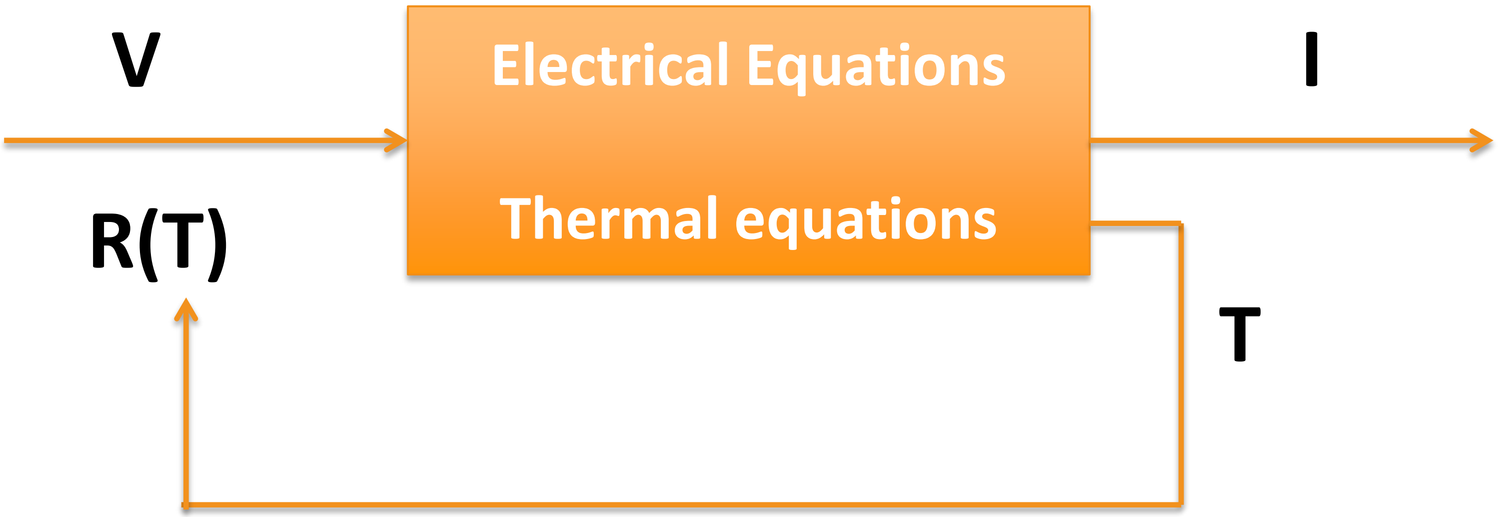
	Pre-fault current [A]		
Prospective fault breaking current [kA]	0	1000	2000
3.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
4.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
5.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
6.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
6.85	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
8.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
10.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
12.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
13.1	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}

Castle Bromwich : **X/R = 23.5** **I_{peak}/ I_{break} = 2.65**

FCL modelling - RSFCL

- Resistive superconducting FCL operation
- Network scenarios
  - Post-fault network conditions - prospective fault currents
  - Pre-fault FCL loading does not effect the post-fault FCL impedance
- Matlab model for transient simulation
- Short simulation process time

RSFCL – Matlab model (Nexans)



Data requirement - RSFCL

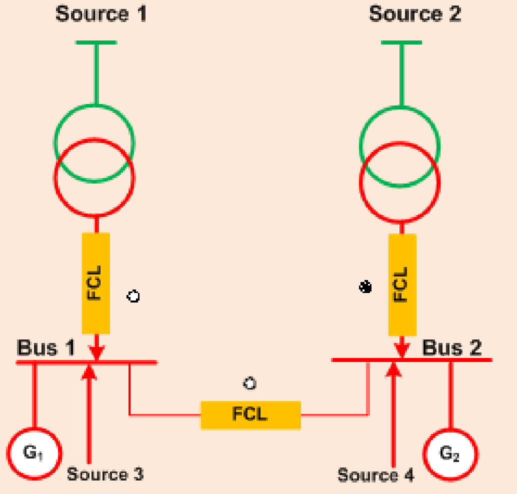
	X/R ratio				
Prospective fault breaking current [kA]	20	25	30	35	40
3.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
3.5	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
4.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
4.5	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
5.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
12.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
12.5	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
13.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
13.5	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}
14.0	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}	R_{FCL}+j X_{FCL}

PEFCL

- Power Electronic FCL operation.
- Modelled as circuit breaker opening the branch immediately after fault.
- Post-fault impedance is assumed to be zero.

Platform – Excel model

Fault Current Limiter model
Substation Test



Fault current limiter technology

- Pre-Saturated Core FCL (PCFCL)
- Resistive Superconducting FCL (RSFCL)
- Solid-State FCL (SSFCL)

Substation Name	Substation Test				
Firm capacity	78	MVA	Generation fault contribution [MVA/MVA]	4.5	-
Switchgears rating (Break)	13.1	kA	Base power	100	MVA
Switchgears rating (Make)	33.4	kA	Base voltage	11	kV
De-rating factor	10	%	Base current	5.25	kA
Switchgear policy rating (Break)	11.8	kA	Base impedance	1.21	ohm

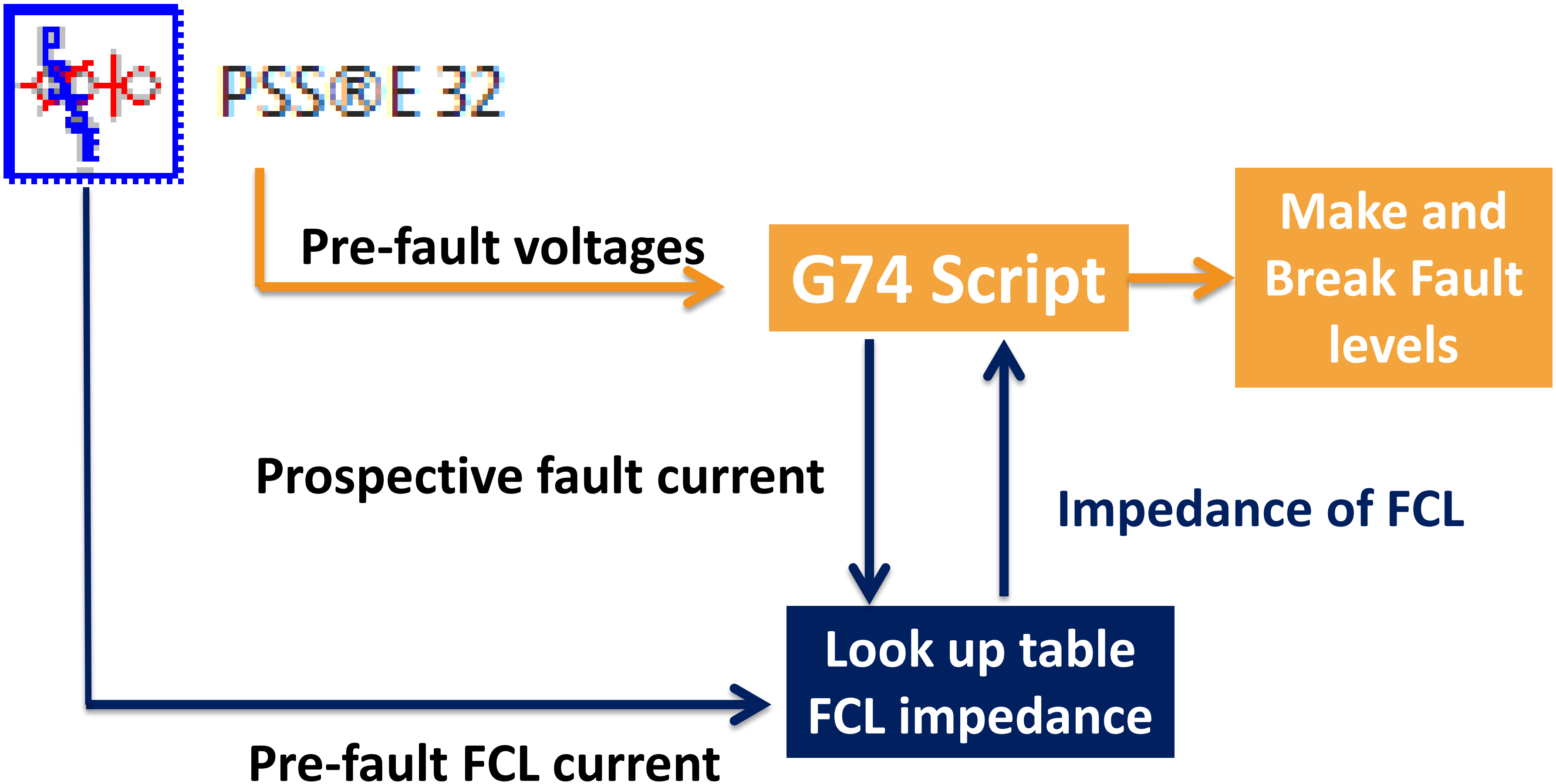
Source 1 - Upstream Fault Contribution			Source 2 - Upstream Fault Contribution		
Upstream breaking fault contribution	7	kA	Upstream breaking fault contribution	8	kA
Upstream making fault contribution	19	kA	Upstream making fault contribution	20	kA
Upstream X/R ratio	20	-	Upstream X/R ratio	10	-
Voltage at Source	1	p.u	Voltage at Source	1	p.u

Source 3 - Downstream Fault Contribution			Source 4 - Downstream Fault Contribution		
Breaking fault contribution	2	kA	Breaking fault contribution	1	kA
Making fault contribution	3	kA	Making fault contribution	2	kA

Pre-Fault FCL loading	50	A

Without FCL	Bus 1	Bus 2	With FCL	Bus 1	Bus 2
Breaking fault current [kA]	18.0	18.0	Breaking fault current [kA]	10.0	10.0
Making fault current [kA]	44.0	44.0	Making fault current [kA]	24.0	24.0
Generation headroom at Bus 1 (G1) [MVA]	0.0	-	Generation headroom at Bus 1 (G1) [MVA]	7.6	-

Platform – FCL PSS/E model



Next steps

- Process the FCL impedance data obtained from manufacturers
- Run transient model for further network scenarios
- Finalise and validate the Excel and PSS/E FCL static
- Improve the developed models based on feedbacks from different users within WPD

Thank you

Any Questions?

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Session 2 – Topic Focus:

Installing Technologies in to FlexDGrid Sites

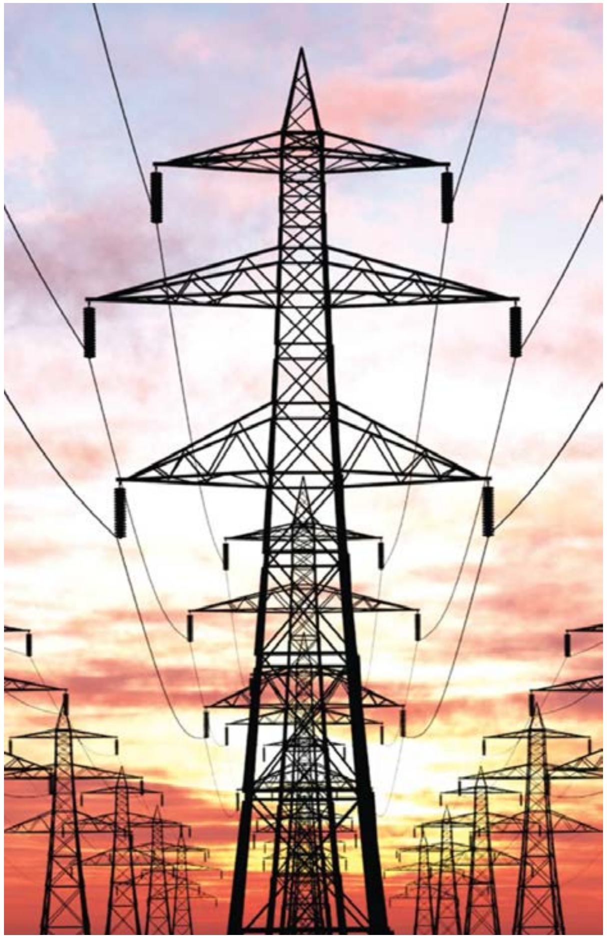
Neil Murdoch

Distribution Engineer, Parsons Brinckerhoff

LCN Fund Low Carbon Networks THE UNIVERSITY OF WARWICK PARSONS BRINCKERHOFF

Introduction

- Overview of Standard Technique
- FCL Losses
- Selection and connection of FCLs at:
  - Castle Bromwich
  - Chester Street & Bournville
  - Kitts Green & Sparkbrook



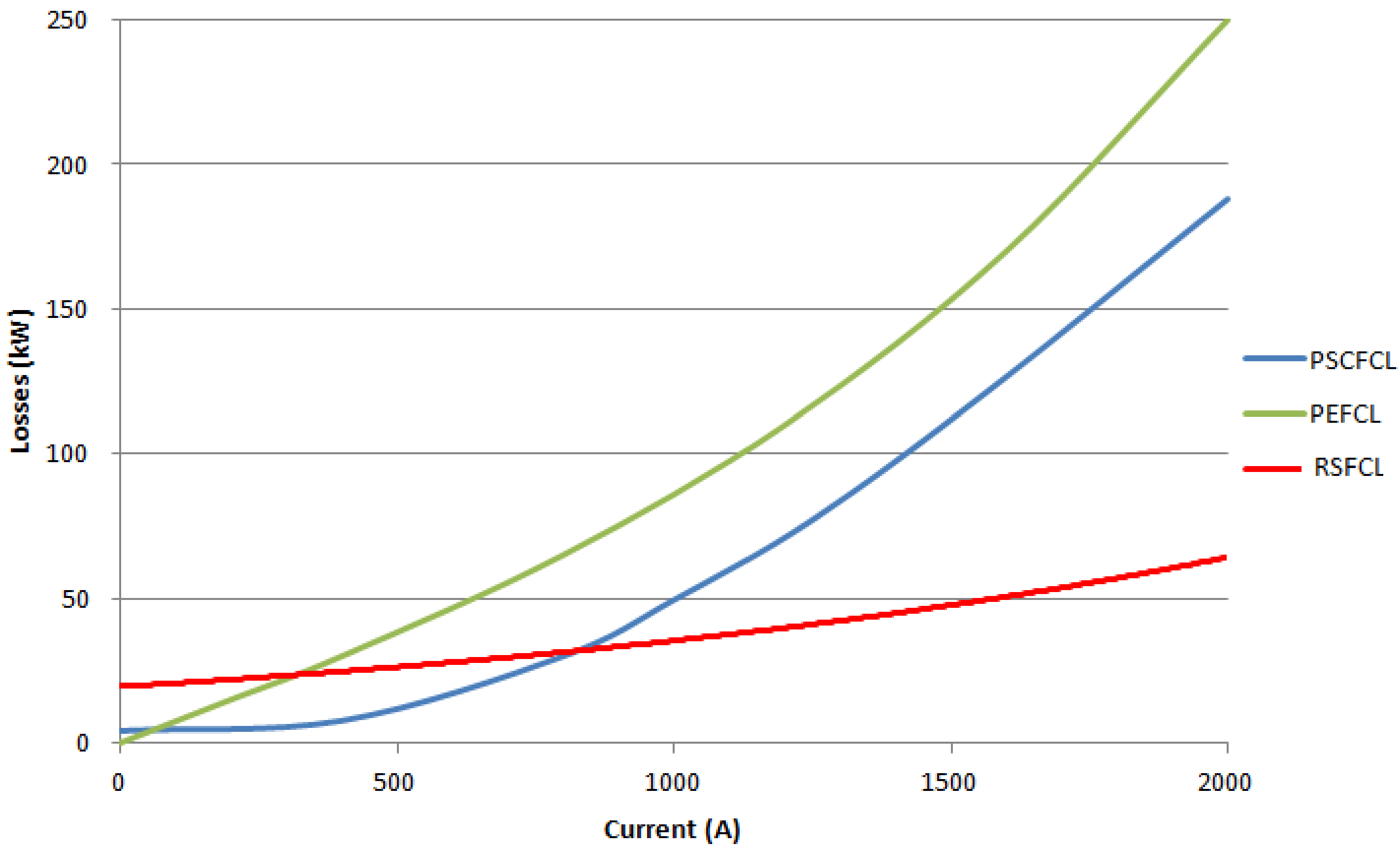
Standard Technique for Fault Current Limiters

- Standard Techniques (STs) are prepared by WPD to explain engineering processes associated with planning, operating, maintaining and replacing the parts of the network.
- An ST has been produced to describe what should be considered when applying and connecting FCLs to the network.
- The following slides explain the elements that have been considered for the FlexDGrid Substations

FCL Losses

- Losses associated with the PEFCL and RSFCL are mainly due to the mechanisms used for keeping the devices at their optimum operating temperature
- The PSFCL losses are a combination of those found in a typical transformer (non-load and load losses) and those used to power the DC bias power supply
- The following graph shows the typical losses for each type of technology

FCL Losses

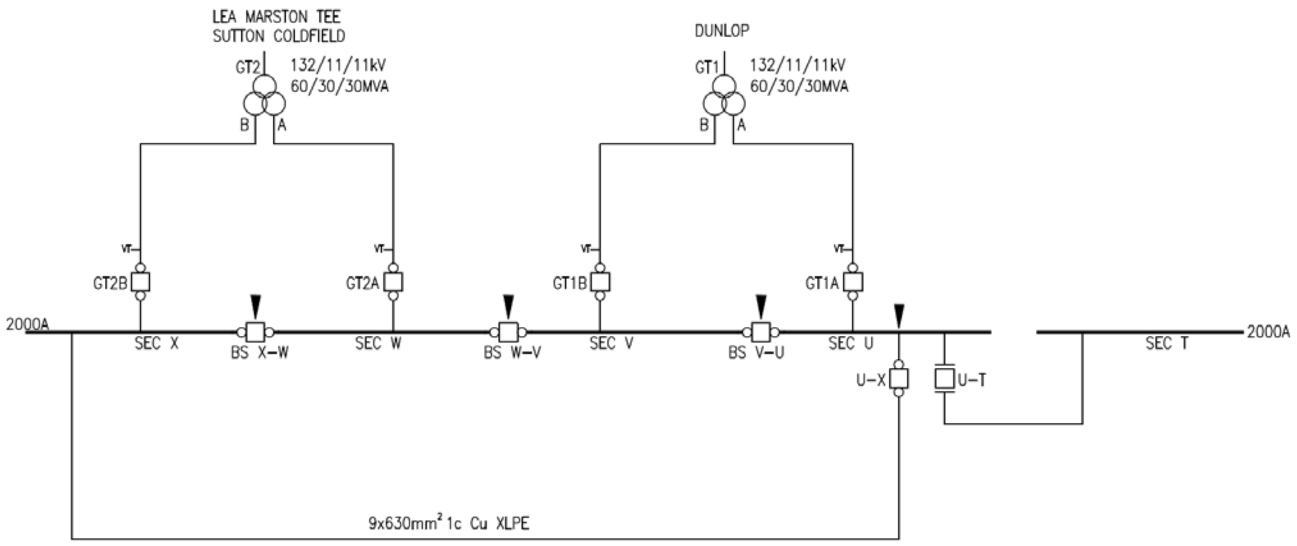

250
200
150
100
50
0
Losses (kW)
0
500
1000
1500
2000
Current (A)
PSCFCL
PEFCL
RSFCL

FCL Losses

- It can be seen that PSCFCL and PEFCL devices result in lower losses in the low “through” current region
- As the level of “through” current increases, the RSFCL offers better performance in terms of losses
- Hence, for applications in a bus-section / interconnector scenario the PSCFCL and PEFCL devices are favoured, whereas the RSFCL device is preferred for higher current applications

Castle Bromwich – Existing SLD

- Substation built in 1999
- GTs fed from different GSPs

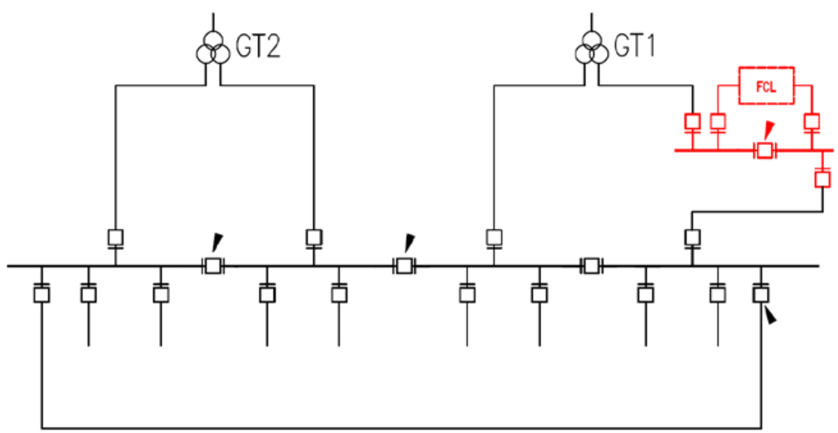


Castle Bromwich – Proposed SLD

– GridON Pre-Saturated Core FCL was chosen

– Connected in the GT1 transformer leg

CASTLE BROMWICH 132/11kV



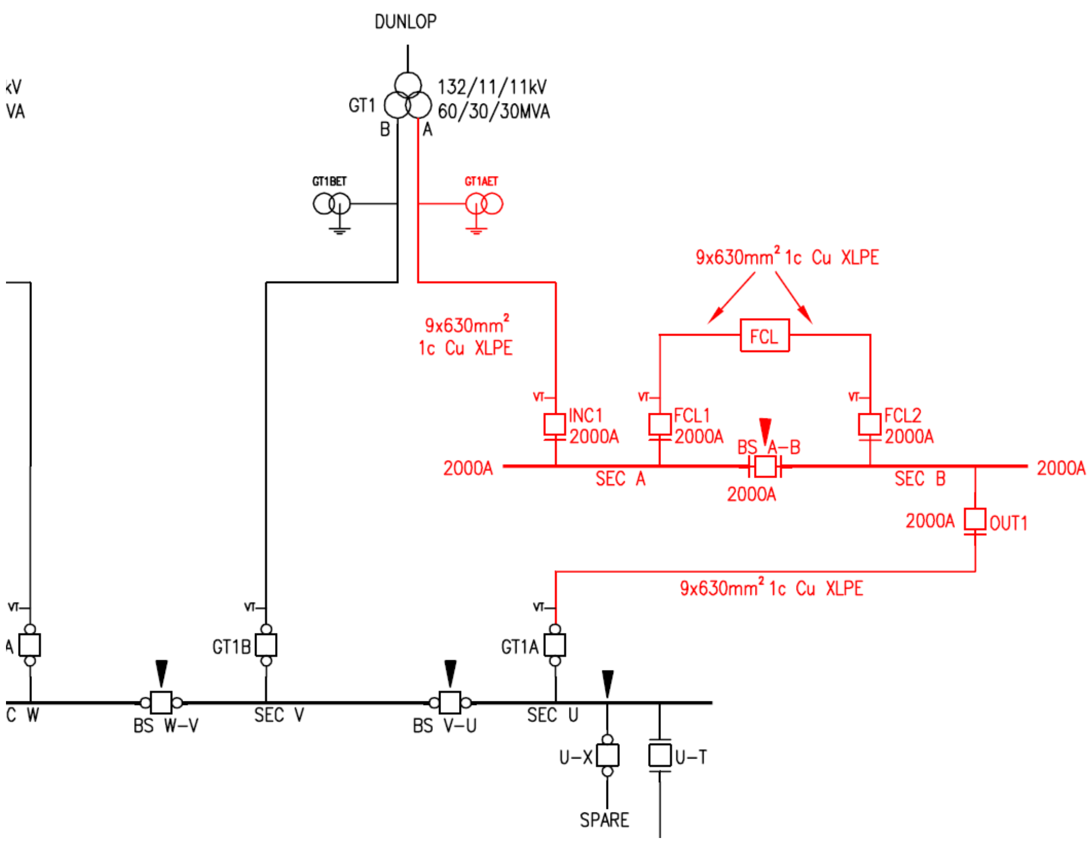
Castle Bromwich Connection Considerations

– Installation in the transformer leg meant that the PSCFCL was required (instantaneous recovery, no disconnection). This would prevent loss of capacity for an 11kV feeder fault.

– However, firm capacity is reduced due to the impedance inserted in the system (load sharing).

– Removal of Thompson Strap and installation of a new earthing transformer

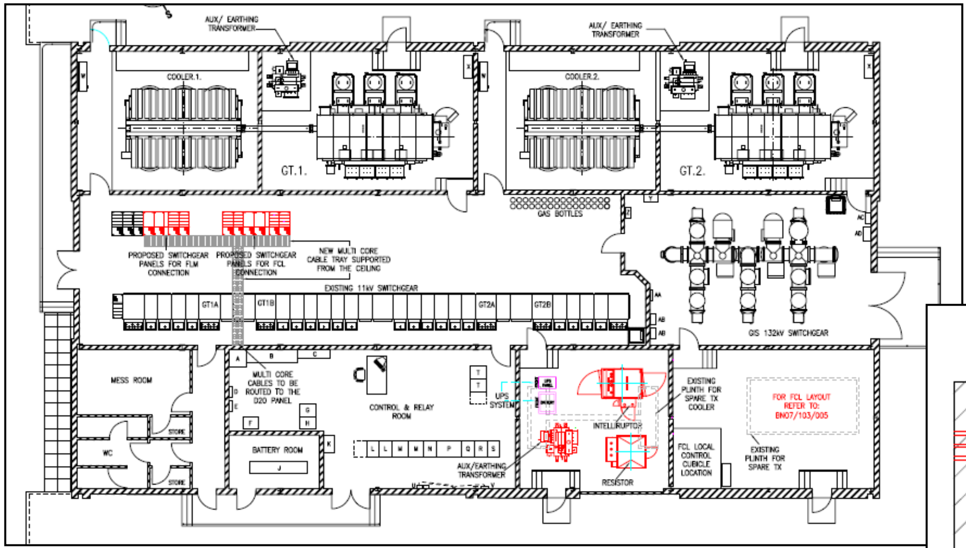
Castle Bromwich Connection Considerations

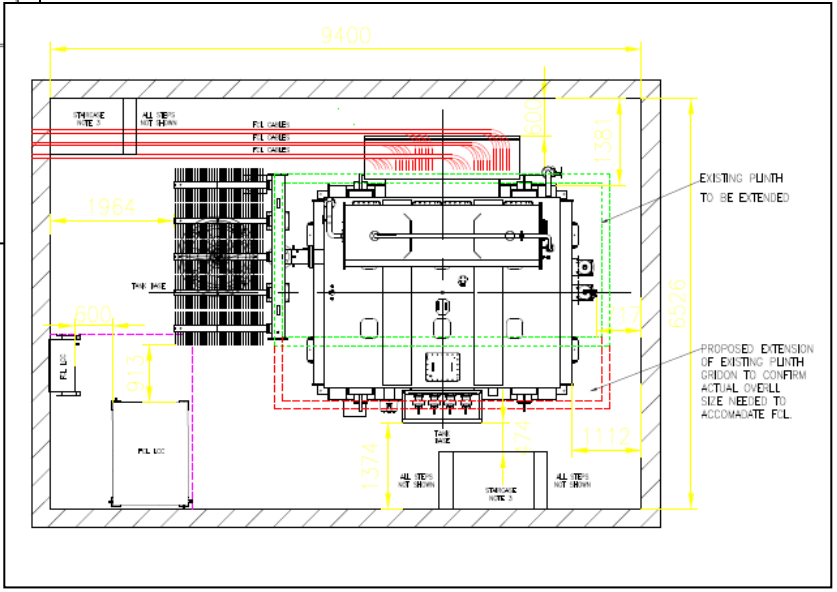


Castle Bromwich Installation Considerations

- The PSCFCL emits a high magnetic field – magnetic shielding to be used in the housing area to allow for any person to walk around the substation
- The device is much heavier than a standard 132/11kV transformer. Reinforcement of the existing plinth foundation required
- Alterations to existing transformer protection scheme to accommodate FCL and 11kV switchgear

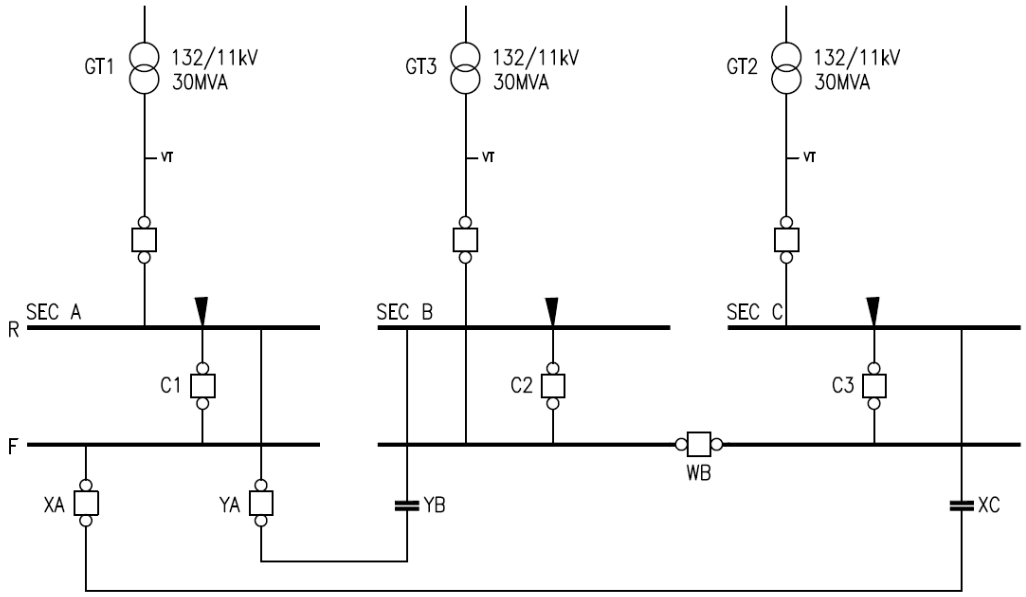
Castle Bromwich Layout





Chester Street – Existing SLD

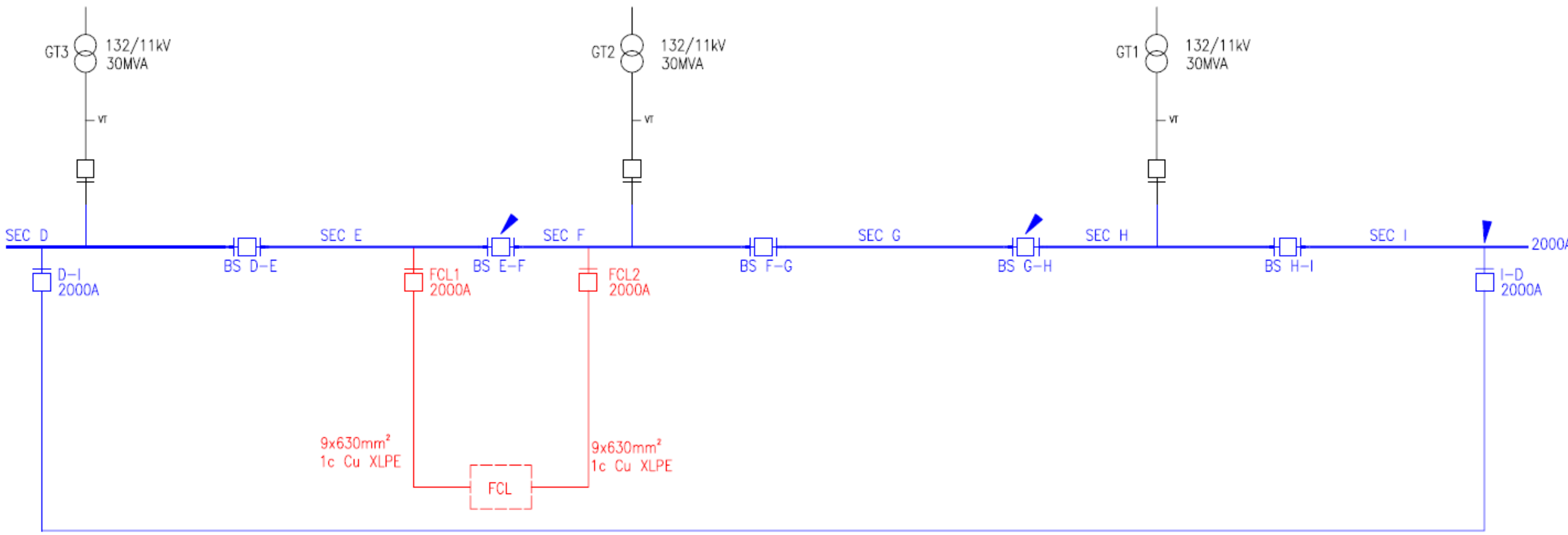
- 11kV switchgear to be replaced under DPCR5 scheme
- 1 GT fed from different GSP



Chester Street – Proposed SLD

– Nexans RSFCL chosen

– Connected across a bus-section



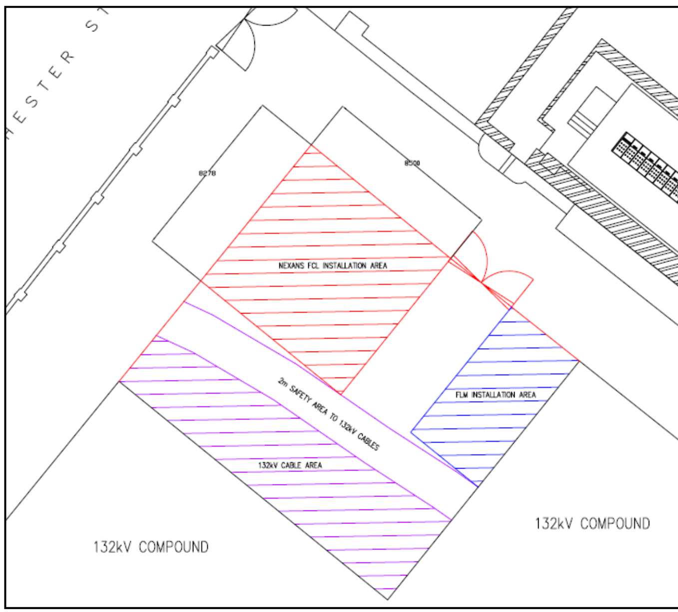
Chester Street Connection Considerations

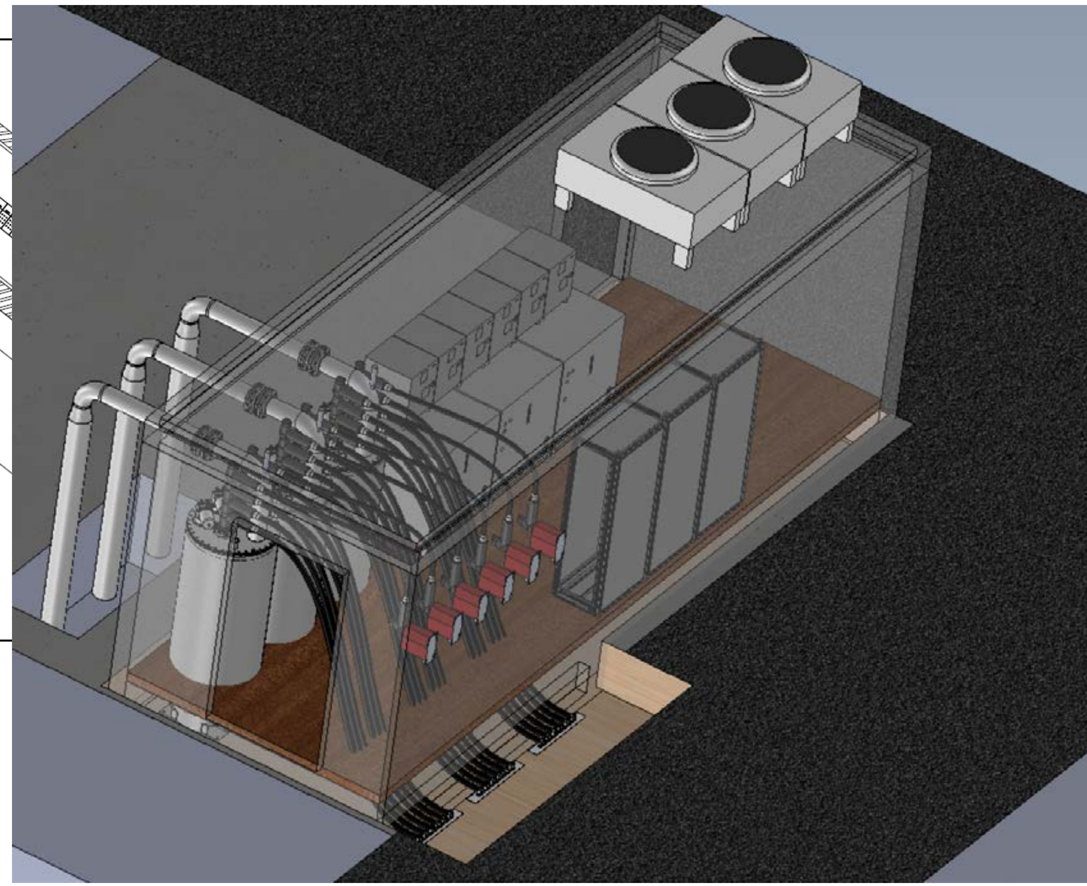
- As the switchgear was being replaced, the obvious solution was to include two new circuit breakers for the FCL connection.
- With the FCL connected across the bus-section, the choice of device was based on performance / cost.

Chester Street Installation Considerations

- Free space was available external to the 11kV switch room
- Nexans are providing a bespoke concrete enclosure to house the RSFCL
- The RSFCL will be provided with a voltage differential scheme which will operate WPD 11kV circuit breakers
- Similar to a transformer, the device will be fitted with pressure relief vents to allow for escape of nitrogen in the unlikely event of catastrophic failure

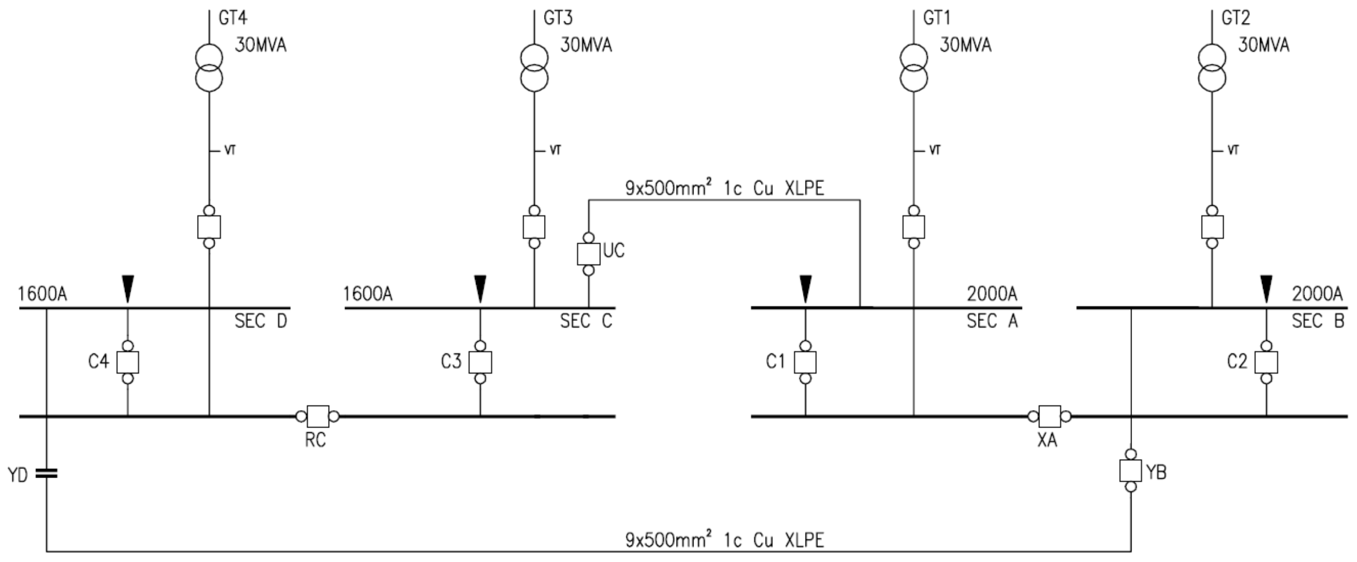
Chester Street Layout





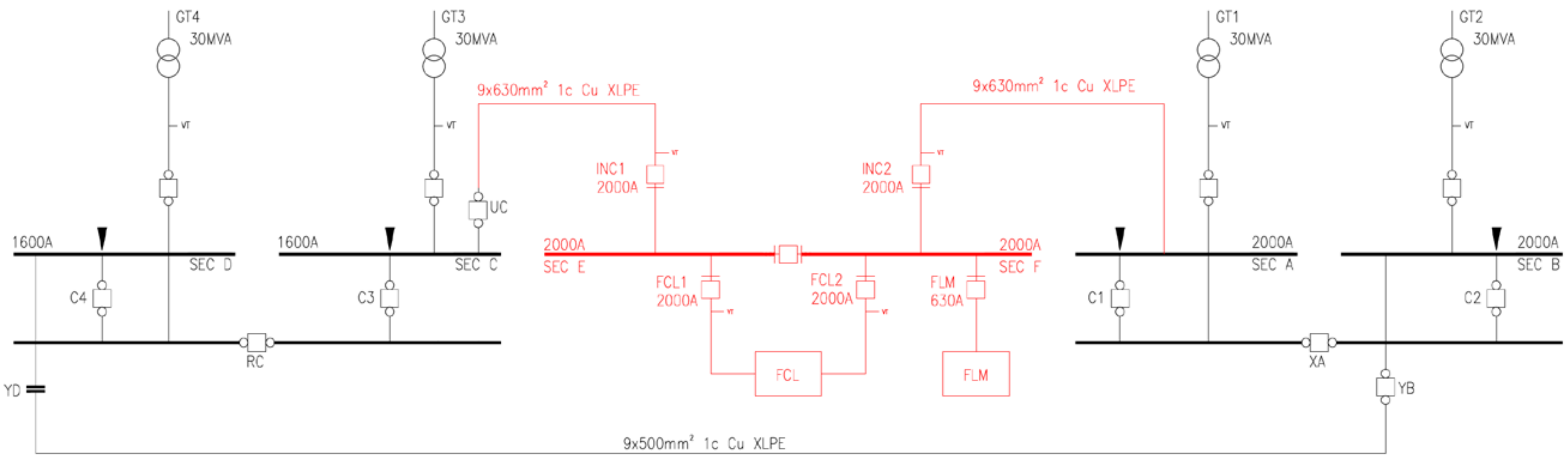
Bournville – Existing SLD

- Two 11kV switchboards connected with two interconnectors
- Four 30MVA transformers



Bournville – Proposed SLD

- Nexans RSFCL chosen
- Connected within an interconnector



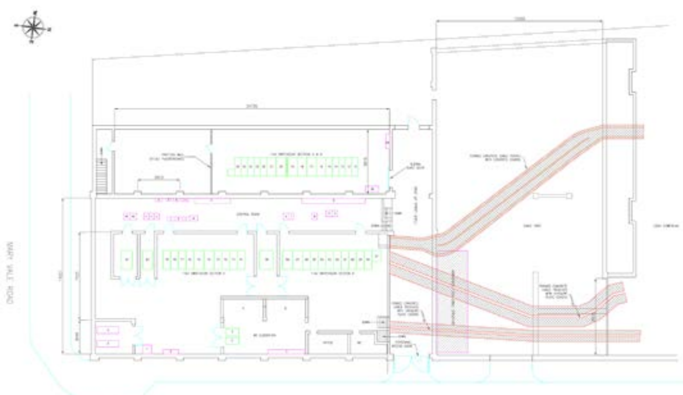
Bournville Connection Considerations

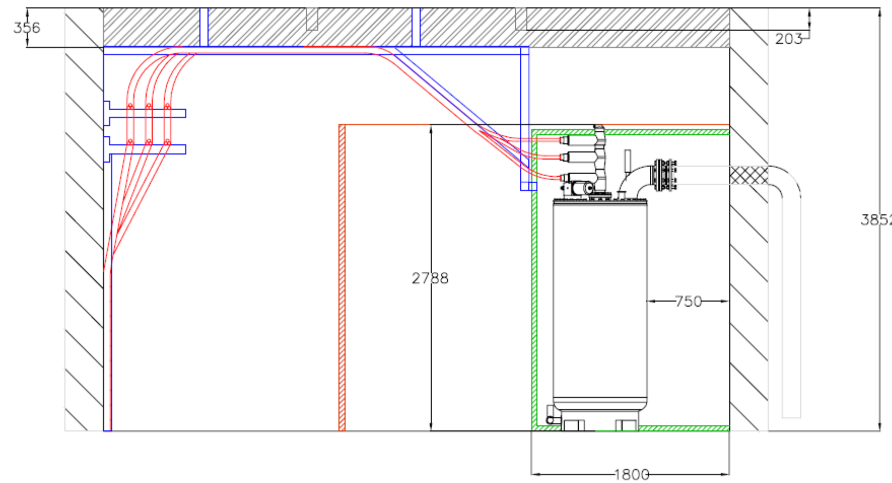
- A new five panel switchboard will be used to connect the FCL within the interconnector.
- Similar to Chester Street, the choice of device was based on performance / cost.

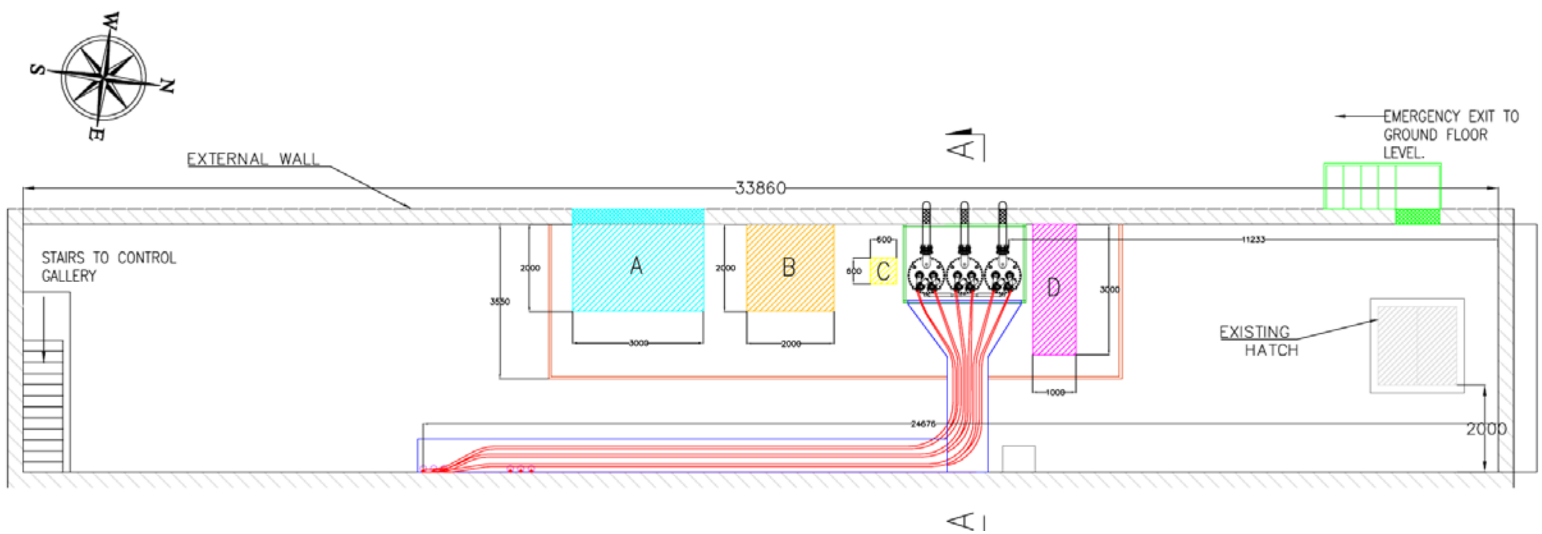
Bournville Installation Considerations

- Major asset replacement planned during RIIO
- Free land external to the switch room reserved for transformer change
- RSFCL to be installed at first floor level above switchgear as it can be dismantled into individual components
- New 11kV switchboard can be adapted for use in asset replacement scheme

Bournville Layout



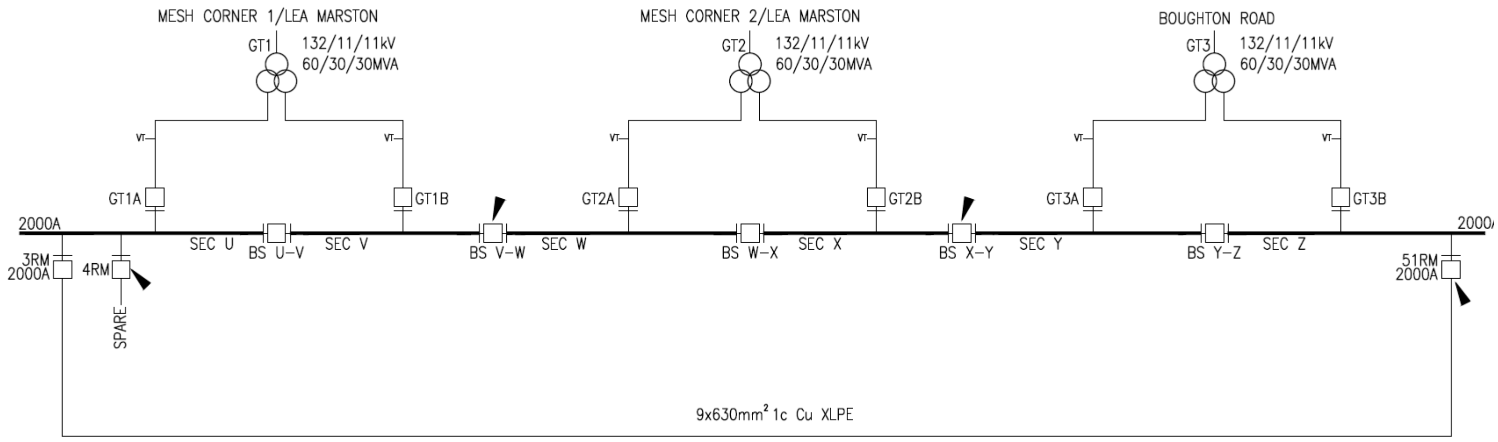




Kitts Green – Existing SLD

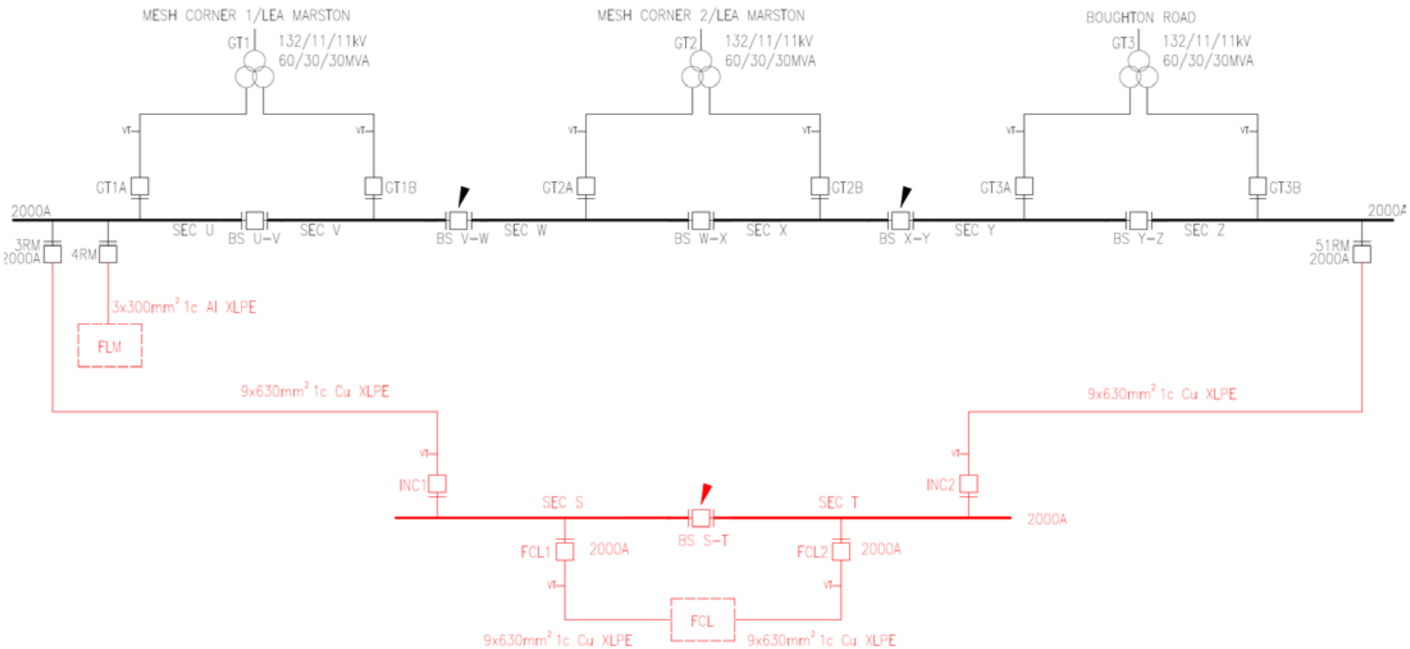
– Three 60MVA transformers running separately, all fed from the same GSP

– Substation built in 2008



Kitts Green – Proposed SLD

- Alstom Power Electronic FCL chosen
- Connected within the interconnector

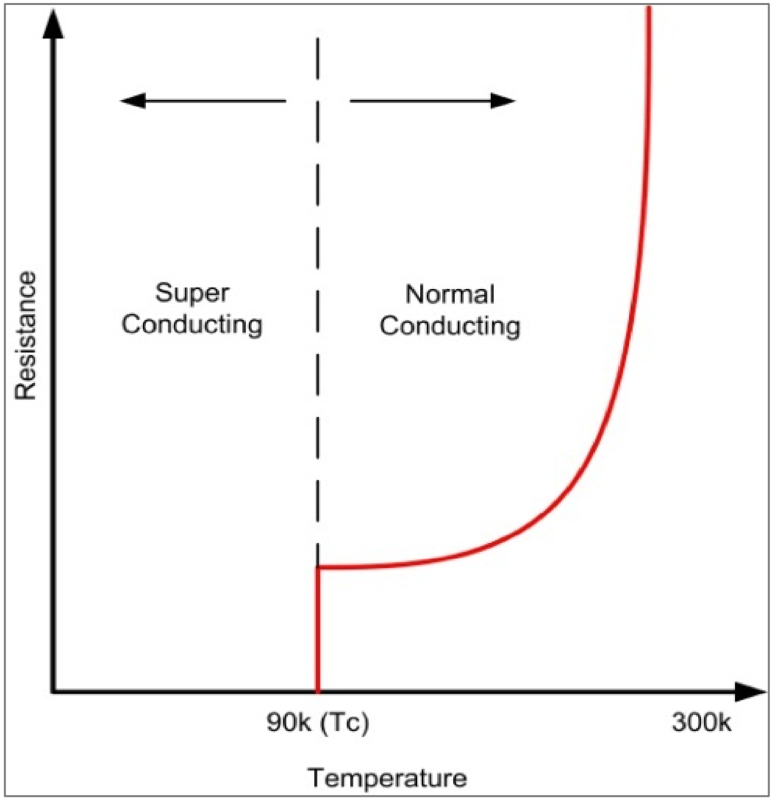


Kitts Green Connection Considerations

- The existing X/R ratio at Kitts Green is very high, therefore PSCFCL was not suitable
- The PEFCL was chosen as the RSFCL could not meet the fault level reduction requirements
- A new five panel switchboard will be used to connect the FCL within the interconnector

Resistive Superconducting Fault Current Limiter

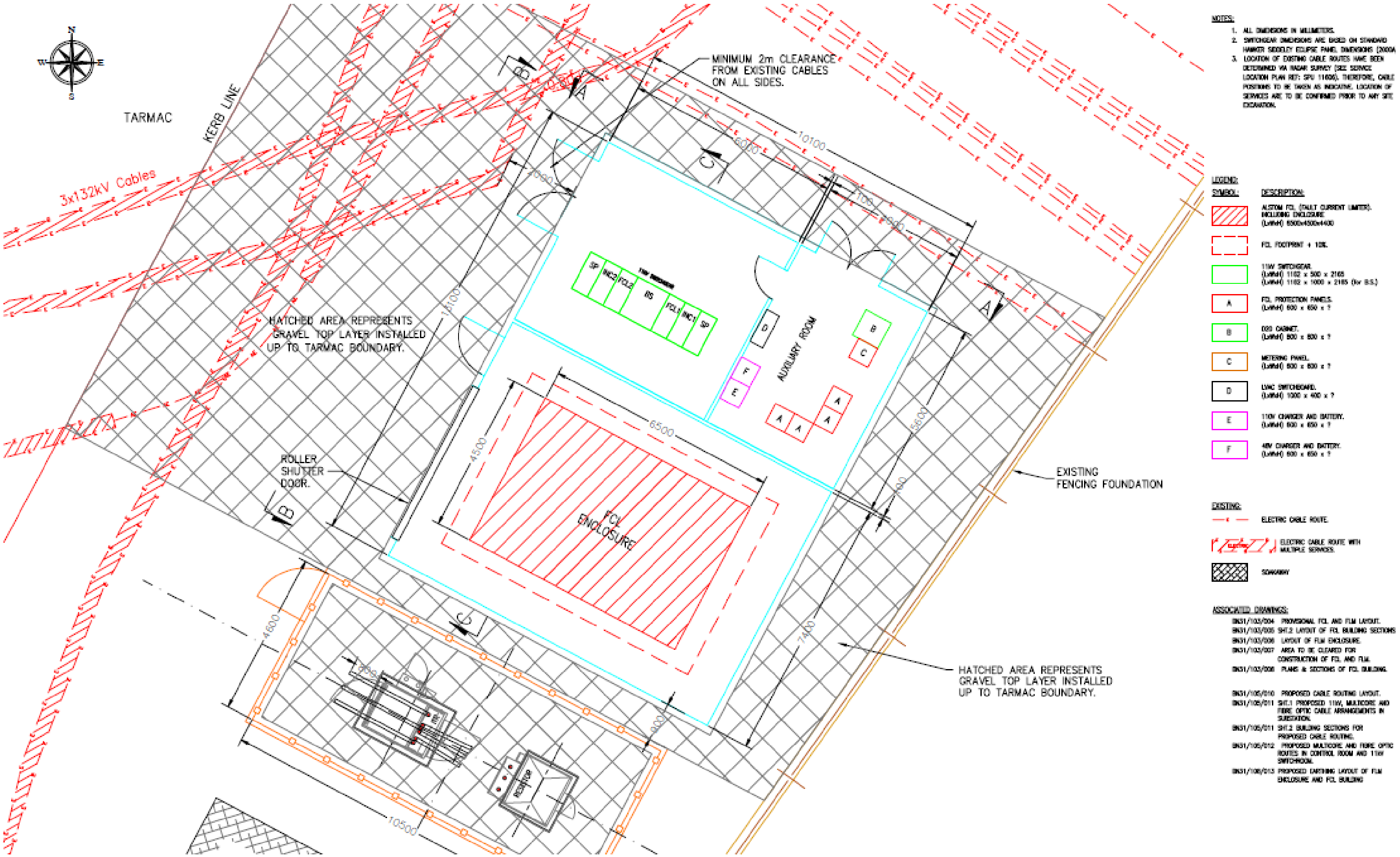
– It can be difficult to get a high continuous current rating and achieve large magnitudes of fault level reduction



Kitts Green Installation Considerations

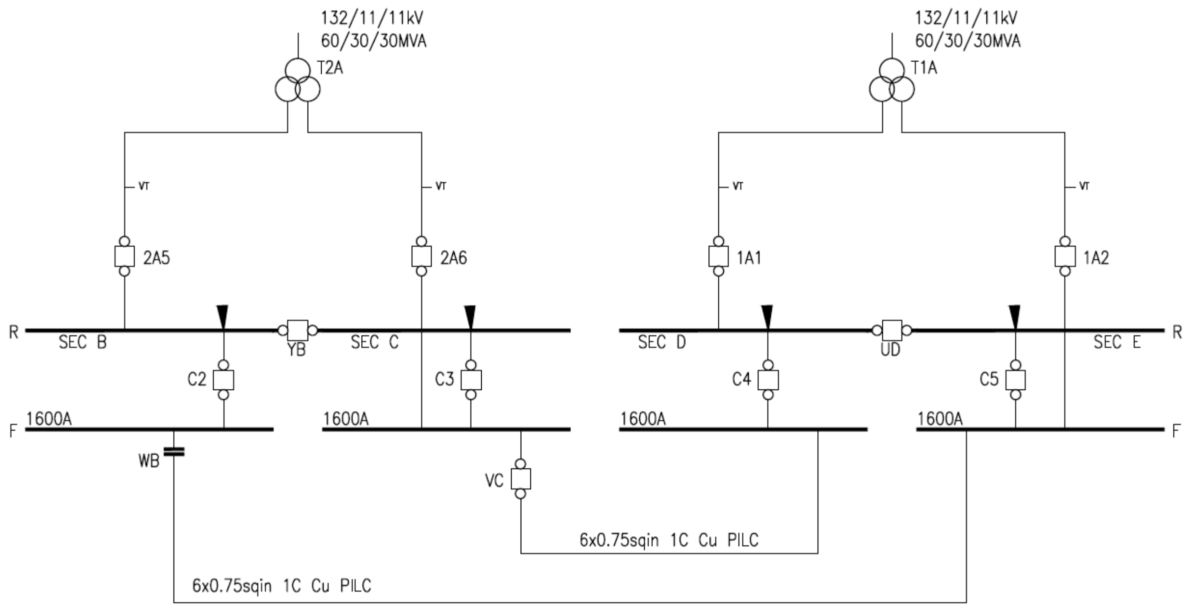
- All substation equipment is indoors, there is no space available in the existing building
- New FCL housing and switch room to be located in available land adjacent to the existing building
- Final operating requirements still being determined by Alstom for the PEFCL

Kitts Green Layout



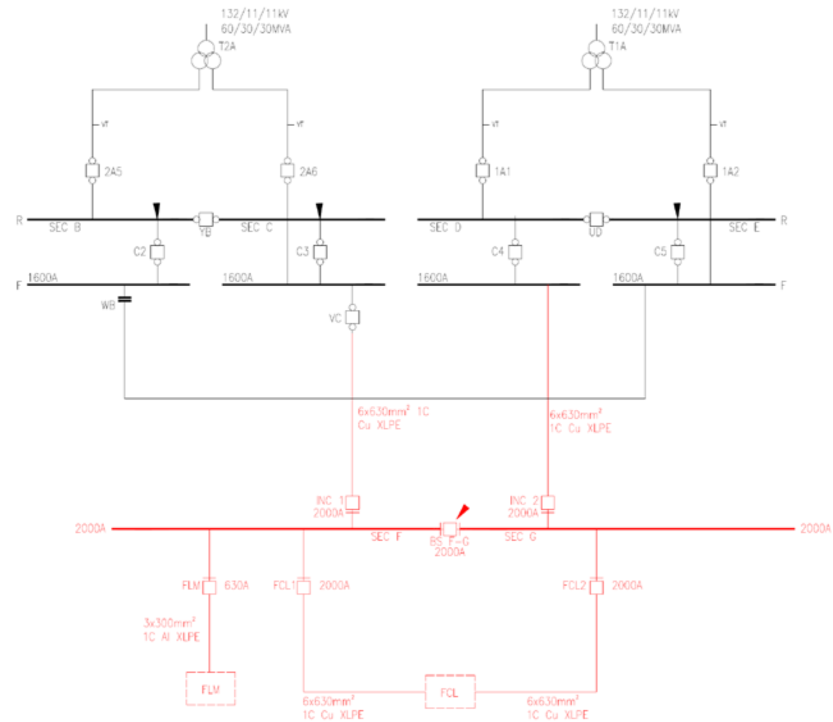
Sparkbrook – Existing SLD

– Two 60MVA transformers feeding two 11kV switchboards with interconnectors between each



Sparkbrook – Proposed SLD

- Alstom Power Electronic FCL chosen, connected within an interconnector



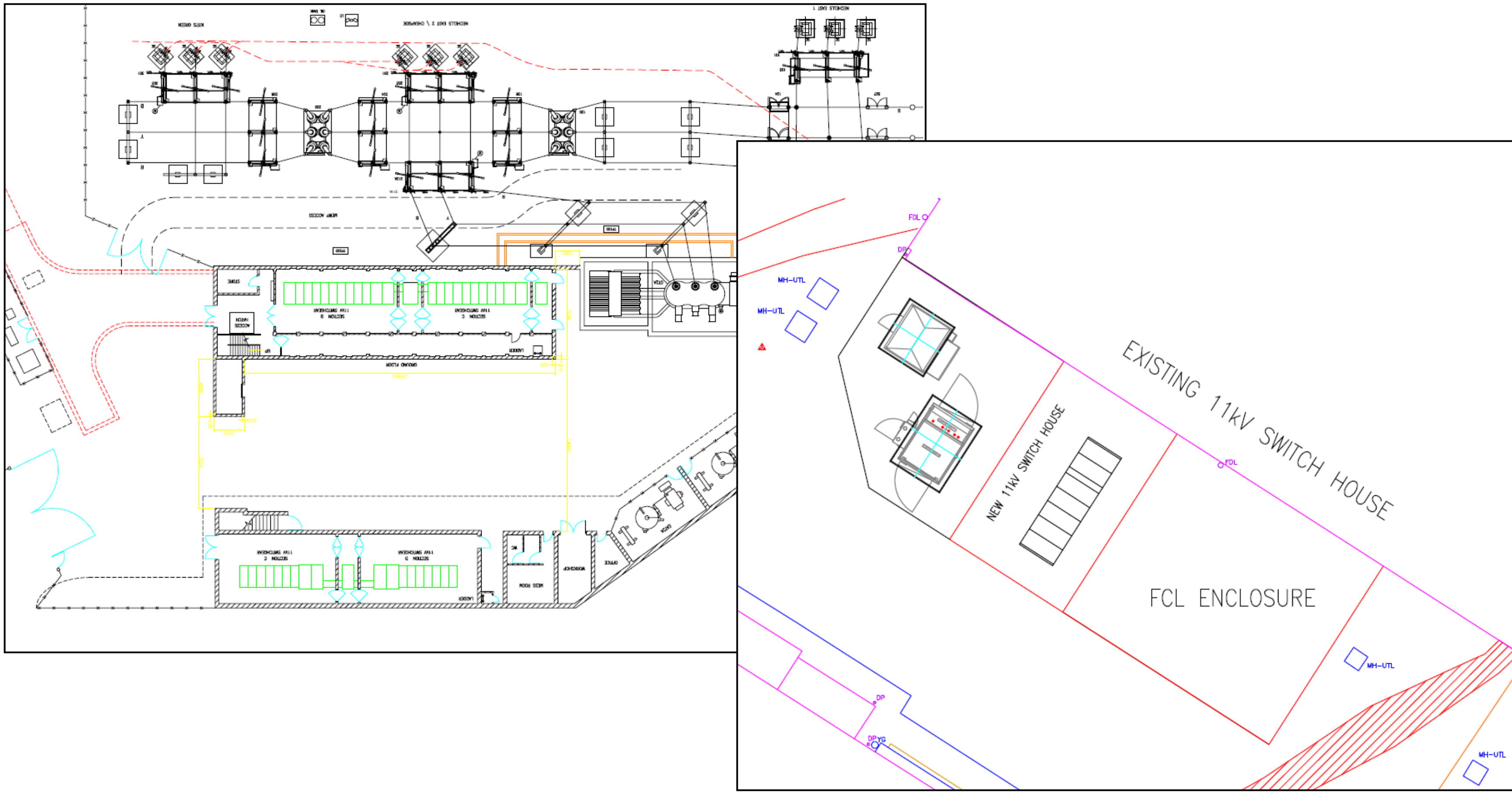
Sparkbrook Connection Considerations

- Similar to Kitts Green, the PEFCL was the only device that met the fault level reduction requirements
- A new five panel switchboard will be used to connect the FCL within the interconnector

Sparkbrook Installation Considerations

- No spare areas within the existing buildings – 11kV switch rooms full to capacity
- New FCL housing and switch room to be located in available land adjacent to switch room 1
- Final operating requirements still being determined by Alstom for the PEFCL

Sparkbrook Layout



WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Open Session

Other DNOs on-going experiences of FCLs on their system

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION
FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Open Session

Turning trials in to BaU – Policies, operational and maintenance procedures

LCN Fund Low Carbon Networks
THE UNIVERSITY OF WARWICK
PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Summary

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Thank you for joining us

Please complete your feedback form and have a safe journey home

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

FCL Dissemination Event

Wednesday 14th September 2016

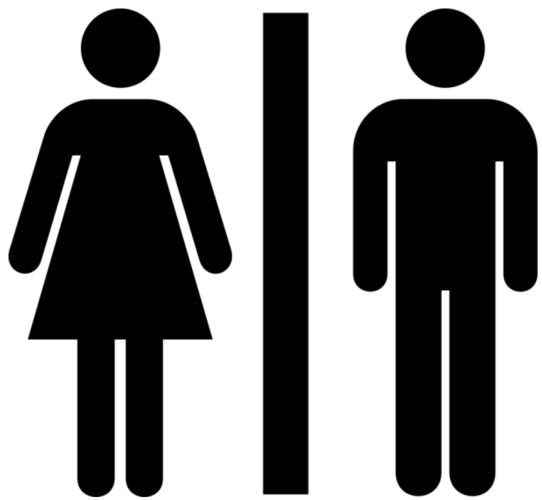
IET Austin Court – Birmingham

Jonathan Berry

Innovation and Low Carbon Networks Engineer

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF

Housekeeping



Agenda

- Welcome and Introduction - 10:00 – 10:15
- Technology Design & Installation - 10:15 – 11:00

COFFEE BREAK

- Technology Operation to Date - 11:15 – 12:00

LUNCH

- Site Visits - 12:30 – 15:30

FlexDGrid – What and Why

What are we doing?

Understanding, Managing and Reducing the Fault Level on an electricity network

Why are we doing it?

Facilitating the early and cost effective integration of Low Carbon generation

Why are we doing it now?

Supporting the Carbon Plan – Connection of generation to the grid and development of heat networks – reducing carbon emissions

What is FlexDGrid?

Three integrated Methods leading to quicker and cost effective customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network Fault Level.

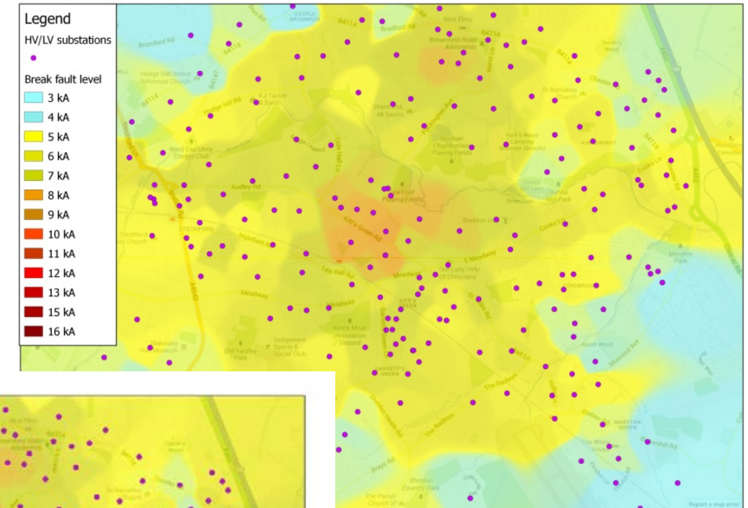
Enhanced Assessment
- Enhanced network models
- Detailed understanding of network Fault Level

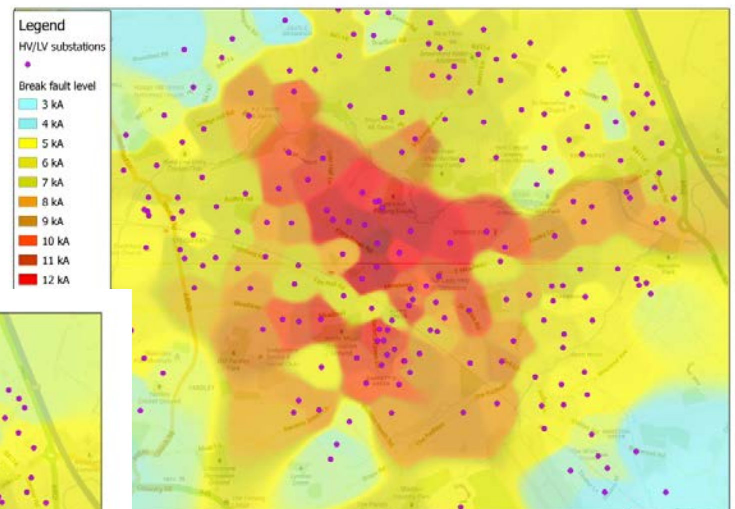
Management
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

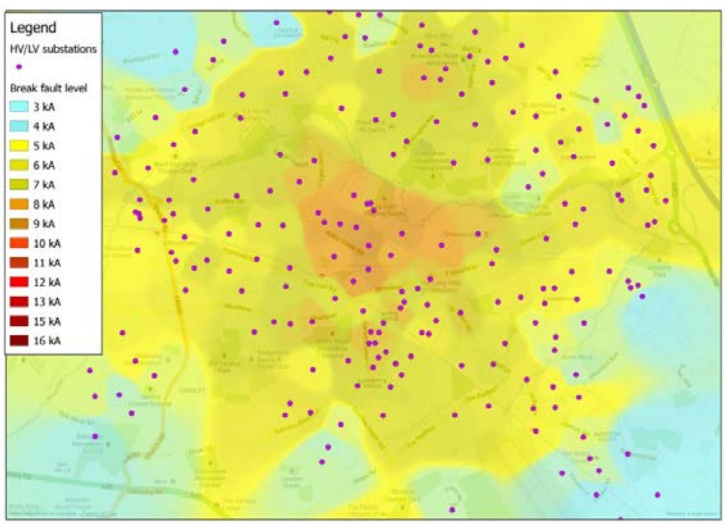
Mitigation
- Reduction of system Fault Level
- Utilised from output of Management

Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional Generation.

Effect on Fault Level







Fault Level Heat Maps

Project Team

WSP
PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Fault Current Limiters

Learning: Technology Design and Installation

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

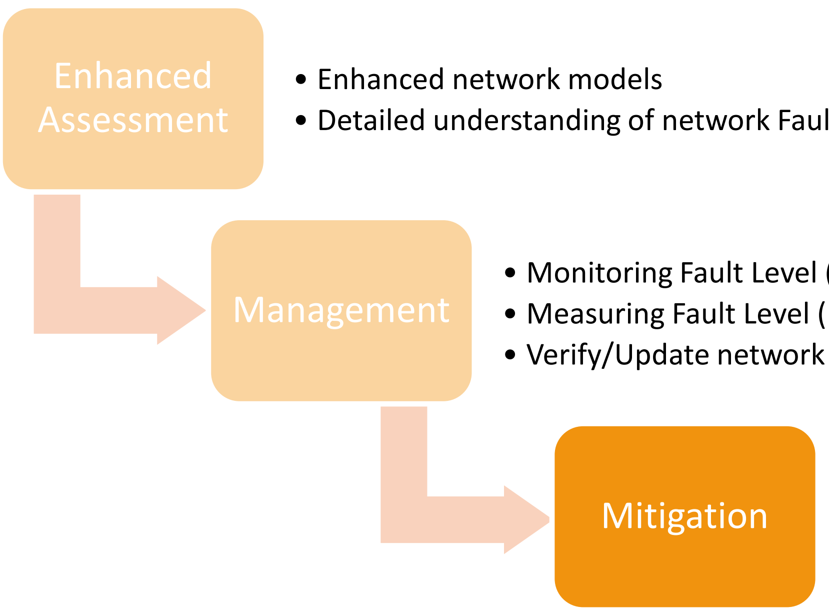
PARSONS BRINCKERHOFF

Introduction

- Overview of Method Gamma
- Pre-Saturated Core FCL
  - Technology
  - Integration of FCL
  - Design of FCL
- Resistive Superconducting FCL
  - As above

FlexDGrid – Method Gamma

Three integrated Methods leading to quicker and cost effective HV customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network fault level.



- Enhanced network models
- Detailed understanding of network Fault Level

- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

- Reduction of system Fault Level
- Utilised from output of Management

FlexDGrid – Method Gamma

- Method Gamma: Fault Level Mitigation Technologies
  - Build on knowledge learned through IFI, ETI and LCNF Projects
  - Install 5 FL mitigation technologies in 5 separate WPD substations
  - Test & trial emerging technologies to quantify performance and network benefits

Summary of Technologies

– Substations and technologies

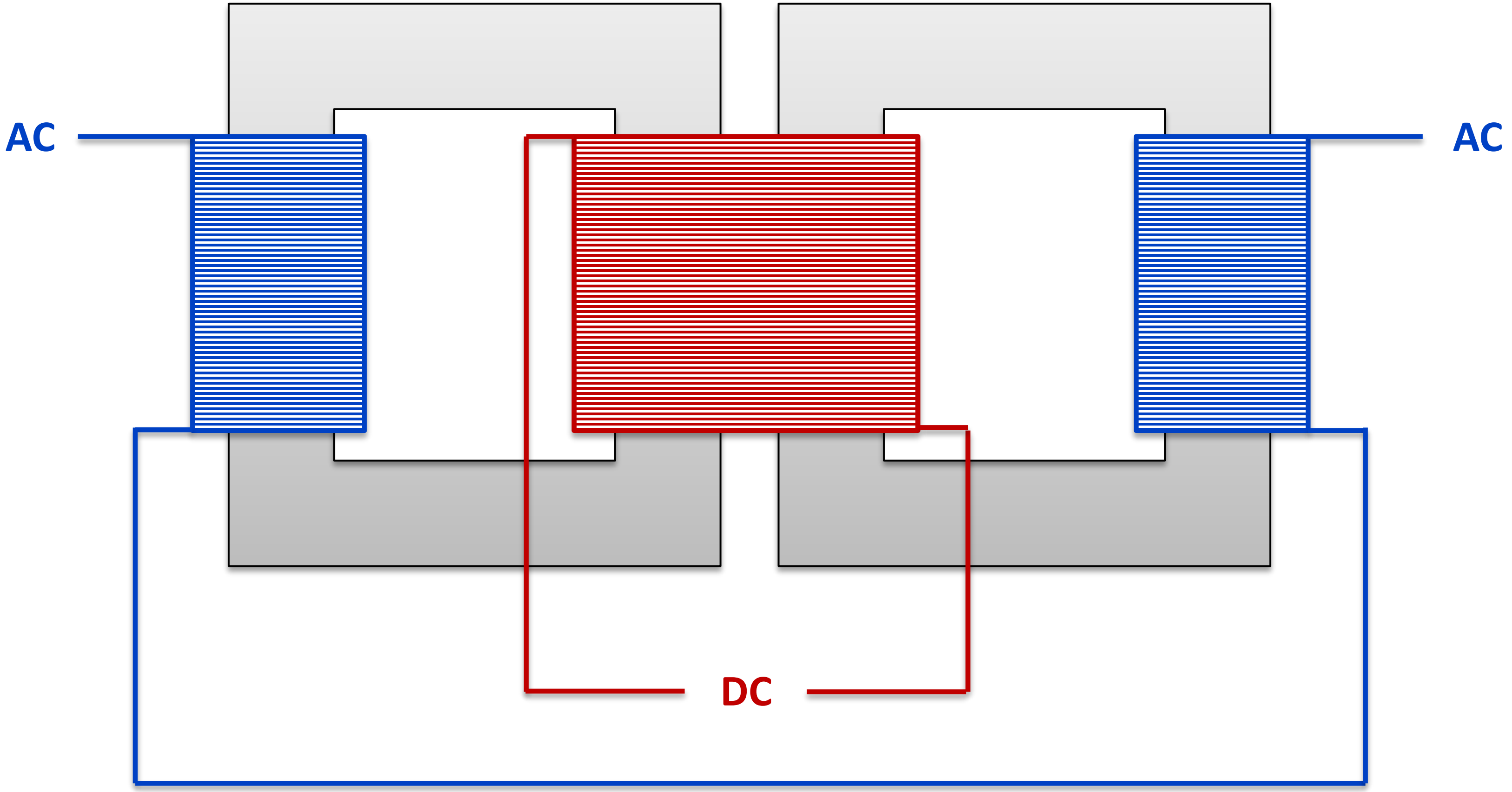
Substation	Technology	Manufacturer
Castle Bromwich	Pre-Saturated Core FCL	GridON
Chester Street	Resistive Superconducting FCL	Nexans
Bournville	Resistive Superconducting FCL	Nexans
Kitts Green	Power Electronic FCL	GE
Sparkbrook	Power Electronic FCL	GE

Pre-Saturated Core Fault Current Limiter

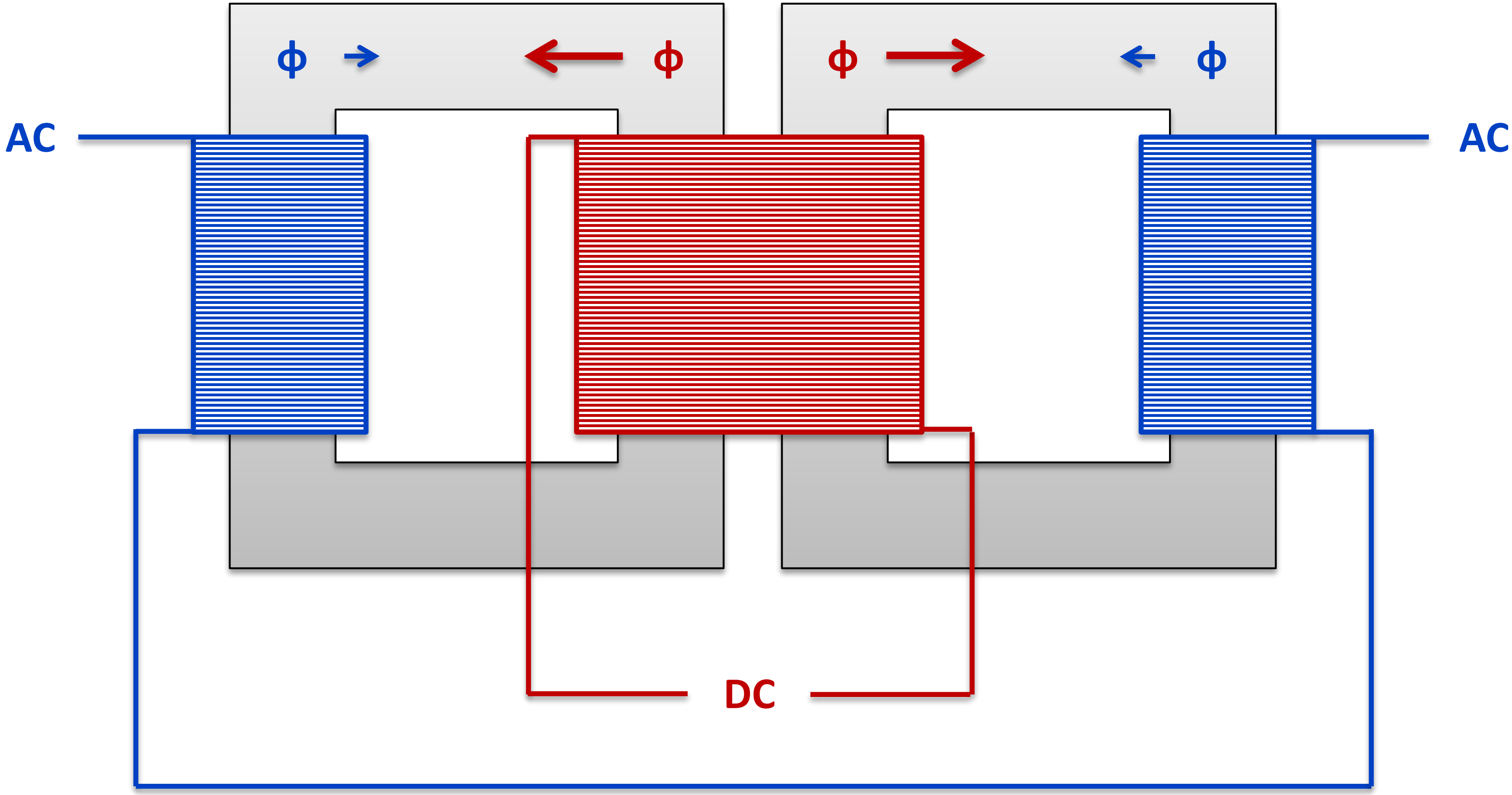
Pre-Saturated Core Fault Current Limiter

- Also known as an "Inductive FCL" the PSCFCL uses the principles of magnetisation in a core to create a variable reactor
- The device comprises:
  - Laminated Cores (similar to that of a reactor)
  - AC Coils (connected in series with the 11kV network)
  - DC Coils (supplied from a local source)

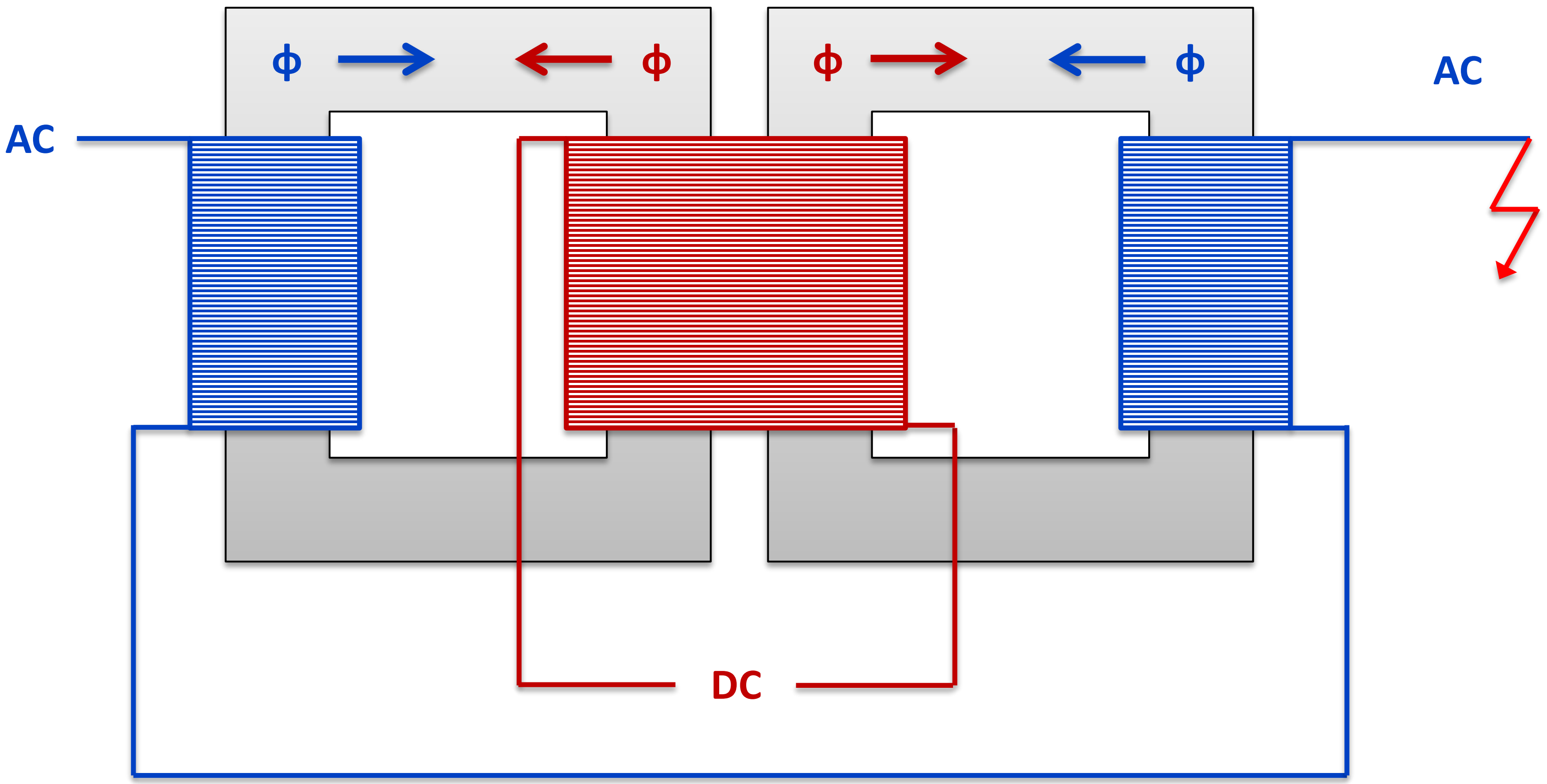
Diagram of PSCFCL



Normal Operation of PSCFCL



Operation of PSCFCL during a fault

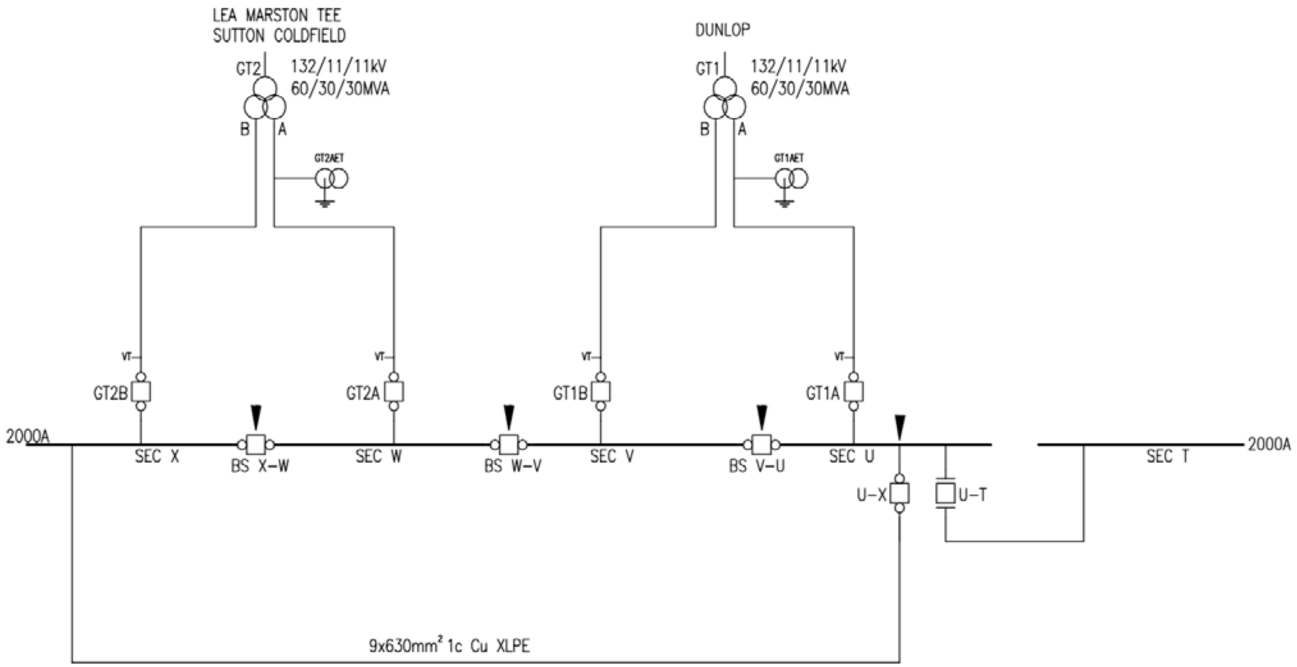


Details for GridON PSCFCL at Castle Bromwich

- Rating: 30MVA ONAN, 38MVA ONAF
- Break fault level reduction required: 44%
- Peak fault level reduction required: 53%
- Mass: 168 Tonnes
- Dimensions (LxWxH): 6.4 x 4.5 x 5.3 m

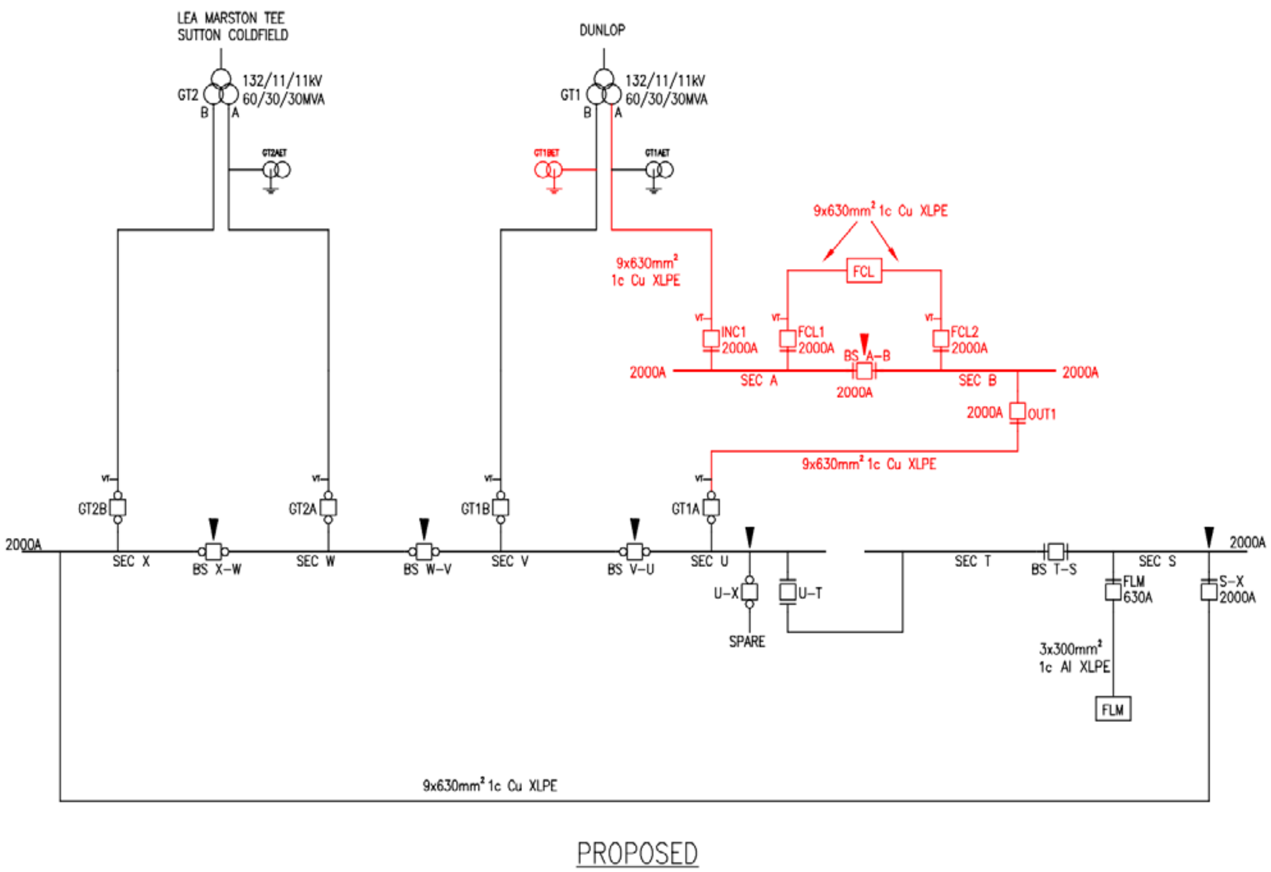
Milestone	Date
Short Circuit Tests	15th August 2014
Factory Tests Complete	6th September 2014
Device Energised	8th April 2015

PSCFCL Integration – Castle Bromwich 132/11kV



EXISTING

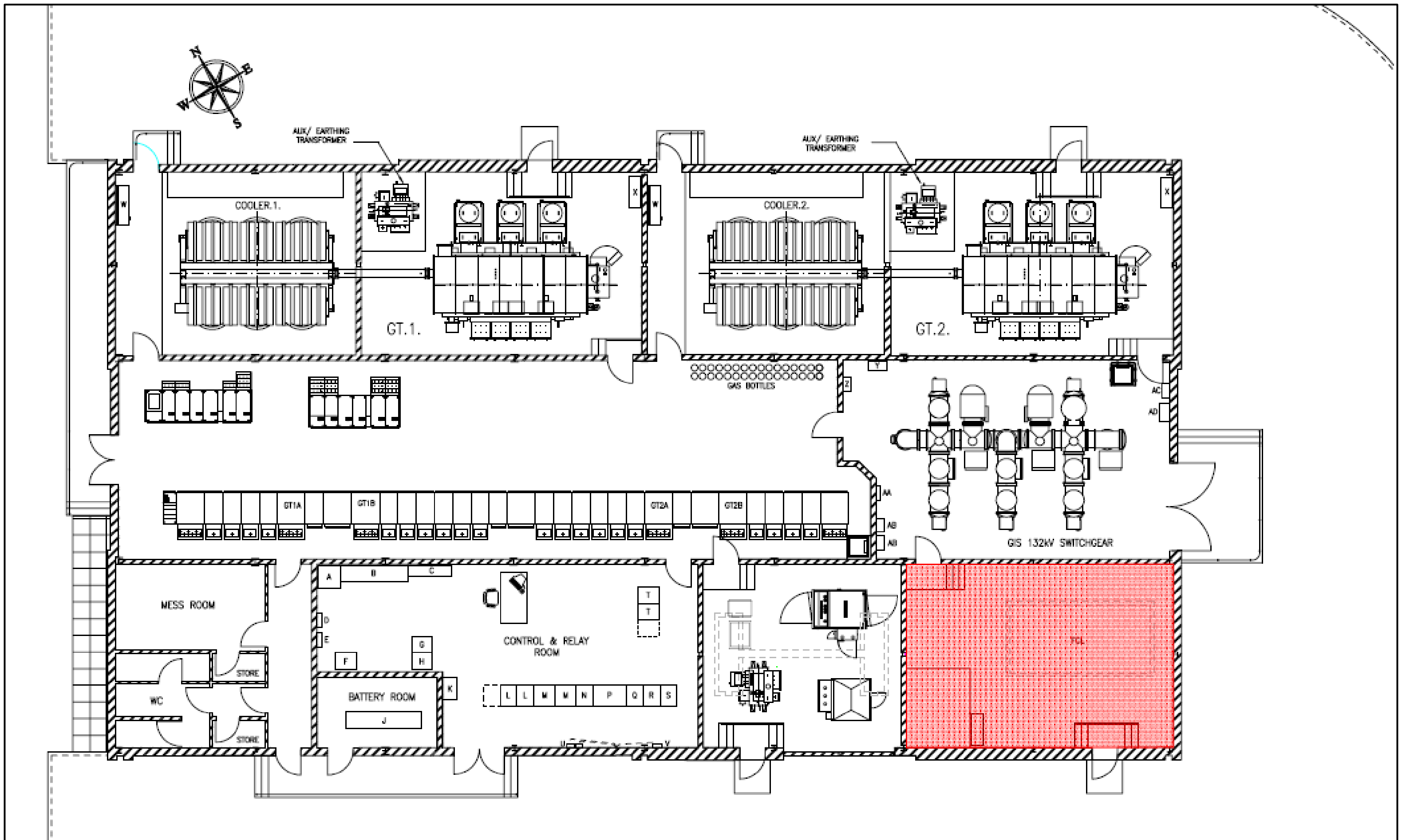
PSCFCL Integration – SLD



PSCFCL Integration – Main Points

- Indoor Installation
- GT1 Thompson Strap for earthing
- Magnetic shielding
- Protection operation
- Load sharing

PSCFCL Integration – Indoor Installation

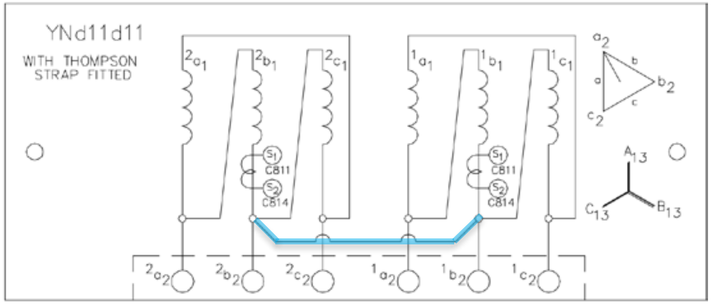


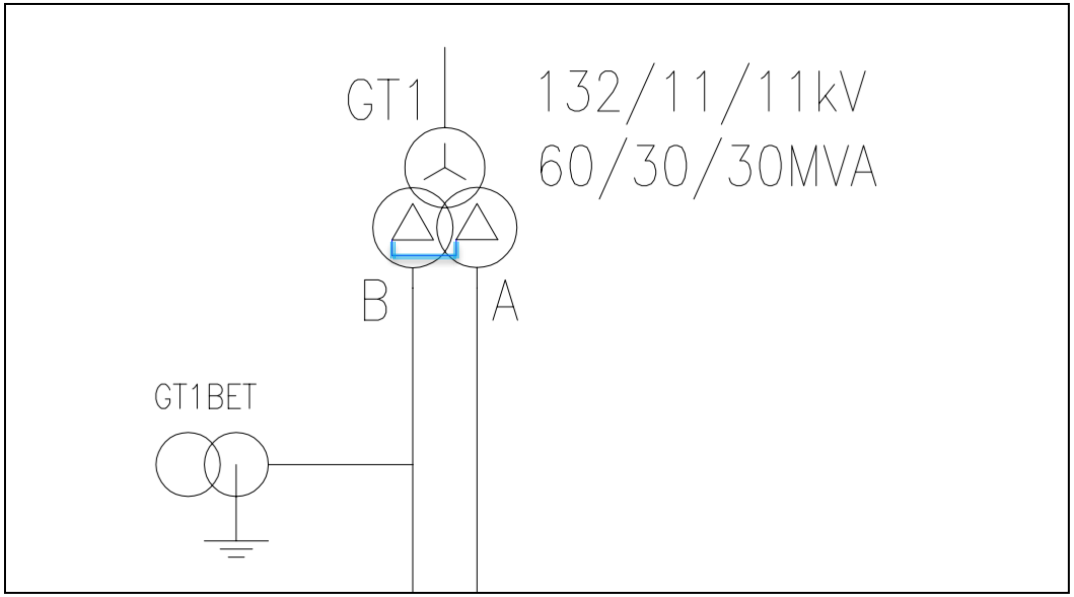
PSCFCL Integration – Indoor Installation

PSCFCL Integration – Indoor Installation

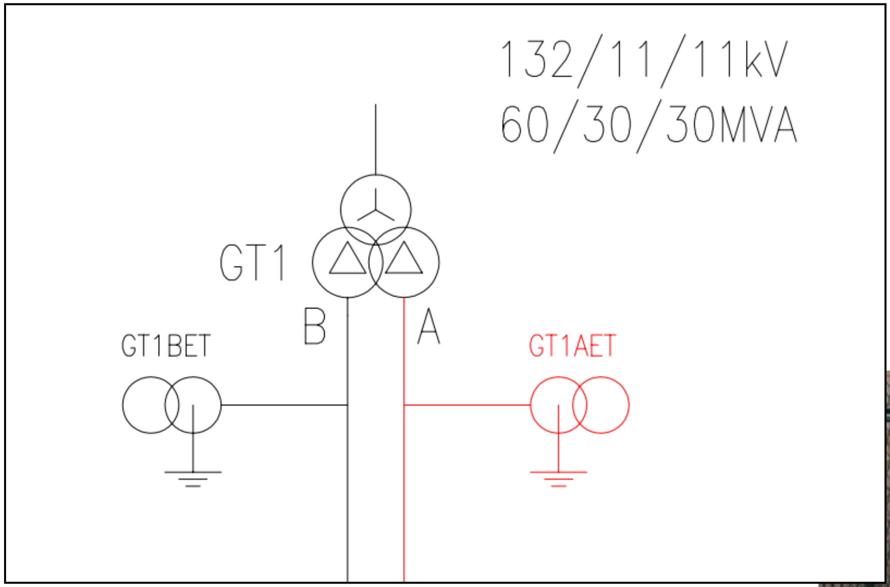
PSCFCL Integration – Indoor Installation

PSCFCL Integration – Thompson Strap





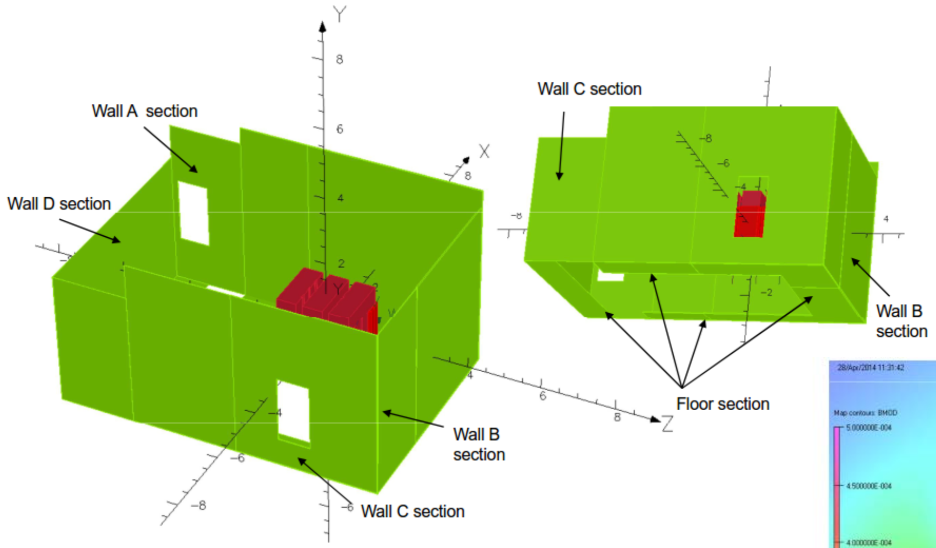
PSCFCL Integration – Thompson Strap

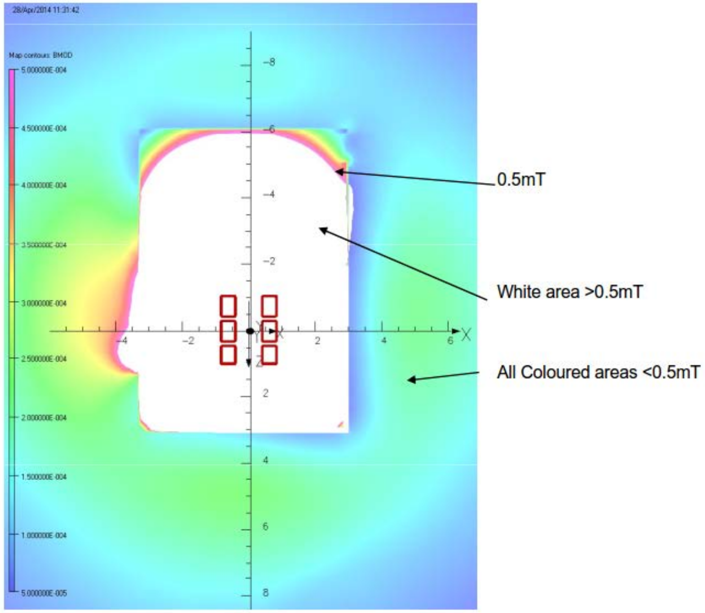


PSCFCL Integration – Magnetic Shielding

- At close proximity, the magnetic field emitted by PSCFCL can be very high and dangerous to people with medical implants (> 0.5mT / 5G)
- Magnetic field varies with DC bias levels
- Desire to not prohibit general access to substation compound
- Magnetic field strength modeled and a shield design produced

PSCFCL Integration – Magnetic Shielding

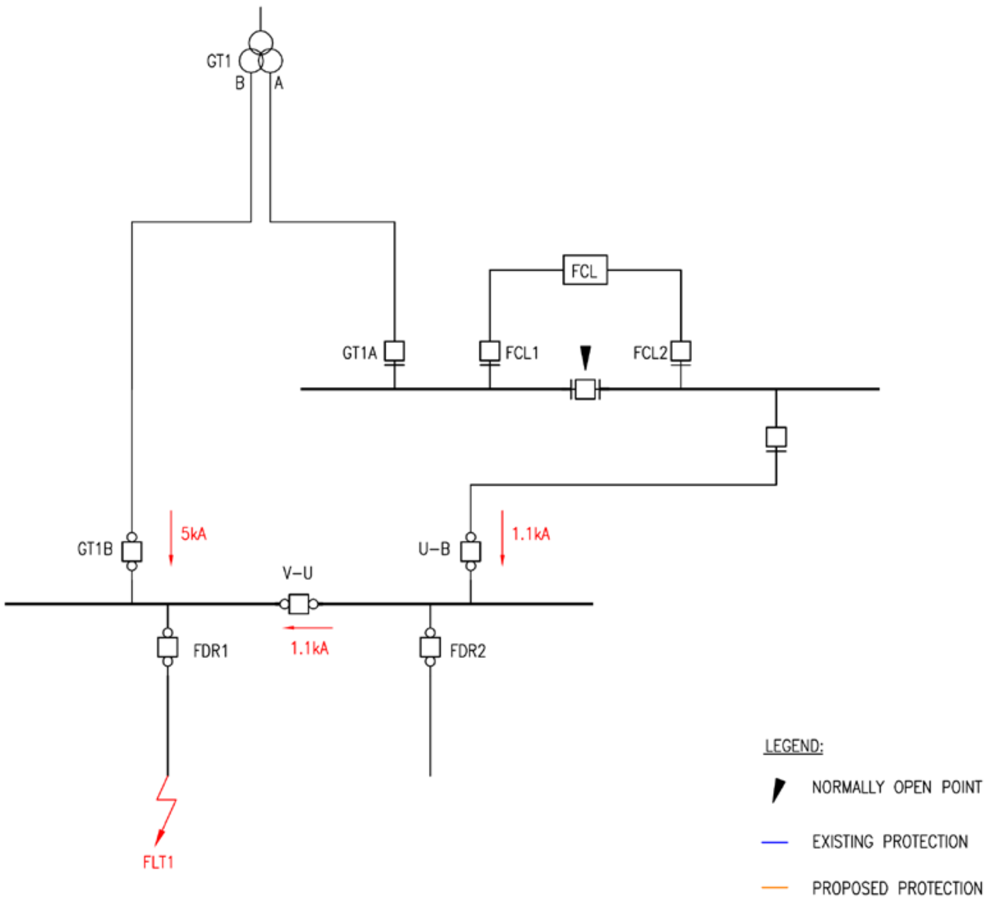




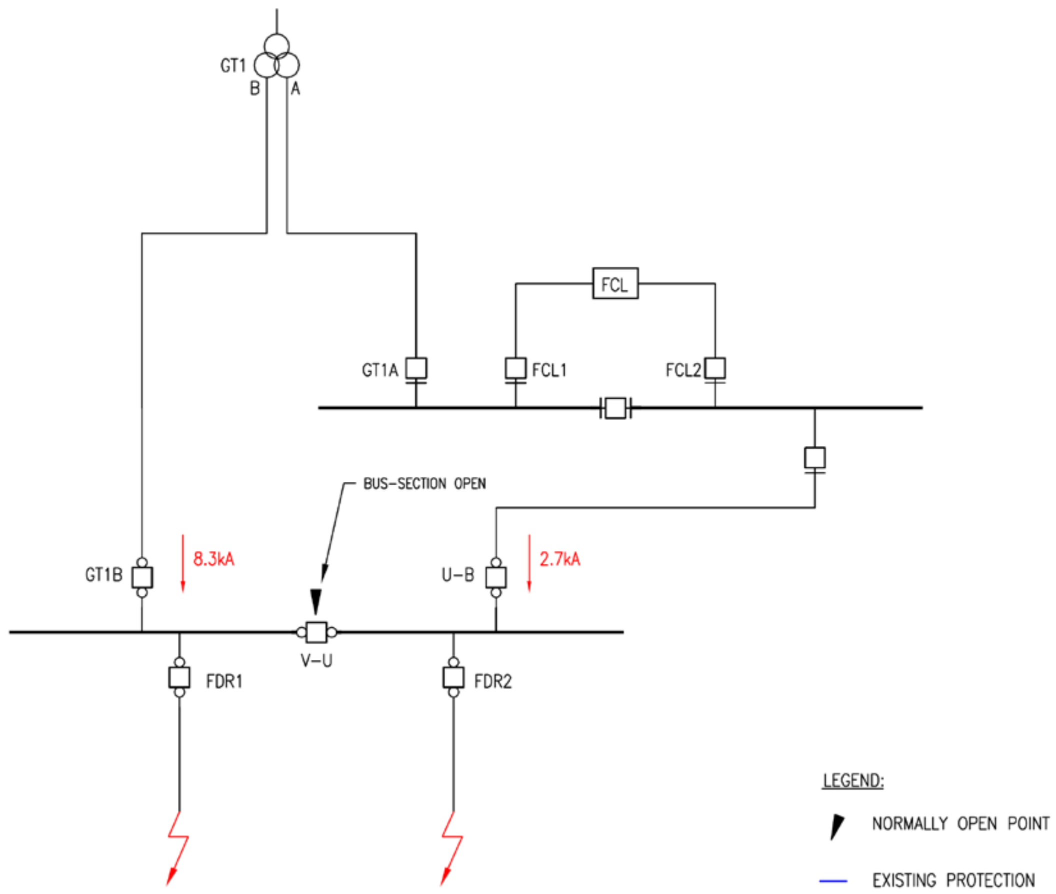
PSCFCL Integration – Protection

- Protection of PSFCL was kept simple with a main protection utilising circulating current and back-up OCEF
- FCL protection panel was designed and similar to standard WPD transformer protection panel
- Existing protection schemes had to be studied to ensure new fault levels were taken into account
- Modification of “partial” busbar protection scheme

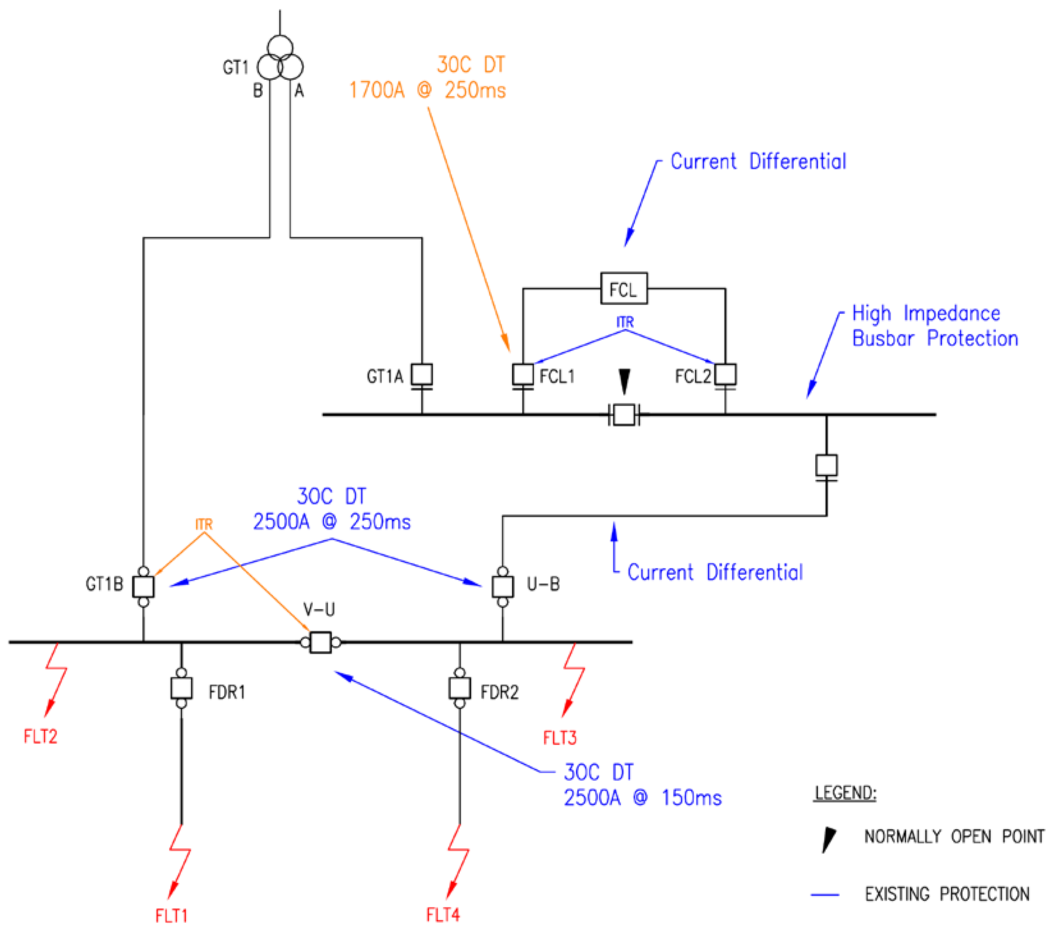
PSCFCL Integration – Protection



PSCFCL Integration – Protection



PSCFCL Integration – Protection

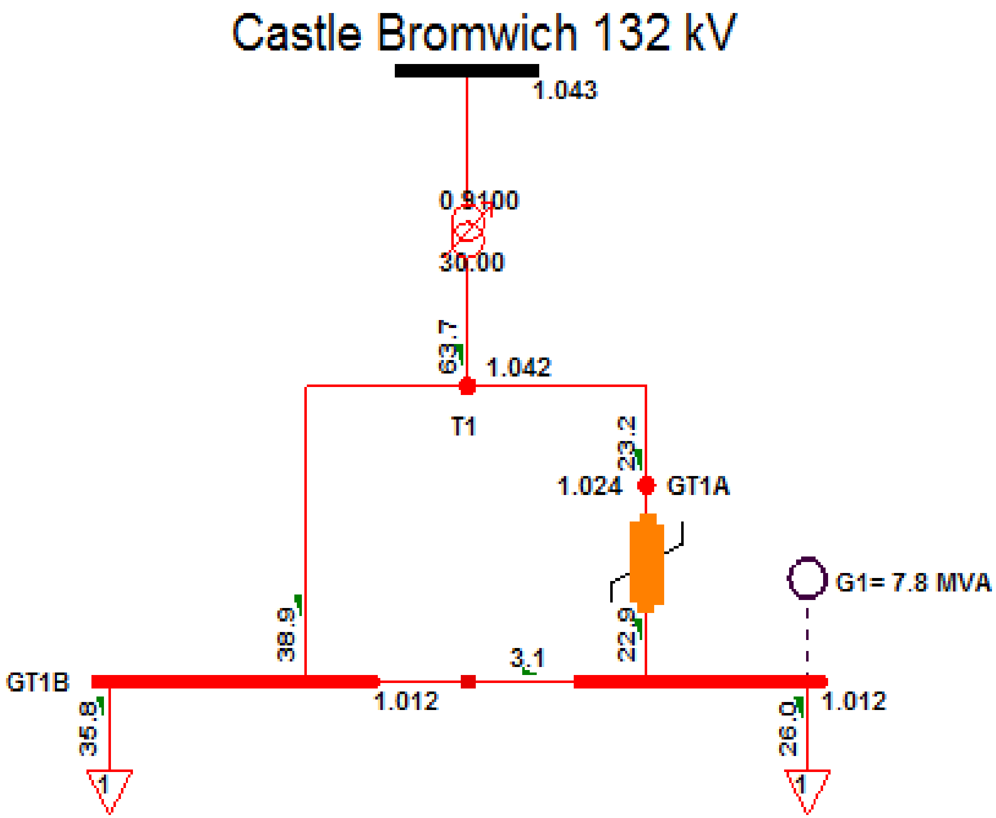


FCL Integration – Load Sharing

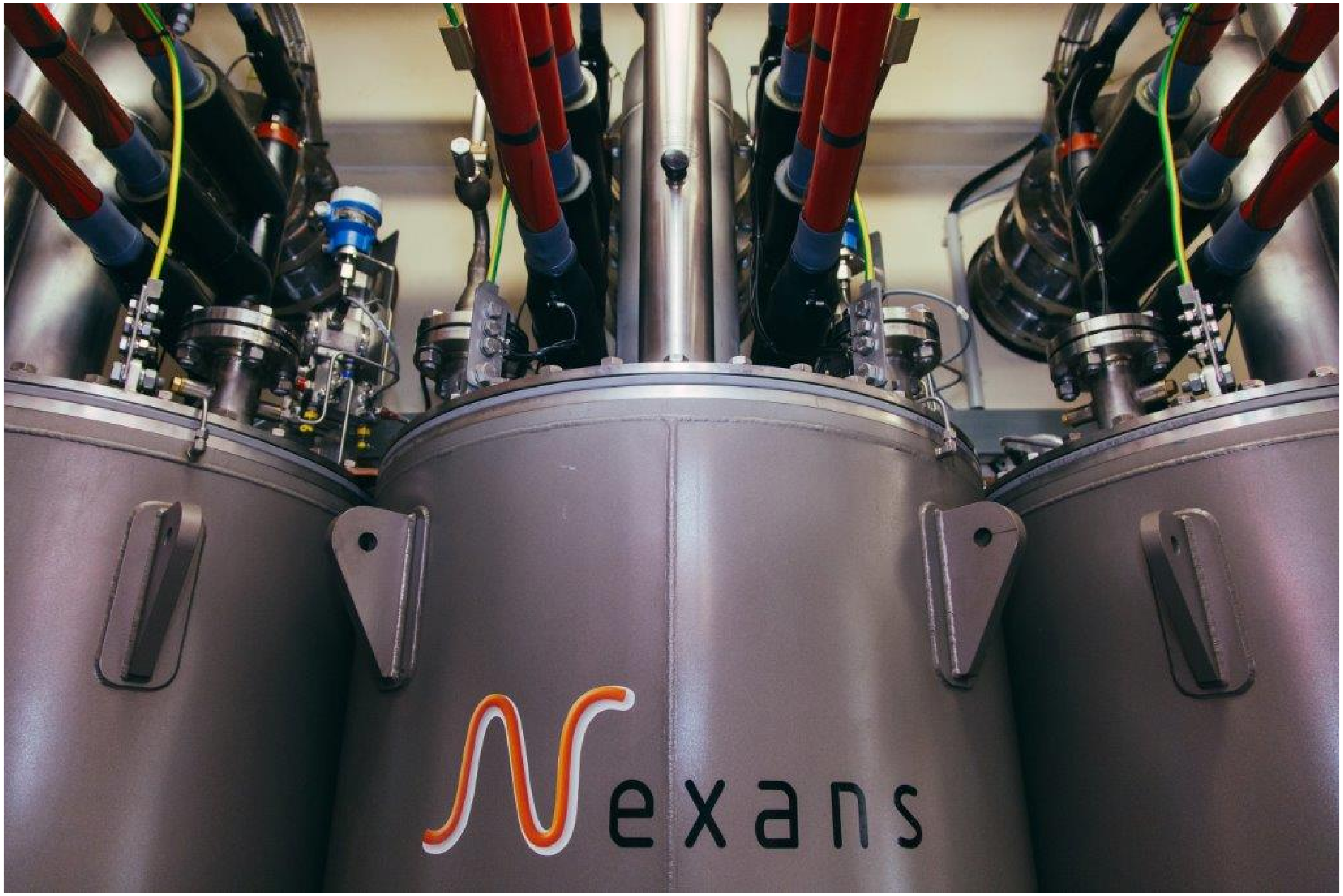
- DC bias current is controlled to save power and also control the steady state impedance of the FCL
- Under normal load conditions FCL impedance impacts on the load sharing across GT1A and GT1B legs

AC Load current RMS [A]	DC bias current [A]
400	130
800	220
1000	270
1250	320
1575	365
2000	490

FCL Integration – Load Sharing

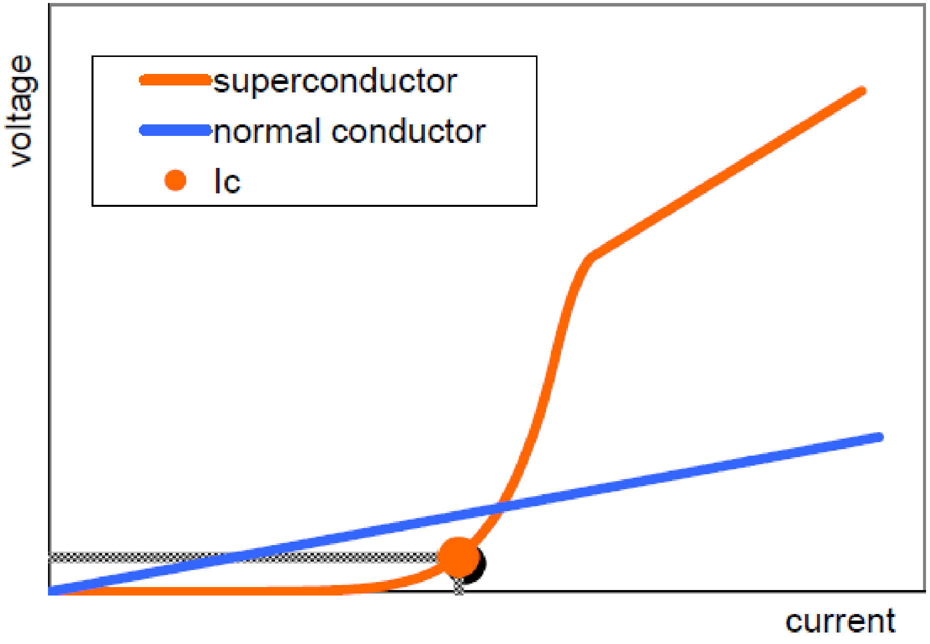


Resistive Superconducting Fault Current Limiter



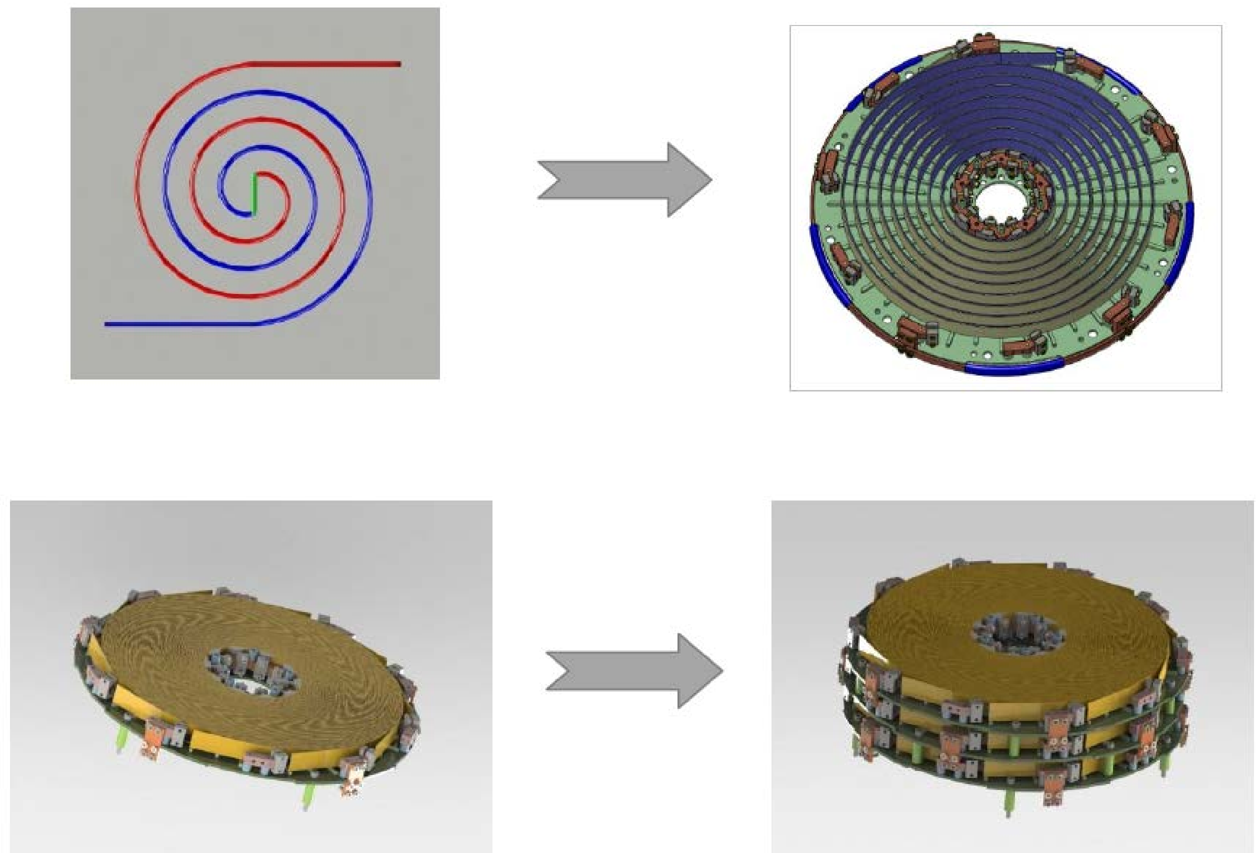
Resistive Superconducting Fault Current Limiter

- Manufactured by Nexans, Germany.
- Exploits the properties of High Temperature Superconducting (HTS) material (Yttrium barium copper oxide).

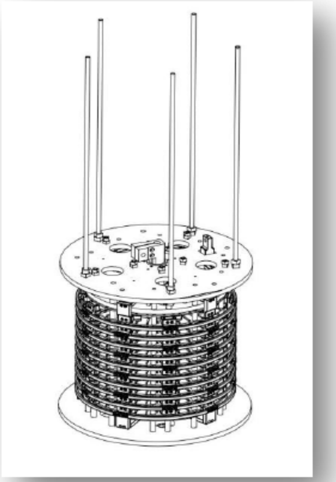


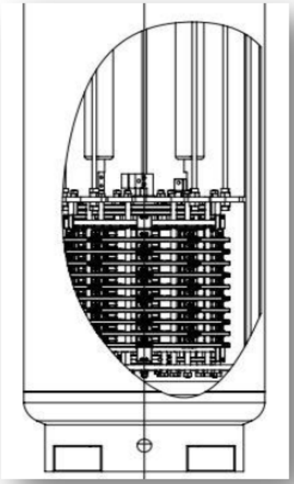
Resistive Superconducting Fault Current Limiter

- Each Component contains bifilar tapes.
- Tapes connected in parallel on the component to get required current rating.
- Components stacked and connected in series to get the required conductor length.



Resistive Superconducting Fault Current Limiter

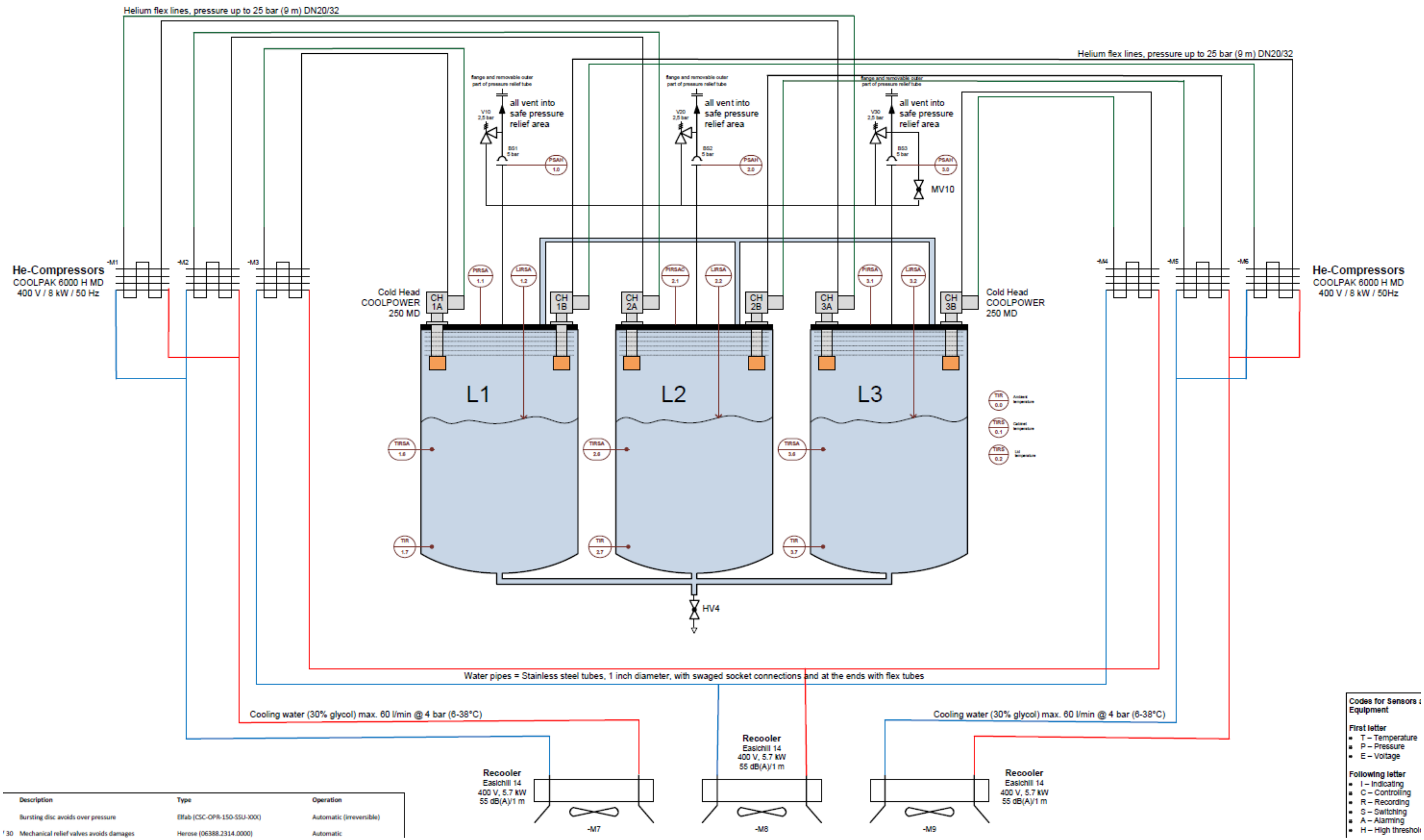




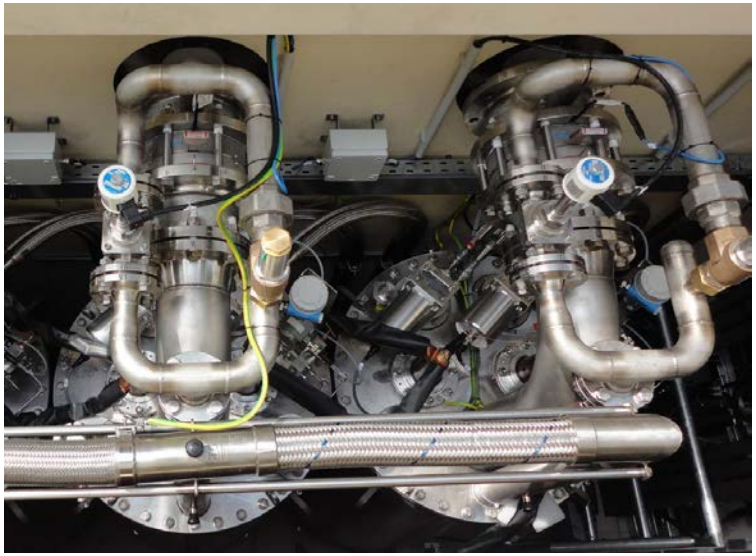
Cooling System

- Two heat exchange circuits:
  - Helium/water at the compressor units.
  - Water/air at the recooler units.
- Helium at high pressure (approx. 14 bar).
- Expanded through the cold head to generate very low temperatures (approx 72k).
- Liquid Nitrogen kept at its boiling point.
- Cooling system is controlled from the device’s main control system.

Cooling System – Schematic

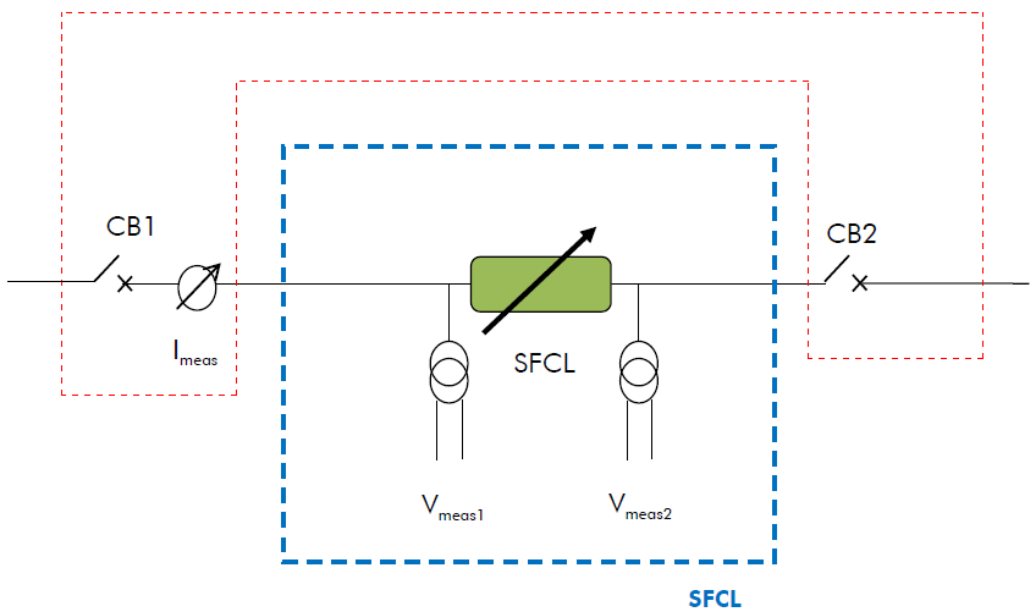


FCLs – Design and Installation

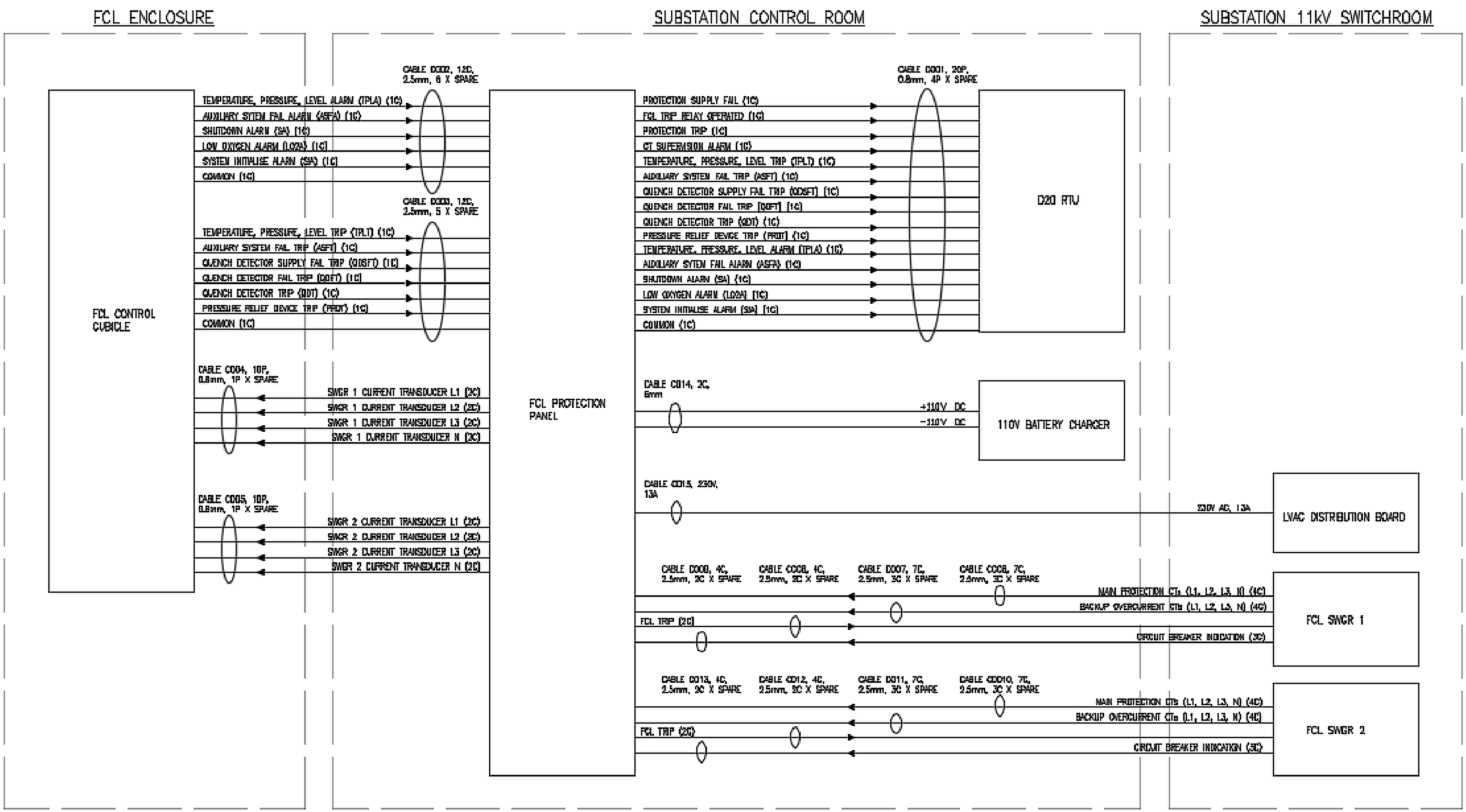


Protection and Control – Device Level

- Voltage differential protection used to detect a quench event.
- RSFCL requires disconnection of the circuit within 100ms.
- Current measurement implemented in the feeder circuit breakers to control the cooling system.



Protection and Control - System Level



Overview

Chester Street 132/11kV Substation:

- 1600A rated
- Peak fault reduction (@10ms) 19.76kA to 9.90kA or below
- Peak fault reduction (@90ms) 7.03kA to 3.68kA or below
- 33.4kA short circuit current withstand capability

Milestone	Date
Factory Tests Complete	23rd September 2015
KEMA Tests Complete	5th October 2015
Device Energised	25th November 2015

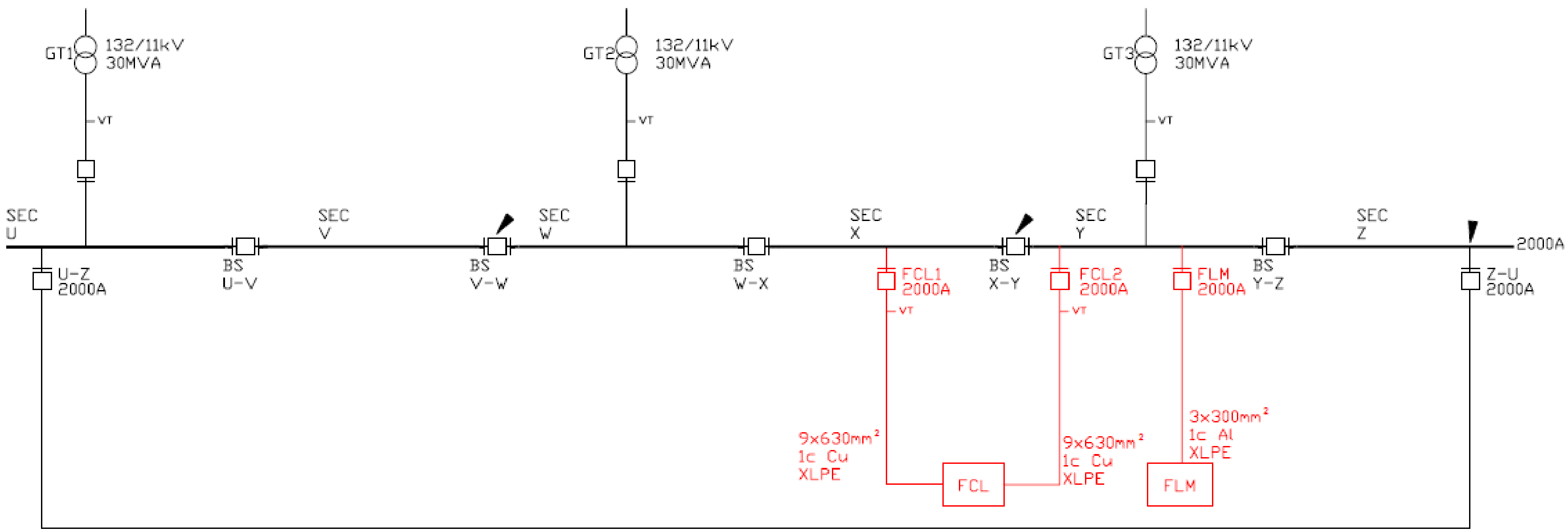
Bournville 132/11kV Substation:

- 1050A rated
- Peak fault reduction (@10ms) 21.97kA to 7.70kA or below
- Peak fault reduction (@90ms) 7.66kA to 3.05kA or below
- 33.4kA short circuit current withstand capability

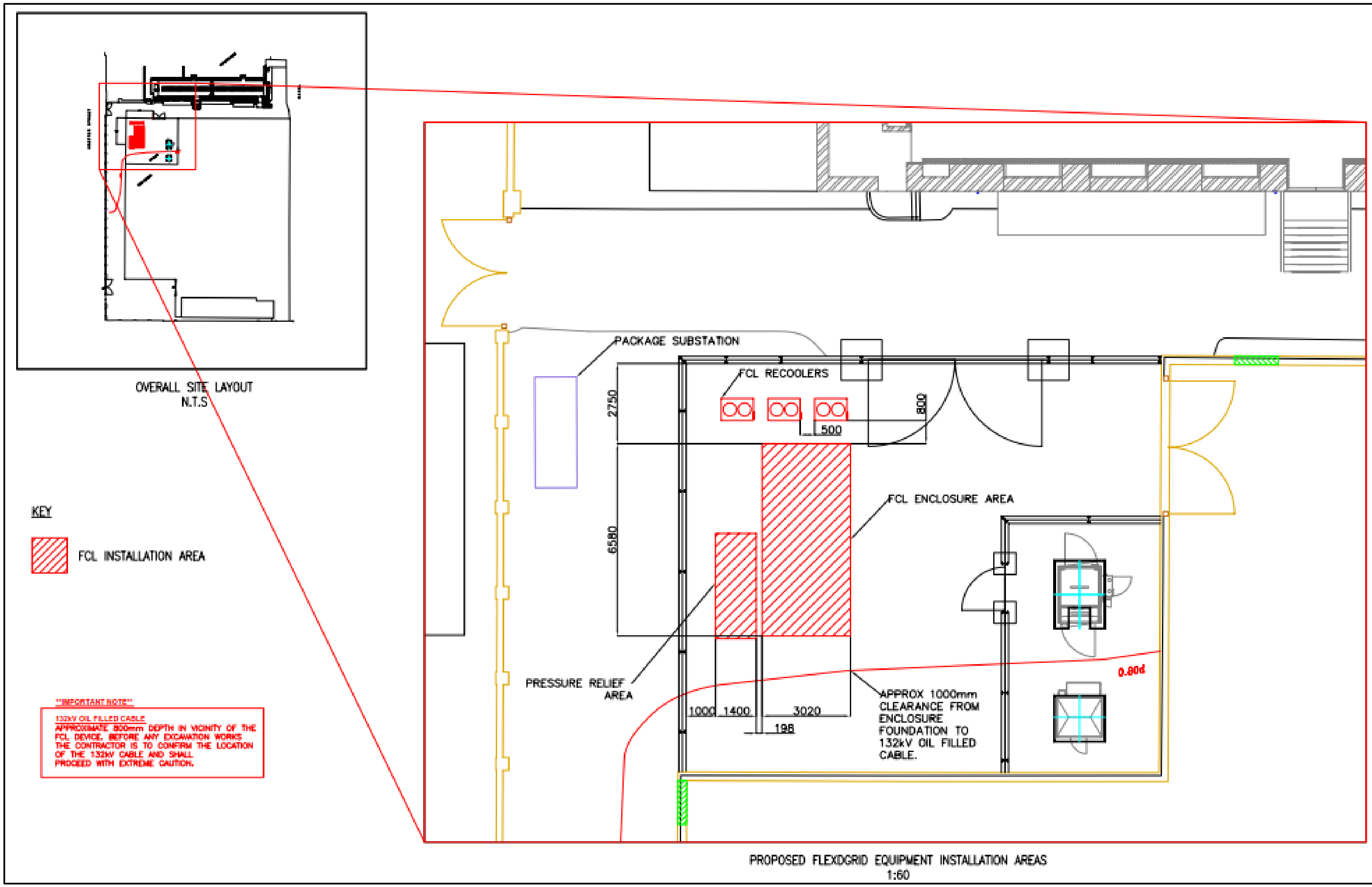
Milestone	Date
Factory Tests Complete	30th November 2015
KEMA Tests Complete	7th December 2015
Device Energised	17th February 2016

Chester Street FCL Network Connection

- Three Grid Transformers run in split configuration.
- RSFCL connected across the bus-section.
- Circuit breaker fail scheme installed:
  - FCL1 trips Bus-section W-X (250ms delay)
  - FCL2 trips GT3 (250ms delay)

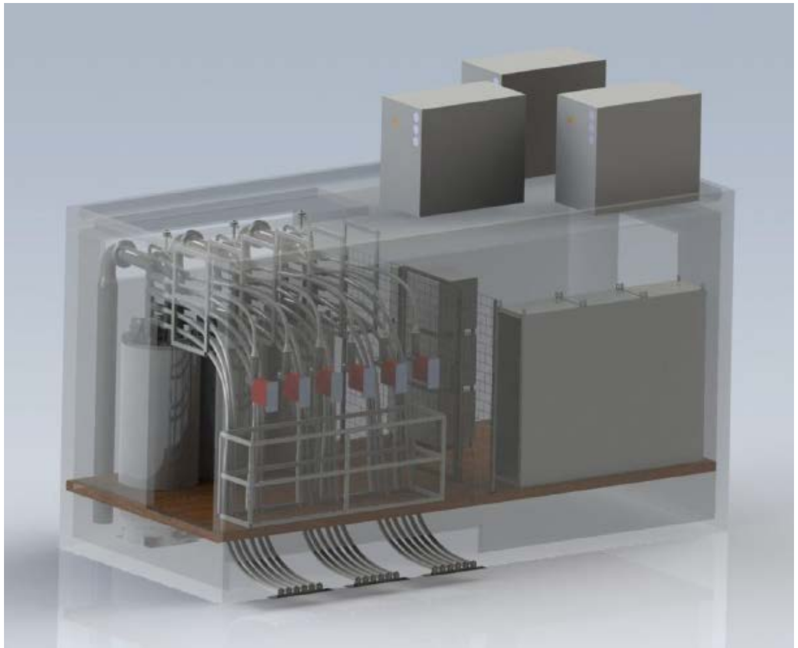


Chester Street RSFCL Installation

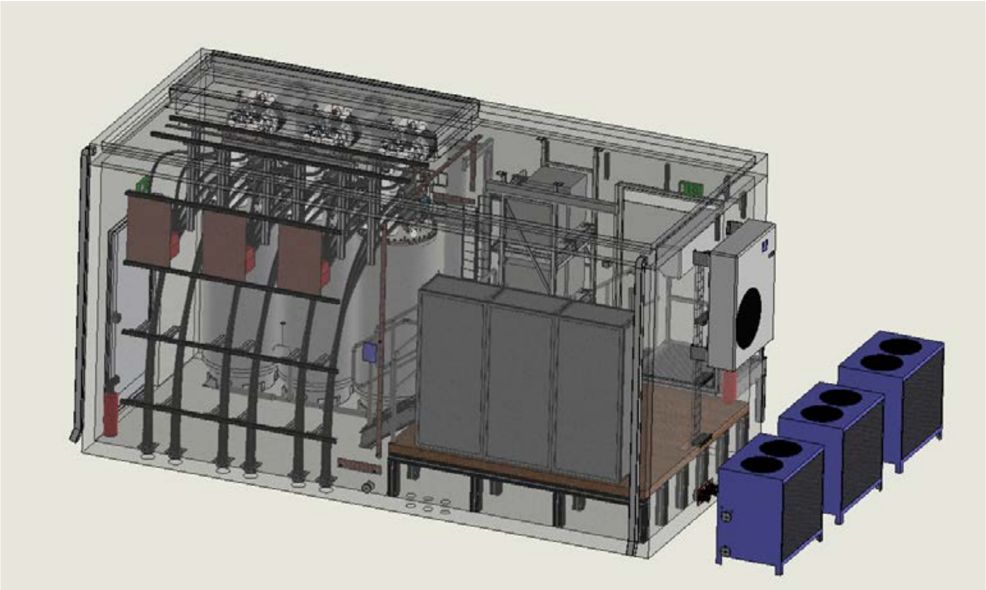


Chester Street RSFCL Installation

Design - Enclosure



- Recoolers moved to ground floor.
- Cable basement removed.
- Compressor rack installed.
- Climate control added.
- Bund for safe containment of liquid Nitrogen.



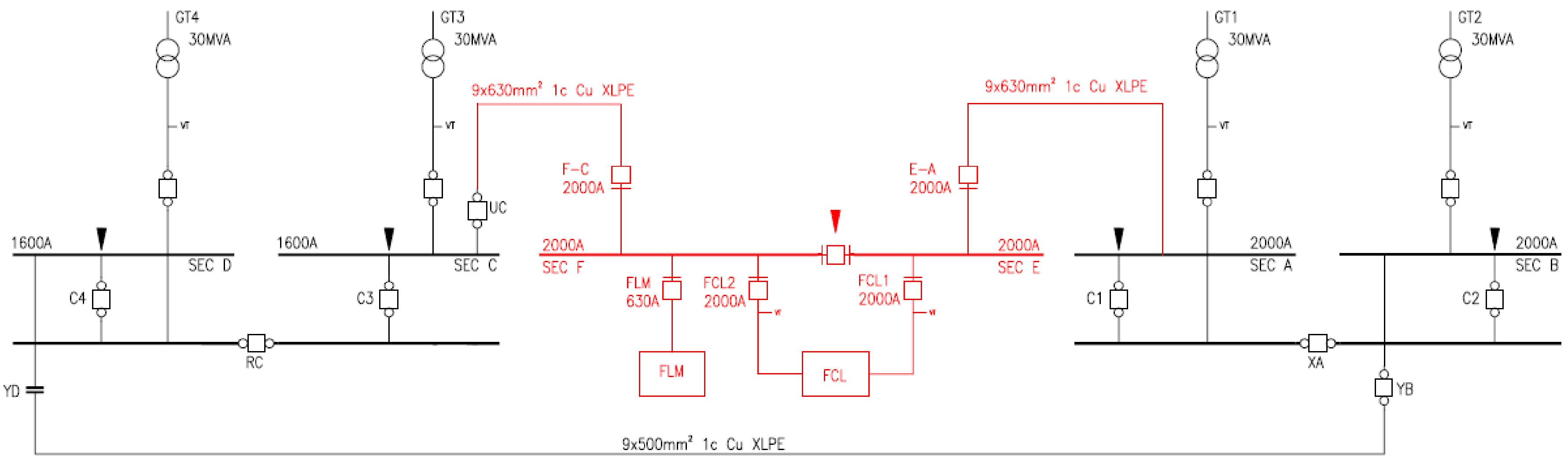
FCL Protection Panel

Provides:

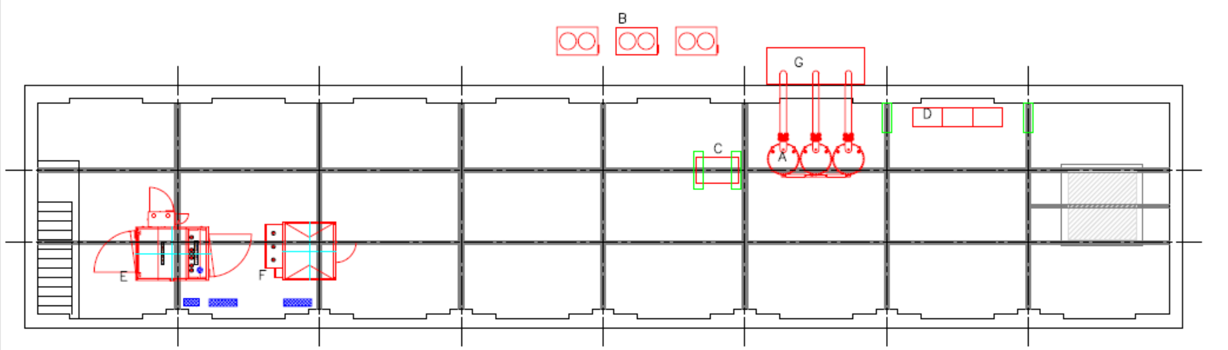
- Unit protection scheme across the FCL.
- Initiates trip signal to FCL feeder circuit breakers.
- Alarm and trip indication.
- Control/indications to/from WPD control.

Bournville FCL Network Connection

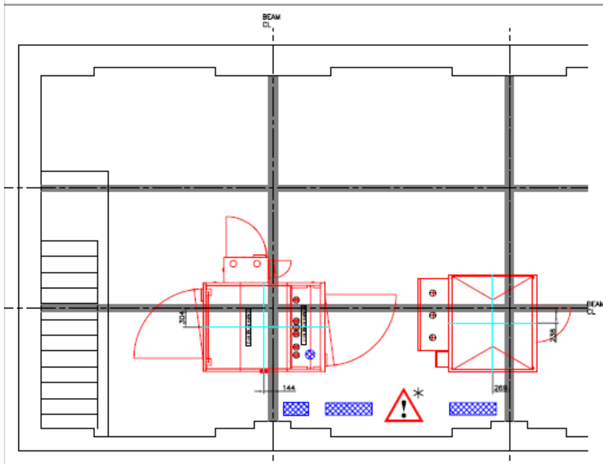
- New 6 panel switchboard installed.
- RSFCL connected in the interconnector A-C.
- Circuit breaker fail scheme installed:
    - FCL1 trips Interconnector E-A (250ms delay)
    - FCL2 trips Interconnector F-C (250ms delay)



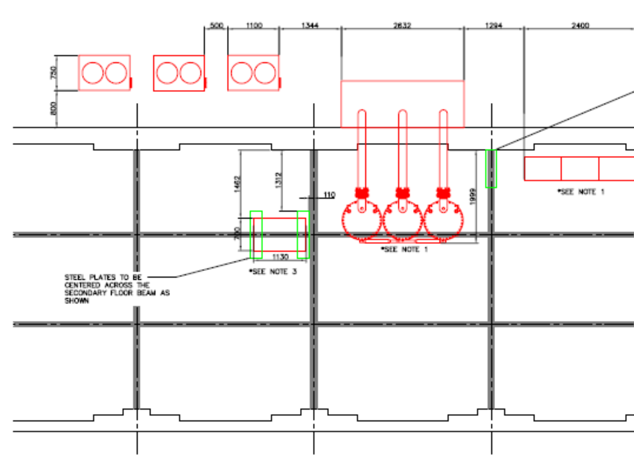
Bournville RSFCL Installation



OVERALL EQUIPMENT LAYOUT, FIRST FLOOR FCL AND FLM EQUIPMENT ROOM,
SCALE 1:50

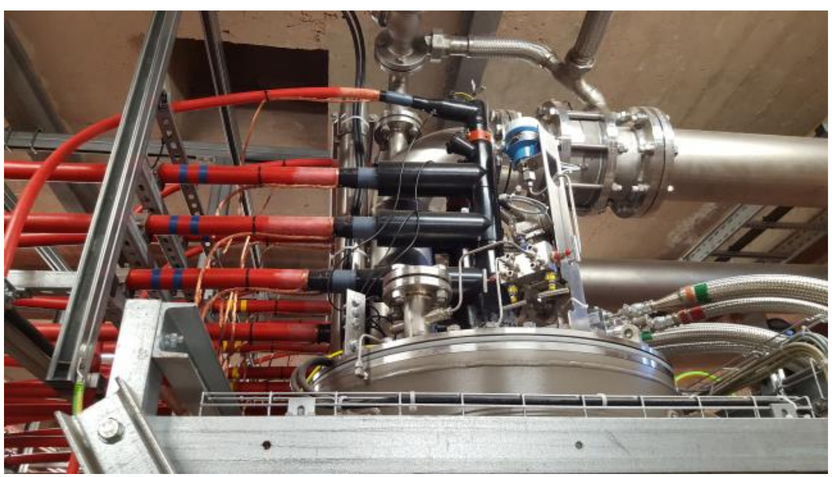


FLM LAYOUT, SCALE 1:30



FCL LAYOUT, SCALE 1:40

Bournville RSFCL Installation



Summary

- Overview of Method Gamma
- PSCFCL and RSFCL
  - Technology
  - Integration of FCL
  - Design of FCL

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions?

Break before FCL Operation and Learning

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

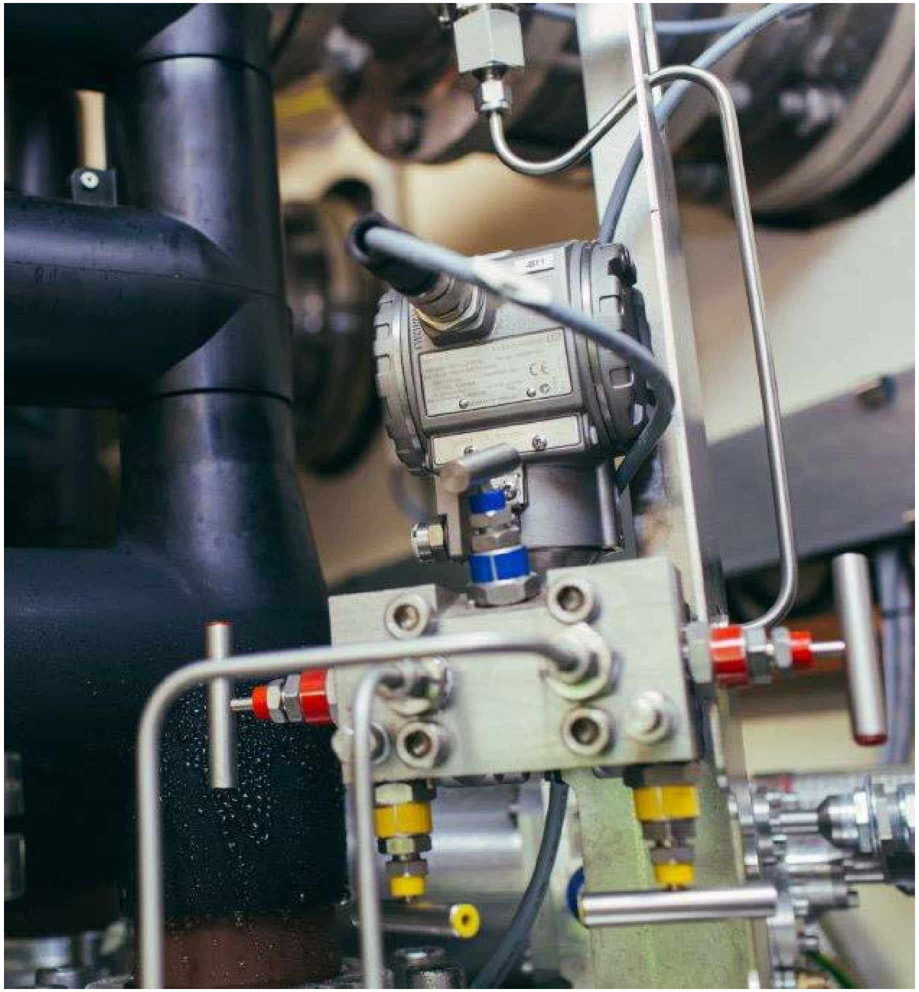
Fault Current Limiters

Learning: Technology Operation

LCN Fund Low Carbon Networks   THE UNIVERSITY OF WARWICK   PARSONS BRINCKERHOFF

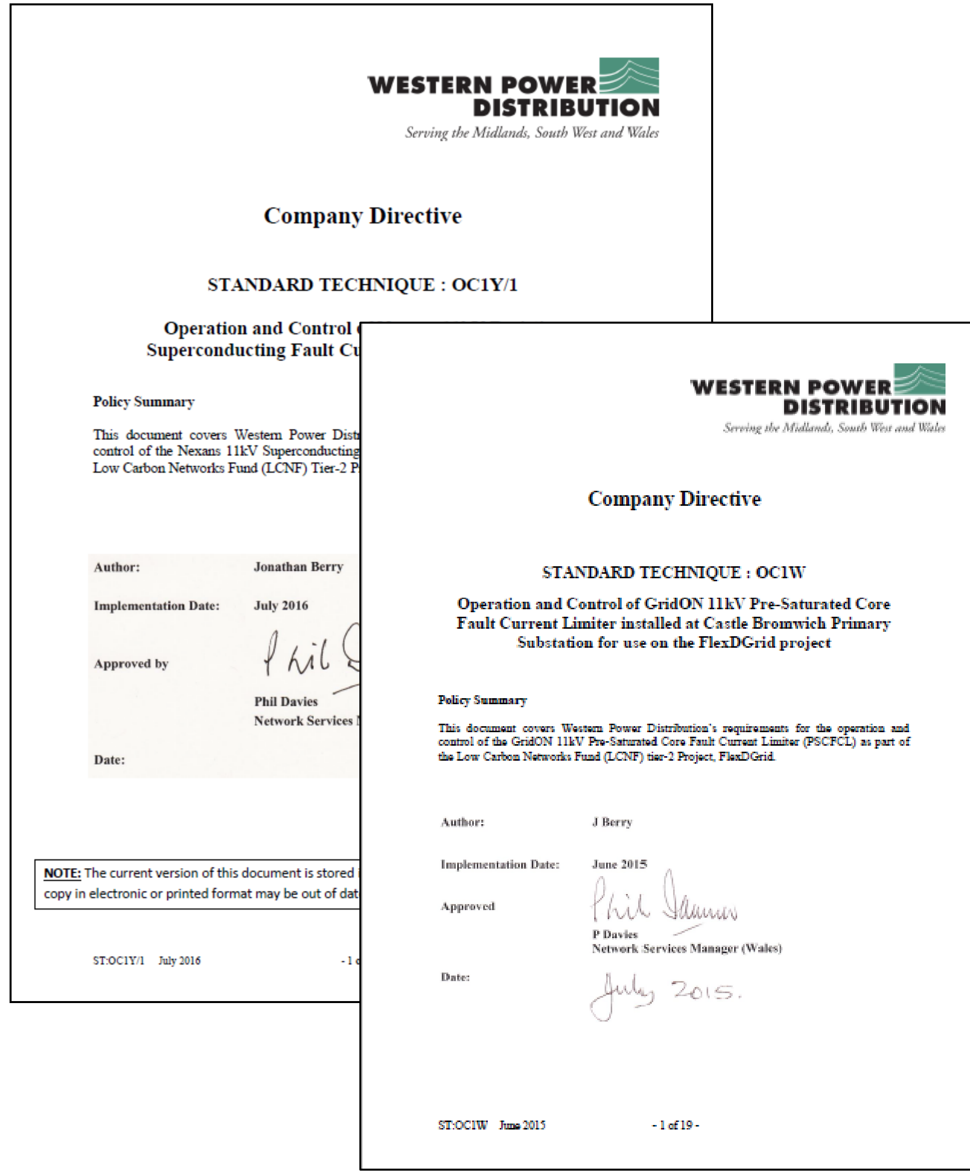
Introduction

- Policy documentation
- PSCFCL and RSFCL
  - — Fault level reduction
  - — Technology operation
  - — Learning points



Policy Documents

- Two documents for each technology:
  - Operation and Control
  - Inspection and Maintenance
- Contents derived from the design and installation process.



WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE : OC1Y/1

Operation and Control
Superconducting Fault Cu

Policy Summary

This document covers Western Power Dist
control of the Nexans 11kV Superconducting
Low Carbon Networks Fund (LCNF) Tier-2 P

Author: Jonathan Berry
Implementation Date: July 2016
Approved by
Phil Davies
Network Services
Date:

NOTE: The current version of this document is stored
copy in electronic or printed format may be out of dat

ST:OC1Y/1 July 2016 -1

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE : OC1W

Operation and Control of GridON 11kV Pre-Saturated Core Fault Current Limiter installed at Castle Bromwich Primary Substation for use on the FlexDGrid project

Policy Summary

This document covers Western Power Distribution's requirements for the operation and control of the GridON 11kV Pre-Saturated Core Fault Current Limiter (PSCFCL) as part of the Low Carbon Networks Fund (LCNF) tier-2 Project, FlexDGrid.

Author: J Berry
Implementation Date: June 2015
Approved
P Davies
Network Services Manager (Wales)
Date: July 2015.

ST:OC1W June 2015 - 1 of 19 -

Policy Documents

Operation and Control:

- Safety considerations
- System description
- Network connection options
- Initialising Sequence
- Energising
- Isolation
- Earthing
- Alarms and trips

Inspection and Maintenance:

- Inspection procedure
- Maintenance guidance
- Maintenance Intervals

3.2.2 The DC bias for the FCL is generated by 5 separate DC power supplies which can provide up to a total of 500A. The required DC bias at 30MVA is 365A and during an overload of 38MVA, 490A of DC bias is required. The DC bias has to be controlled to ensure that the fault limiting performance is not reduced (too high DC bias) whilst ensuring that the device impedance is not too high (too low DC bias).

3.3 General Arrangement

3.3.1 Figure 3-2 below shows the general arrangement of the FCL.

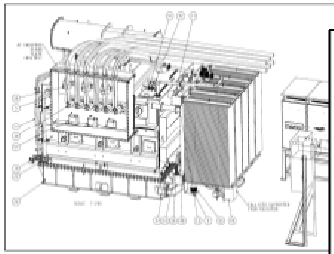


Figure 3-2: General Arrangement of FCL

3.3.2 There are two cubicles associated with the FCL. The AC cubicle is the sm which houses the Programme Logic Controller (PLC), Human Machine Int module, relays, FCL status monitor, condition monitor and auxiliary wiring. Th contains the DC power supplies used to create the DC bias for the FCL. The are supplied from a separate UPS system and battery located in the adjace Monitor equipment room.

3.3.3 The FCL is equipped with on-board radiators and a single fan providing ONAF cooling fan is controlled by the PLC which monitors the AC load current flo the FCL. The fan is switched on when the current in the FCL exceeds 1575A (fan switches off once the current drops below 1400A.

3.3.4 In addition to the standard devices found on a transformer, the FCL is also eq Calisto Dissolved Gas Analysis (DGA) device and a regenerative breather.

6.3 DC Supplies

6.3.1 Upon energisation of the auxiliary supply, the DC power supplies will begin a start-up sequence initiated by the PLC. This start-up sequence involves the DC power supplies ramping up from 0A to 490A, then settling back to the lowest DC current of 130A. This DC bias will ensure that the cores of the FCL are saturated.

6.3.2 When the PLC senses a change in the 11kV AC current (through the CTs in the 11kV cable box), the DC bias will be automatically adjusted to ensure that the AC impedance of the FCL is maintained within limits. Table 6-1 shows the target DC bias current against the 11kV AC current.

11kV AC Primary Current (A)	DC Bias Current (A)
0 – 400	130
401 – 800	220
801 – 1000	270
1001 – 1250	320
1251 – 1575	365
1576 – 2000	490

Table 6-1: 11kV AC current vs. DC Bias

6.4 FCL Initialising Sequence

6.4.1 Prior to energising the FCL on the 11kV network, the system must first of all run an initialising sequence. To perform this sequence the supply to the DC cubicle shall be switched on at the UPS, in turn energising the AC cubicle and the PLC. The PLC will then check all the alarm and trip signals and begin to power up the DC supplies. The initialising process lasts about 2 minutes and during this time the "System Initialise Alarm" will be present.

6.5 Isolation

6.5.1 For disconnection and isolation of the FCL the sequence shall be as follows:

- Close Bus-Section A-B – this will allow any load current to by-pass the FCL. Note that this will result in a short-term solid parallel of windings GT1A and GT1B
- Open Bus-Section U-V – this will break the parallel of GT1A and GT1B windings
- Open FCL circuit breakers – this will remove the FCL AC winding from the network. The DC bias current will still be present but will drop to 130A

6.5.2 After isolation, should there be a need to work on the FCL, the DC bias must be turned off. This is achieved by switching off the main LVAC supply from the UPS to the DC cubicle. Points of isolation can then be applied to the 11kV FCL circuit breakers and LVAC supply switch at the UPS. Section 6.7 details how to earth the FCL prior to carrying out work.

Fault Level Reduction

– Unfortunately(!), we have had no faults on the 11kV networks which have FCLs connected

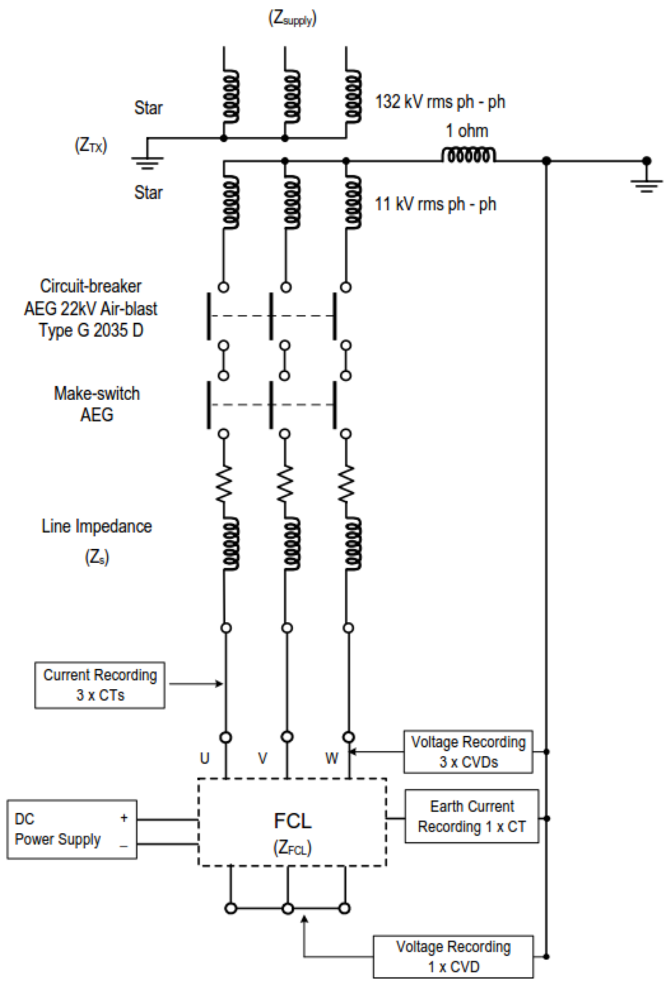
– However, thorough HV testing has demonstrated the performance of the FCLs

– The following slides explain the short circuit testing of the FCLs

Fault Level Reduction – GridON FCL

– Tested at Ausgrid's Testing & Certification Lab in Sydney
– FCL underwent several short circuit tests to determine the performance
– Testing was successful with the FCL meeting the requirements of the contract

Fault Level Reduction – GridON FCL



Fault Level Reduction – GridON FCL

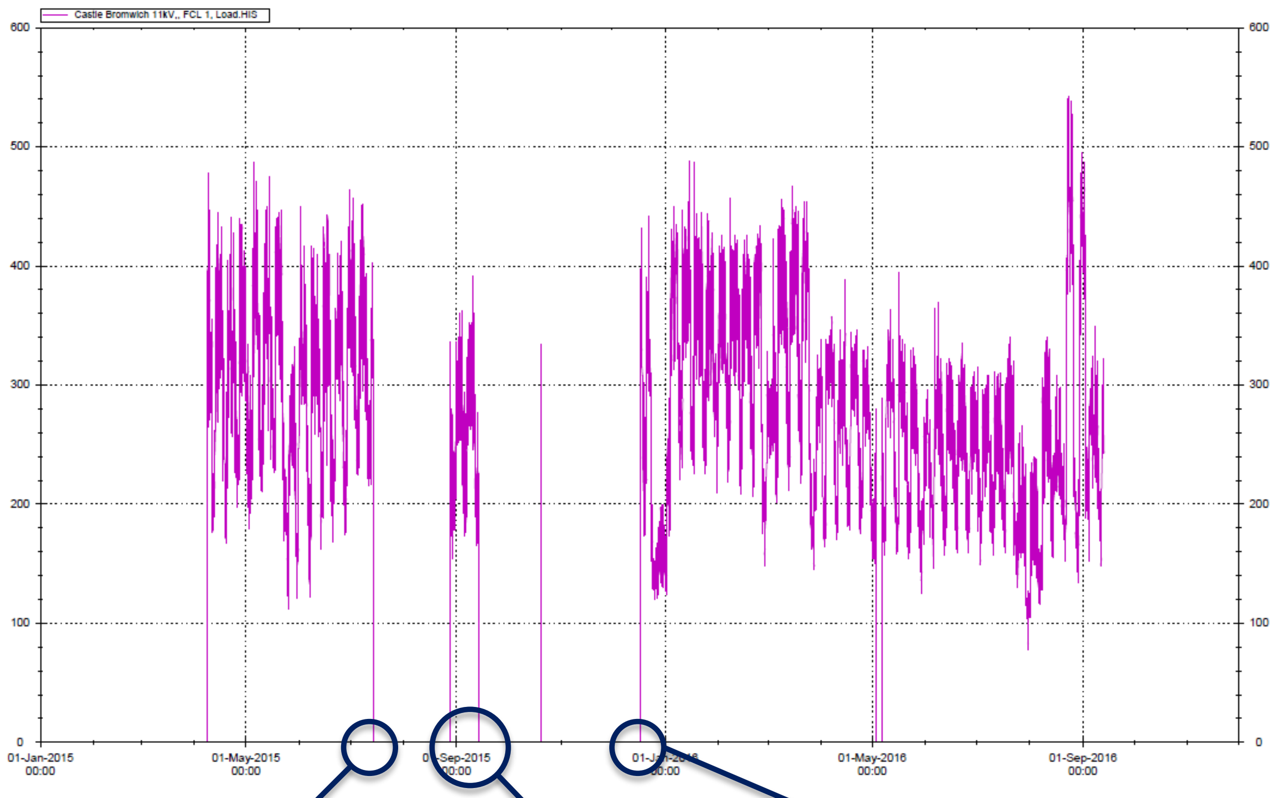
– Summary of short circuit tests are shown below:

Scenario	Prospective Current	Required Limitation	Actual Limitation
RMS Break (nom. DC Bias)	6.85kA	4.06kA	3.71kA
RMS Break (min. DC Bias)	6.85kA	4.06kA	3.75kA
Peak Make (nom. DC Bias)	20.2kA	10.16kA	10.13kA

Technology Operation

Milestone	Date
Device build complete	11th July 2014
Successful SC testing at TCA, Sydney	15th August 2014
Successful Type Tests, Glen Waverley	6th September 2014
Device delivered to Castle Bromwich	10th December 2014
Device Energised	8th April 2015

Technology Operation



Investigation of DC Alarm (14 July)

Energisation (28 Aug) after investigation and subsequent trip (14 Sept)

Device re-energised (17 Dec)

Technology Operation – GridON FCL

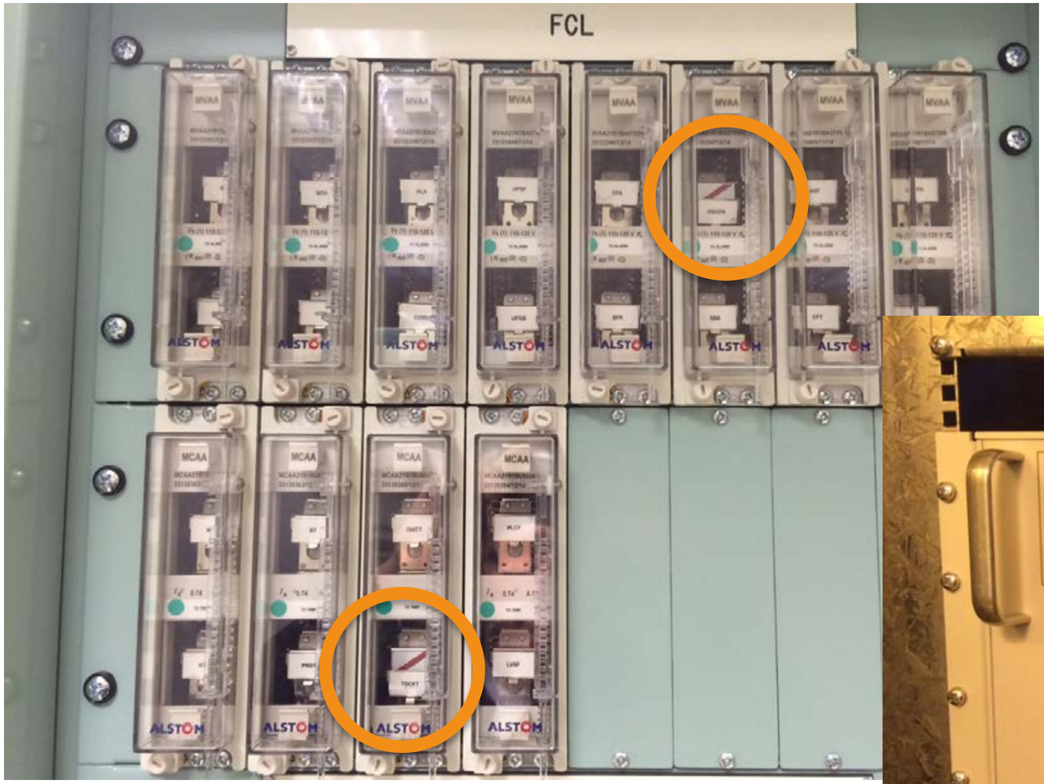
– Initial alarm received for “One DC Supply Failed”, FCL switched off for GridON investigation

– Investigation found the DC supplies to be operating correctly

– Other tests were taken and the decision was made to re-energise the FCL

– Device tripped “Two DC Supplies Failed” approximately 2 weeks later

Technology Operation – GridON FCL



Technology Operation – GridON FCL

- GridON carried out a full investigation after the FCL tripped
- It was found that the DC sensing circuit was capturing “0A” even though they were supplying the minimum bias current (130A)
- The DC sensor and circuit were re-designed and the FCL was re-energised on 17 December 2015

Learning – GridON FCL

Changes in Design

The initial design from GridON agreed during contract:

- 5.4x4.2x5.0m (LxWxH)
- 161 Tonnes

During the detailed design phase the device footprint and weight increased to:

- 6.4x4.6x5.4m (LxWxH)
- 168 Tonnes

An extra 20% allowance had been made during WPD design

Learning – GridON FCL

Magnetic Shield

Contract stated that magnetic field outside of the enclosure had to be kept below 5mT

- Design produced required further structural calculations
- Installation of one shield wall after FCL installation
- Shield had to be covered to protect sharp edges

Carefully consider installation of shield in overall design

Learning – GridON FCL

Short circuit testing

Witnessing of short circuit testing revealed issues with high magnetic field during faults:

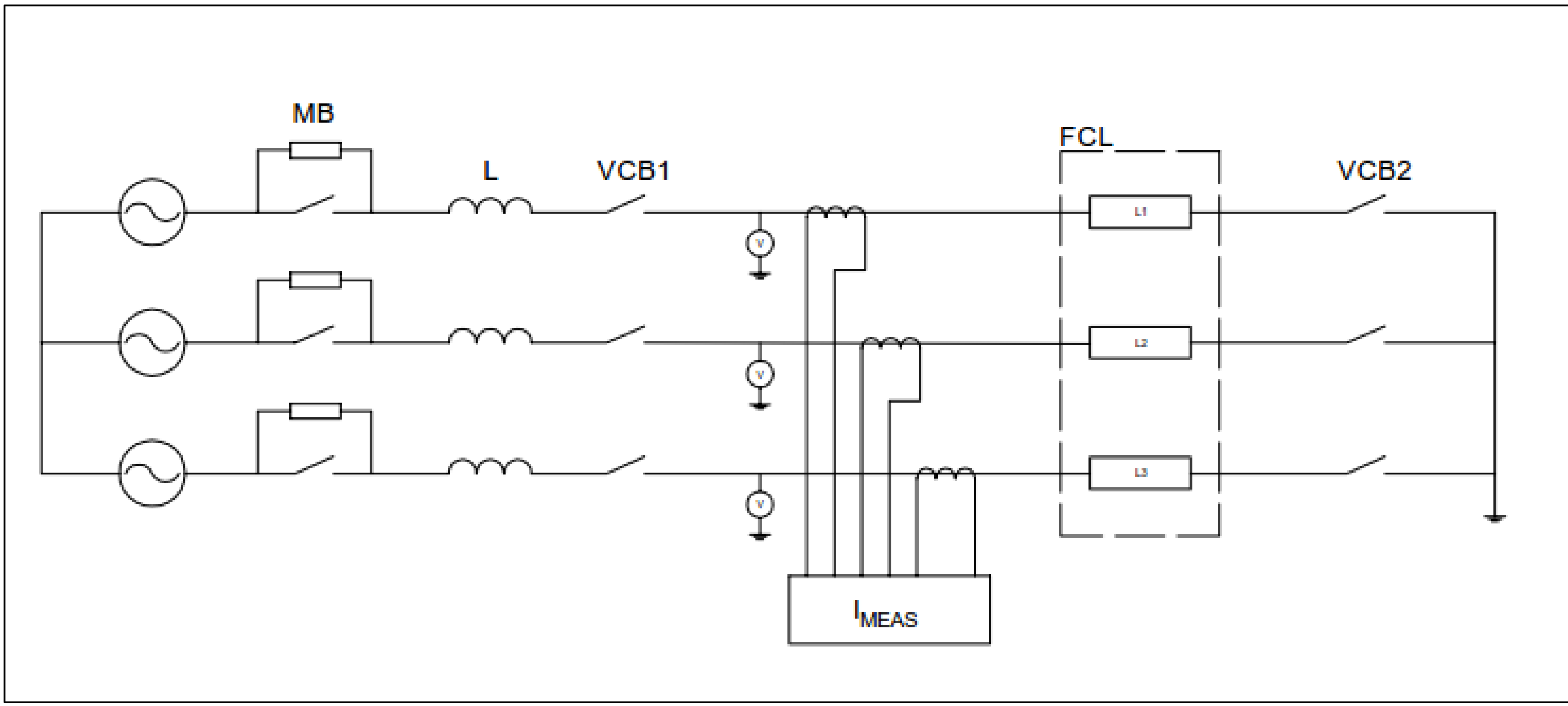
- Operation of buchholz relay
- Alarm from de-hydrating breather
- Alarm from Calisto Gas Monitor

These issues were rectified before final testing so that the performance onsite was not affected

Testing – Nexans RSFCL

- Tested at KEMA's Testing Lab in Arnhem, Netherlands
- FCL underwent several short circuit tests to determine the performance
- Testing was successful with the FCL meeting the requirements of the contract

Testing– Nexans RSFCL



Testing Performance – Short Circuit Current Limitation

- Peak prospective current set to above >19.76kA.
- Applied to Phase L3.
- Applied to Phase L1.
- Peak prospective current limited to <9.90kA
- Break current limited to <3.0kA (3.68kA)

Short-circuit current limitation tests								
Test no.			151005 4008	151005 4009	151005 4010	151005 4011	151005 4012	
	L1	kV	-	-	6,5	6,5	6,5	
Applied voltage, phase value	L2	kV	-	-	6,6	6,6	6,6	
	L3	kV	-	-	6,6	6,6	6,6	
Applied voltage, line value		kV	-	-	11,4	11,4	11,4	
	L1	kA	14,2	14,2	10,4	10,2	9,14	
Peak value of current	L2	kA	16,1	16,1	9,22	9,07	9,85	
	L3	kA	-20,0	-20,0	-9,07	-9,11	-8,50	
	L1	kA	7,13	7,12	2,81	2,83	2,87	
Symmetrical current, end	L2	kA	7,13	7,13	2,96	2,95	2,90	
	L3	kA	7,17	7,17	2,86	2,83	2,99	
Average curr. end, three phase		kA	7,14	7,14	2,88	2,87	2,92	
	L1	ms	100	100	98,8	98,8	98,4	
Current duration	L2	ms	100	100	103	103	103	
	L3	ms	96,8	96,9	103	103	103	
Trip signal after fault inception		ms	-	-	24	15	15	

Remarks	
151005-4008	Checking of the prospective current.
151005-4009	Checking of the prospective current.
151005-4010	Before test the SFCL was set to recool after limitation. Maximum prospective peak current was applied in phase L3. No visible disturbance.
151005-4011	Before test the protection device of the SFCL was adapted. Before test the SFCL was set to blow off nitrogen after limitation. Maximum prospective peak current was applied in phase L3. Slight emission of nitrogen gas after the test.
151005-4012	The SFCL was set to blow off nitrogen after limitation. Maximum prospective peak current was applied in phase L1. Moderate emission of nitrogen gas after the test.

Testing Performance – Short Circuit Withstand

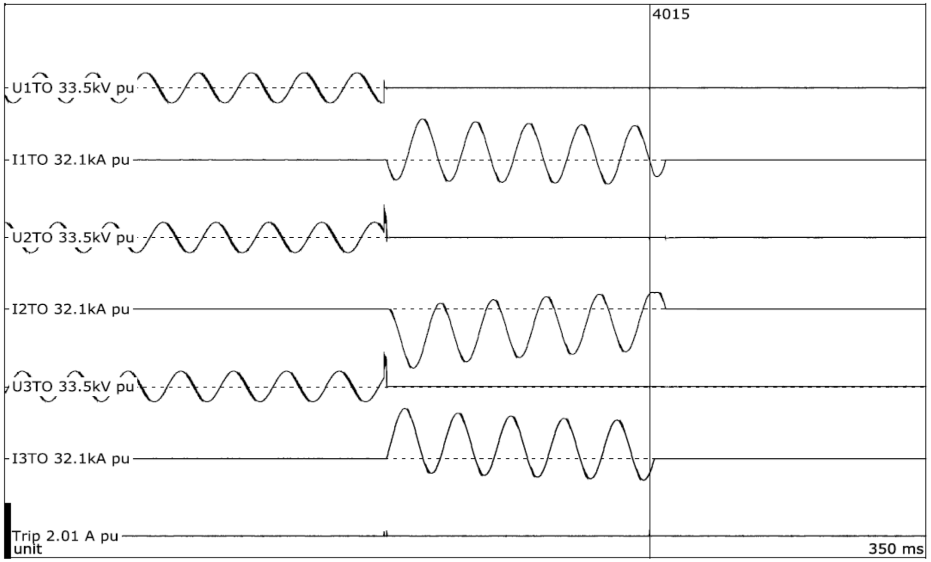
- Peak prospective current set to above >33.4kA.
- Applied to Phase L2.
- Peak prospective current limited to 9.59kA.

Short-circuit current limitation test								
Test no.			151005 4014	151005 4015	151005 4016			
	L1	kV	-	-	6,5			
Applied voltage, phase value	L2	kV	-	-	6,5			
	L3	kV	-	-	6,5			
Applied voltage, line value		kV	-	-	11,3			
	L1	kA	22,9	23,6	-9,47			
Peak value of current	L2	kA	-34,2	-34,2	-9,59			
	L3	kA	29,7	28,9	10,6			
	L1	kA	12,0	12,0	2,98			
Symmetrical current, end	L2	kA	12,1	12,1	3,02			
	L3	kA	12,2	12,1	2,93			
Average curr. end, three phase		kA	12,1	12,1	2,98			
	L1	ms	106	106	107			
Current duration	L2	ms	106	106	103			
	L3	ms	102	102	107			
Trip signal after fault inception		ms	-	-	12			

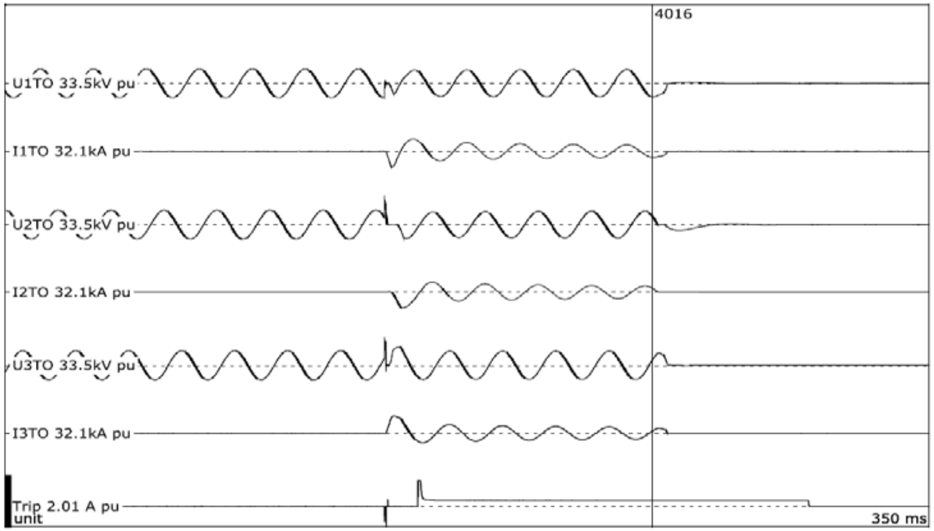
Remarks	
151005-4014	Checking of the prospective current.
151005-4015	Checking of the prospective current.
151005-4016	The SFCL was set to blow off nitrogen after limitation. Maximum prospective peak current was applied in phase L2. Moderate emission of nitrogen gas after the test.

FCLs - Operation

Short-circuit current limitation test



Short-circuit current limitation test



Testing Summary

Chester Street

Prospective Current (@10ms) (kA)	Prospective Current (@90ms) (kA)	Applied Phase	Required Limitation (@10ms) (kA)	Required Limitation (@90ms) (kA)	Limited Current (@10ms) (kA)	Limited Current (@90ms) (kA)	Trip Signal (ms)
20.0	7.17	L3	9.90	3.68	9.07	2.86	24.0
20.0	7.17	L3	9.90	3.68	9.11	2.83	15.0
20.0	7.17	L1	9.90	3.68	9.14	2.87	15.0

Bournville

Prospective Current (@10ms) (kA)	Prospective Current (@90ms) (kA)	Applied Phase	Required Limitation (@10ms) (kA)	Required Limitation (@90ms) (kA)	Limited Current (@10ms) (kA)	Limited Current (@90ms) (kA)	Trip Signal (ms)
22.5	8.0	L1	7.70	3.05	6.64	2.05	13.3
22.5	8.0	L2	7.70	3.05	6.56	2.03	13.6
22.5	8.0	L3	7.70	3.05	6.43	1.98	13.6

Safety Considerations

- Pressure relief valves:
  - Electromechanical
  - Mechanical (>2.5 bar)
  - PRD (>5bar)
- Bund for safe containment of liquid nitrogen
- Oxygen sensor for detection of low oxygen levels
- Access/Egress
- Policy documentation

Operation Overview

- No 11kV network faults!

However, issues with the cooling systems:

- Chester Street FCL currently unavailable.
- Bournville FCL currently unavailable.

- Manufacturer is currently working to fix cooling system issues.

Learning – Issues with Cooling System

- Chester Street FAT (18-20th May 2015).
- Cooling system was unable to regulate the temperature of the LN_2 to the required set-point.
- The temperature was rising slowly and would have eventually led to a quench event.

Caused By:

- Higher than expected electrical losses due to eddy currents.
- Air leak into the cryostat vessels through safety valve under sub-atmospheric pressure conditions.

Solution:

- Device rating reduced - 1300A continuous operation, 1600A for 5 hours maximum.
- Replace 3 off safety valves with single electronic valve with correct rating.

Detailed cooling system calculations required in future with adequate margin applied.

Learning – Issues with Cooling System

- First time with cooling system in sustained operation.

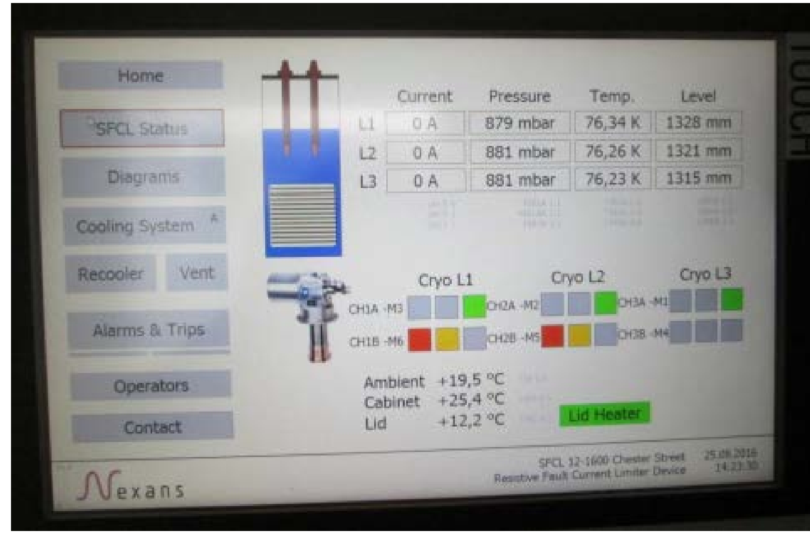
A number of recooler faults at both Chester Street and Bournville:

- Damaged pipework during commissioning.
- Water level dropping below the trip level.
- Air intake becoming clogged with debris leading to inadequate air flow.

A number of issues with the compressor components:

- Minor helium leak due to loose connections.
- Water leak at the connection.
- Power supply failures.

Learning – Issues with Cooling System



<u>Works required at Chester Street to fix the cooling system issues:</u>

- Recooler M9 has an undiagnosed fault (overheating and low cooling water level). The manufacturer is organising an investigation by a specialist company.
- With M9 switched off the cooling capability of the device is limited. Decision taken to keep the FCL disconnected.
- The first scheduled maintenance for the recoolers is due in September.

<u>Works required at Bournville to fix the cooling system issues:</u>

- M5 compressor unit power supply has failed and requires replacement.
- Investigate root cause of why compressors M3 and M6 were not operational.
- Repair a water leak to compressor M5.
- Refill Nitrogen level.

Learning – Enclosure

Advantages:

- Majority of components pre-installed.
- Control system wiring pre-installed.
- Easier for testing.
- Less pipework.

Disadvantages:

- Significant additional weight (approx. 29t)
- Logistics to transport and offload.

Conclusion:

- Minimal improvements required to the design.
- Larger enclosure to allow better access for cable termination.
- Preferred solution to the alternative of installing the device in an existing building, provided that there is sufficient space in the substation compound.

Summary

- Policy documentation
- PSCFCL and RSFCL
  - Fault level reduction
  - Technology operation
  - Learning points

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions?

Lunch followed by site visits

LCN Fund Low Carbon Networks · THE UNIVERSITY OF WARWICK · PARSONS BRINCKERHOFF