WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Technical Dissemination

Wednesday 26th April 2017

Holiday Inn - Birmingham

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Housekeeping

Agenda

Agenda	
09.30 – 10.00	Arrival and Tea & Coffee
10.00 – 10.15	Welcome and Introduction
10.15 – 10:45	Modelling: Development and Outputs
10:45 – 11.15	FLMs: Design and Implementation
11.15 – 11:30	**Coffee Break**
11:30 – 12.30	FCLs: Design and Implementation
12.30 – 13.30	**Lunch**
13:30 – 14:30	FLMs: Enhancing Modelling Practices and Alternative Connections
14:30 – 14:45	**Coffee Break**
14:45 – 15:45	FCLs: Operation and Benefit
15:45 – 16:00	Next Steps and Close

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 – Methods

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

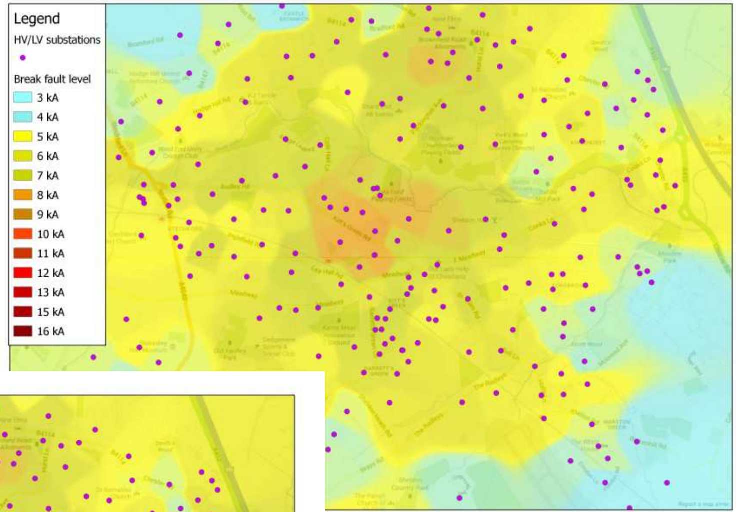
Management

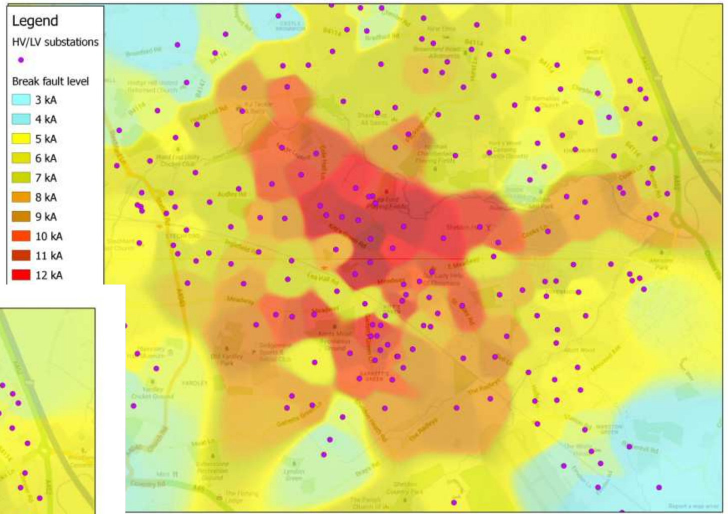
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

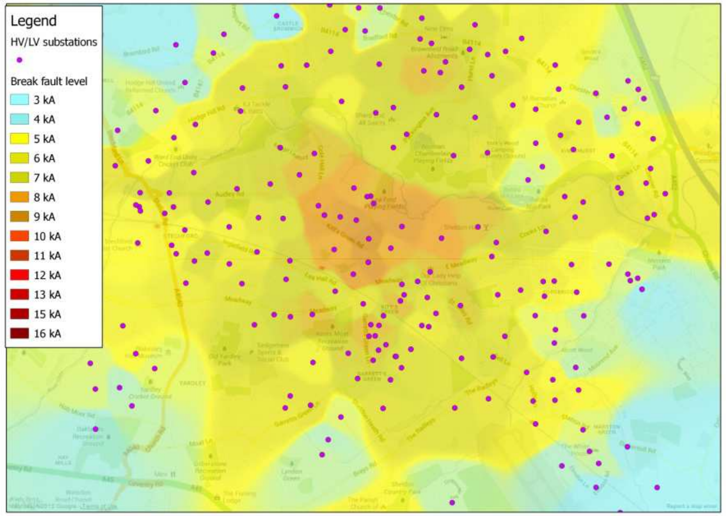
Mitigation

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

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

Technical Dissemination

Modelling: Development and Outputs

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

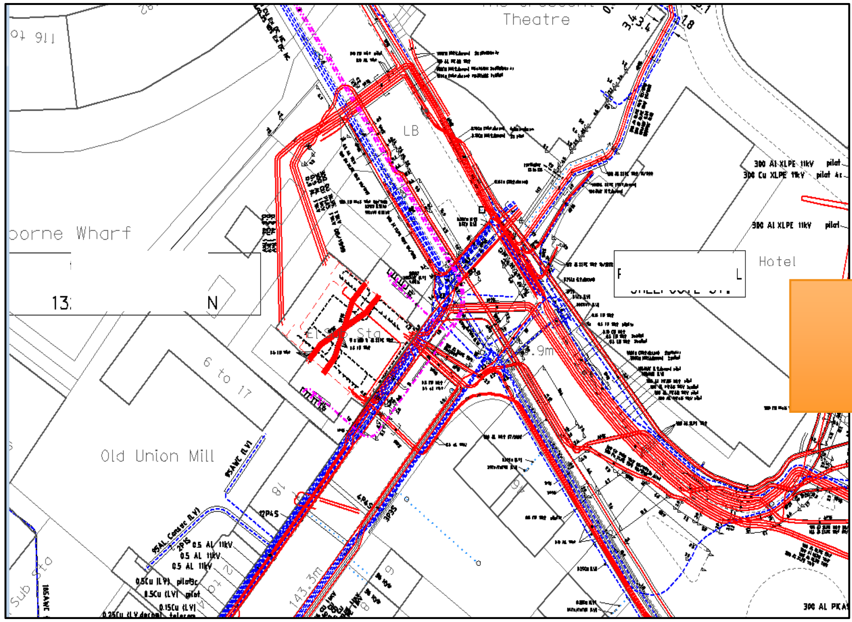
Method Alpha - Introduction

- Developed the central Birmingham HV electricity computer model
- Evaluate fault level analysis assumptions and carried out a sensitivity analysis of network modelling parameters;
- Developed tools and methodologies for an enhanced fault level calculations
- Developed fit-for-purpose tools and computer models for assessing the impact of FCLs on network fault levels

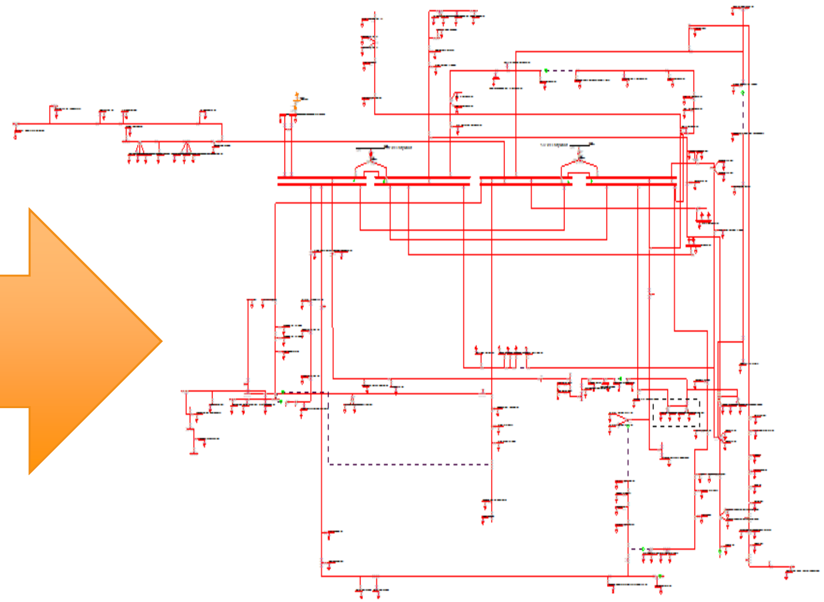
Modelling HV network

- HV network models (PSS/E platform): Network topology, circuit impedances, busbar configuration, generators data and demand at secondary substations.
- Integration into WPD EHV model – a complete model from GSP to Secondary Substations.
- Developed a methodology and automation tools for modelling HV networks using BaU databases
- PSS/E models of HV networks of 15 primary substations: 3,041 secondary substations and 1,878 km HV circuits

HV networks topology – EMU to PSSE

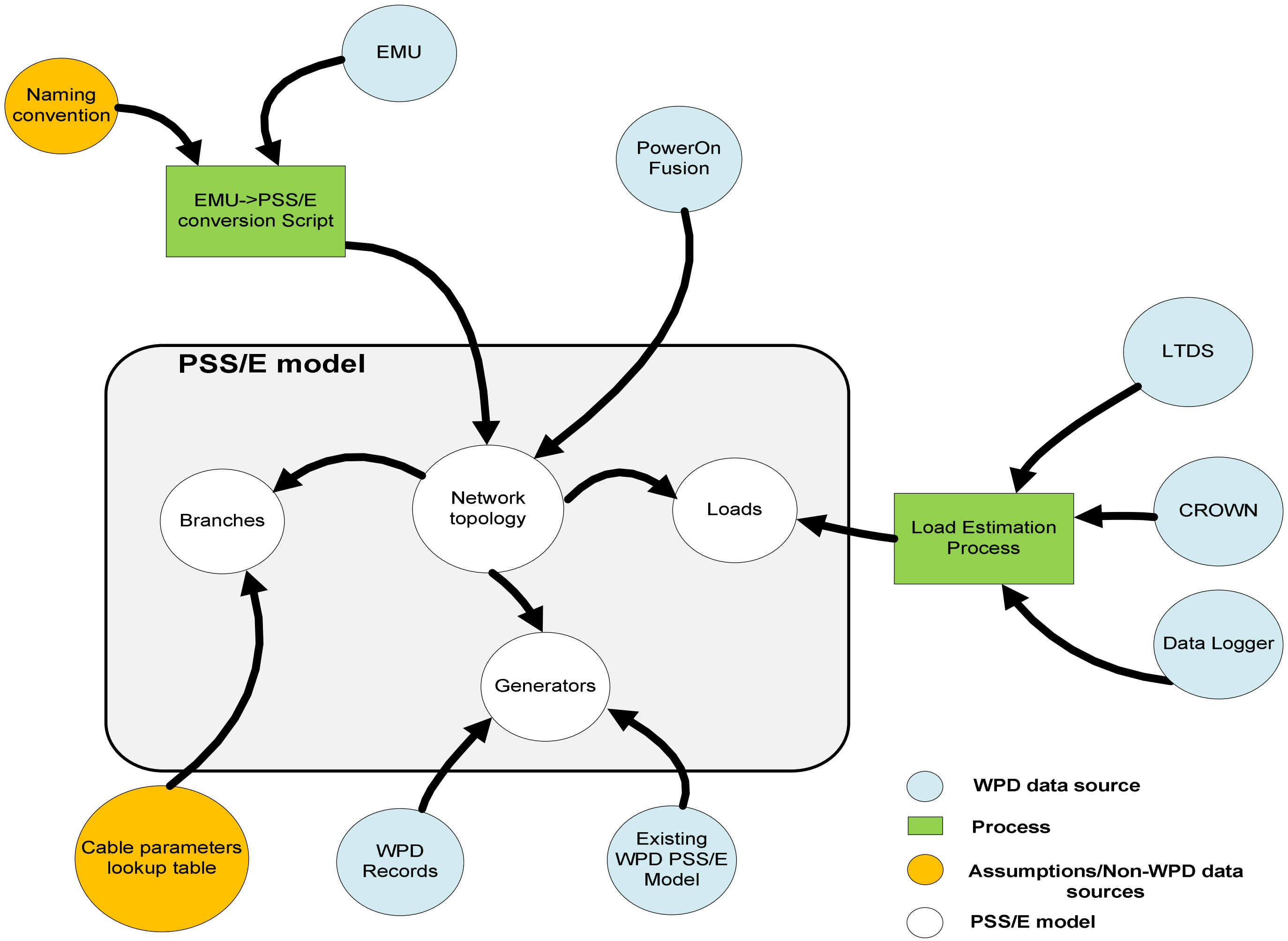


EMU

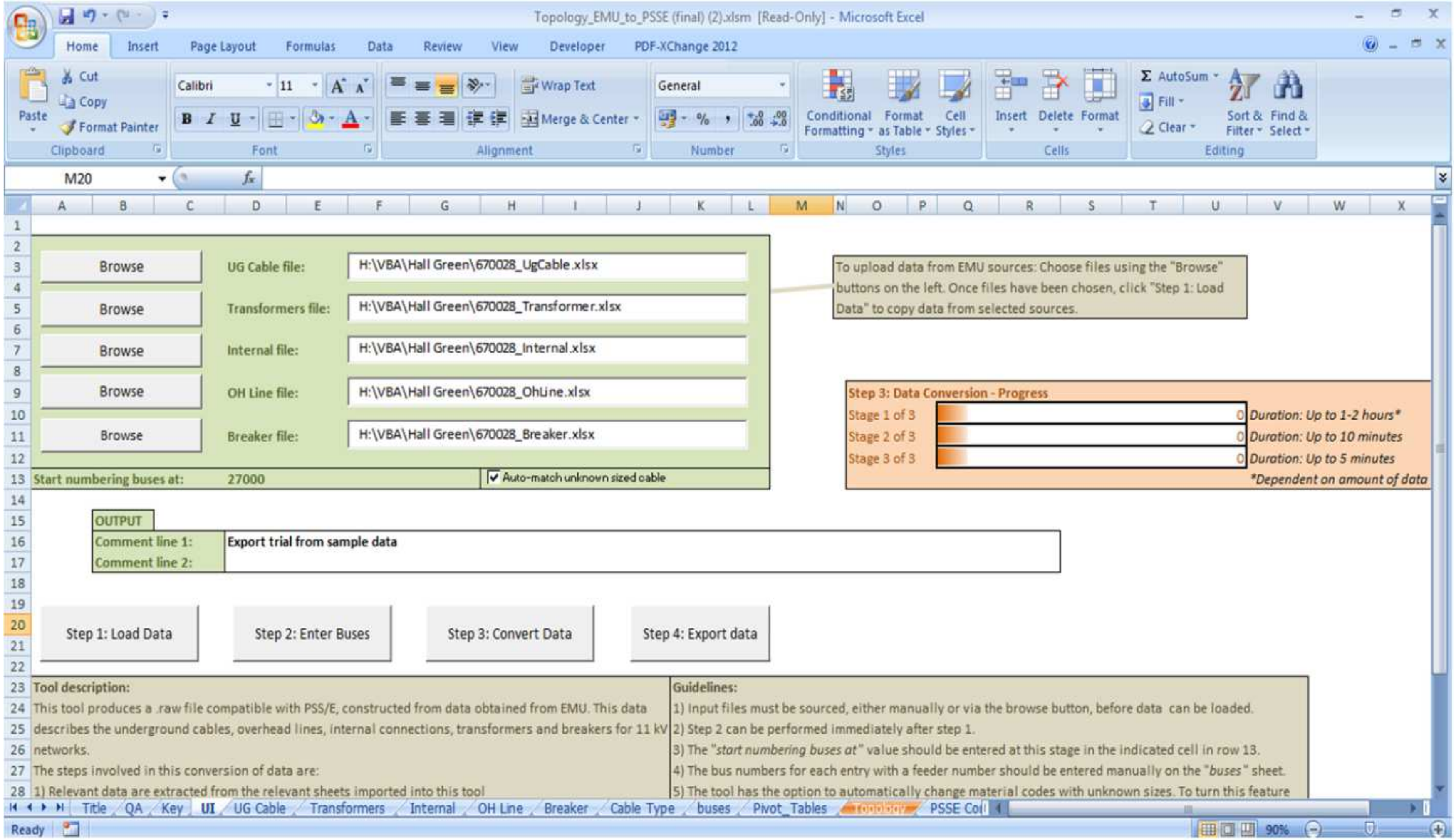


PSS/E

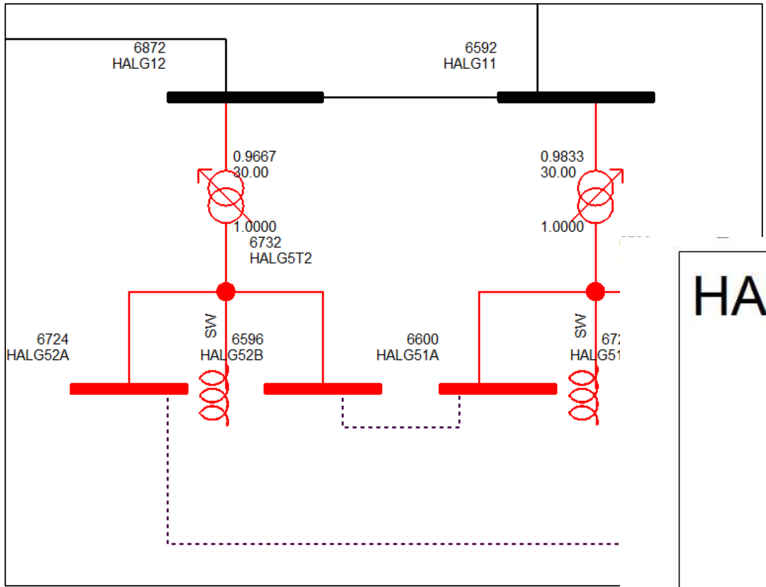
HV networks modelling methodology

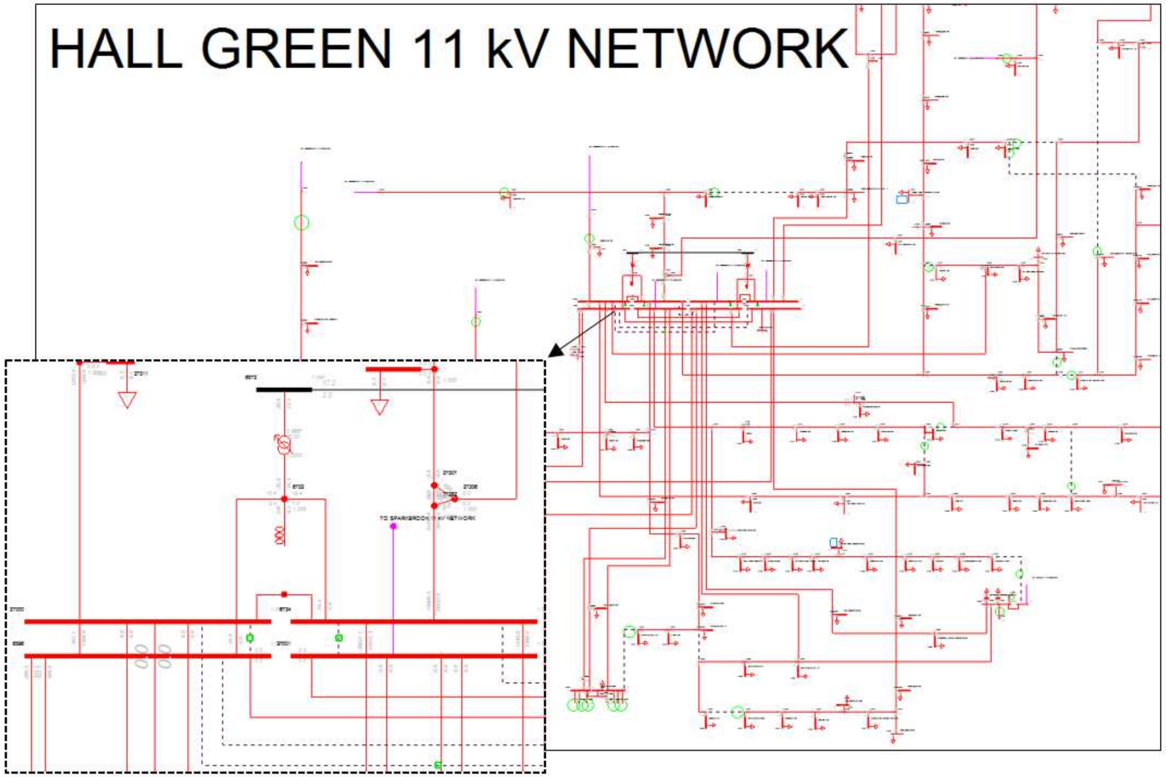


Automation Tool

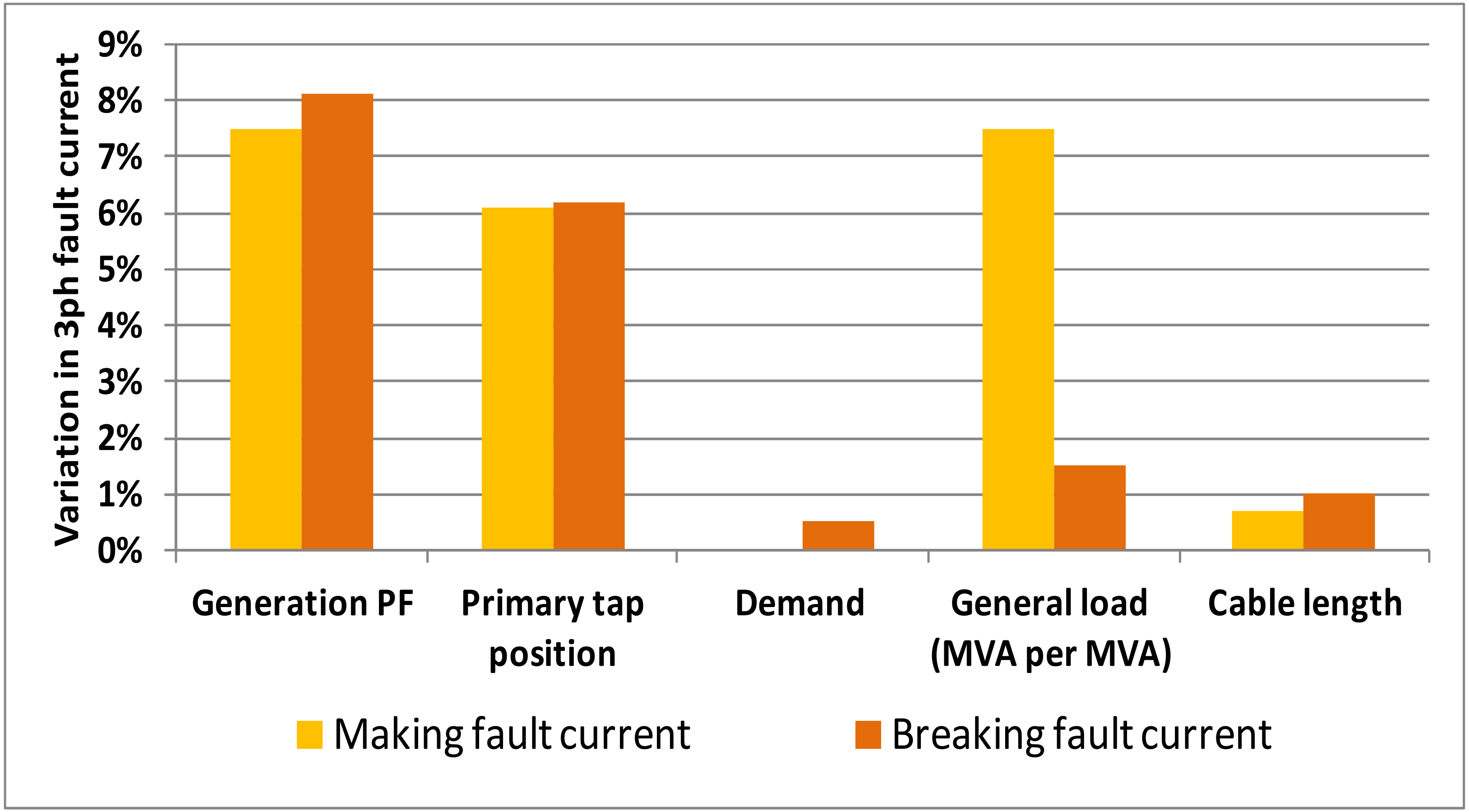


HV network modelling – integration into EHV model

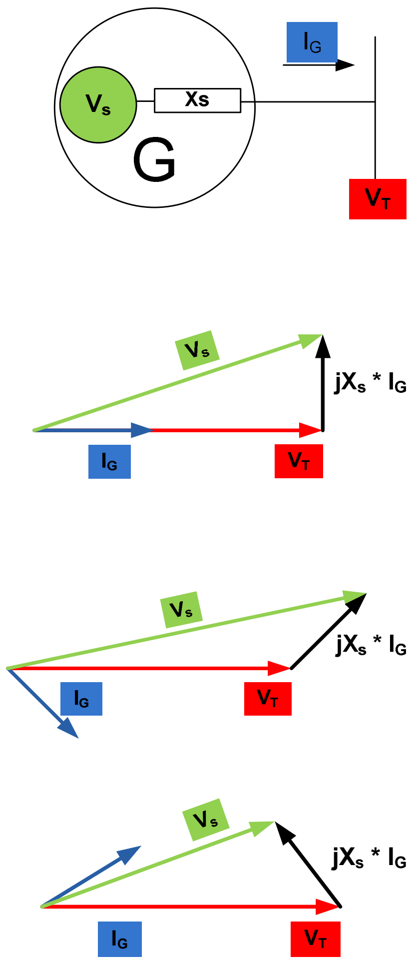


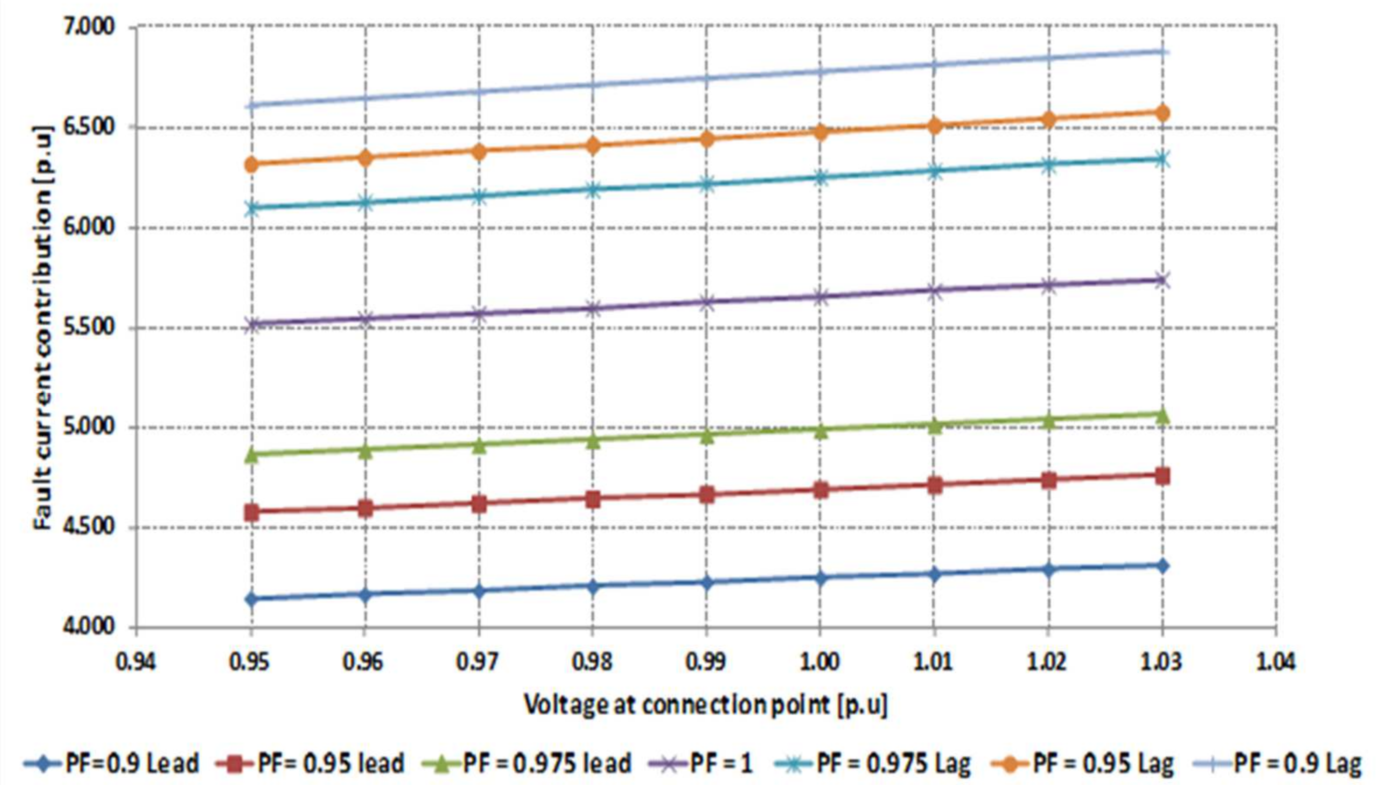


Fault level sensitivity analysis



Fault level sensitivity analysis – Generator PF





Tools for Fault level analysis

Fault Level Guidance Tool

- Provide a fault level assessment platform for WPD planning engineers who may not have access to power system analysis software for connection studies as part of the G59 generation application process.
- Reduce the time and effort that is spent on data gathering and network modelling for connection studies.

Fault Level Guidance Tool

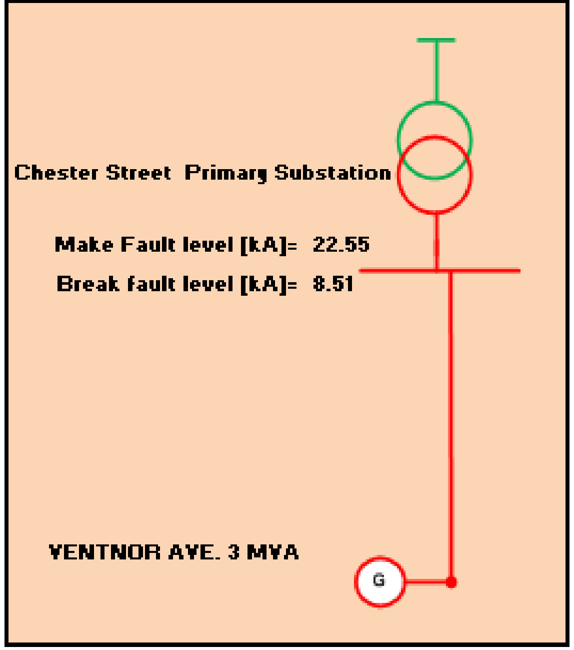
Fault level estimation – Generation Connection

Primary Substation Name	Chester Street		
Connection point / Site Number	VENTNOR AVE.	724142	
Voltage [kV]	11		
		Make [kA]	**Break [kA]**
Switchgear ratings	@ Chester Street	32.8	11.4
	@ VENTNOR AVE.	33.4	13.1
		Make [kA]	**Break [kA]**
Fault levels before connection	@ Chester Street	21.4	7.8
	@ VENTNOR AVE.	20.49	10.44
		R [ohm]	**X [ohm]**
Equivalent impedance from VENTNOR AVE. to CHESTER STREET primar		0.209	0.118
Generator	**Generator rating [MVA]**	3.0	
	Transient reactance [p.u]	0.22	
	Sub-transient reactance [p.u]	0.19	
	Transient reactance [ohm]	8.9	
	Sub-transient reactance [ohm]	7.7	
		Make [kA]	**Break [kA]**
Generation fault current contribution	@ Chester Street	1.15	0.71
	@ VENTNOR AVE.	1.17	0.83
		Make [kA]	**Break [kA]**
Fault level after connection	@ Chester Street	22.55	8.51
	@ VENTNOR AVE.	21.67	11.26
Issued by	Name		
Date	02 March 2014		

Base Units	
Base power [MVA]	100
Base voltage [kV]	11
Base current [kA]	5.25
Base impedance [Ohm]	1.21

Read Fault Level Report

Generation connection @ VENTNOR AVE.



Email the results (*.pdf)

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions?

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Technical Dissemination

FLMs: Design and Implementation

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

Introduction

- Overview of Method Beta
- FLM Integration Options
- Site Selection Process
- FLM Technology
- Site Installation

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

FlexDGrid – Method Beta Overview

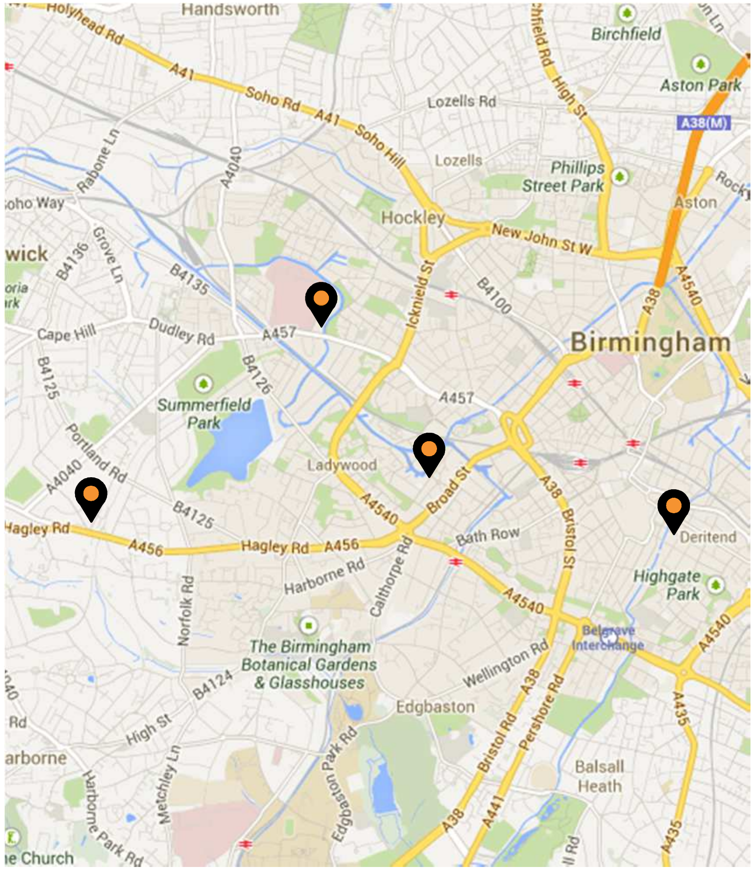
- Method Beta: Fault Level Measurement Technology
  - Build on knowledge learned through previous Projects
  - Install an FLM technology in 10 separate WPD substations
  - Use results from trials to inform changes to modeling policy (Method Alpha)
  - Customer control based on Fault Level Contribution

FLM Integration Options

– Initial stage of FlexDGrid identified four integration options for FLMs:
  - Existing Spare breaker
  - Two panel board from spare legacy breaker
  - 3 panel board moving existing open point
  - Board extension

Site Selection

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



Sites Selected for FLM Installation

Substation	
Castle Bromwich 132/11kV	Hall Green 132/11kV
Chester Street 132/11kV	Elmdon 132/11kV
Bournville 132/11kV	Chad Valley 132/11kV
Kitts Green 132/11kV	Shirley 132/11kV
Bartley Green 132/11kV	Nechells West 132/11kV

FLM Technology

S&C ELECTRIC COMPANY
Excellence Through Innovation

nortech

Outram Research Limited

HVR INTERNATIONAL

Active Fault Level Monitor

- Developed as part of the Tier 1 LCNF Project “Active Fault Level Monitor”
- The device comprises
  - S&C IntelliRupter PulseCloser
  - Outram Research PM7000
  - Nortech Envoy
  - HVR Resistor Bank

S&C IntelliRupter PulseCloser

Operation Principle

- Device originally designed to test a three phase network before a permanent re-close.
- Application modified to close a phase and then pulse another phase placing a 4ms phase to phase fault on the 11kV network.
- Operation occurs at 100ms apart on the peak and trough of the fully closed phase current wave

Outram Research PM7000

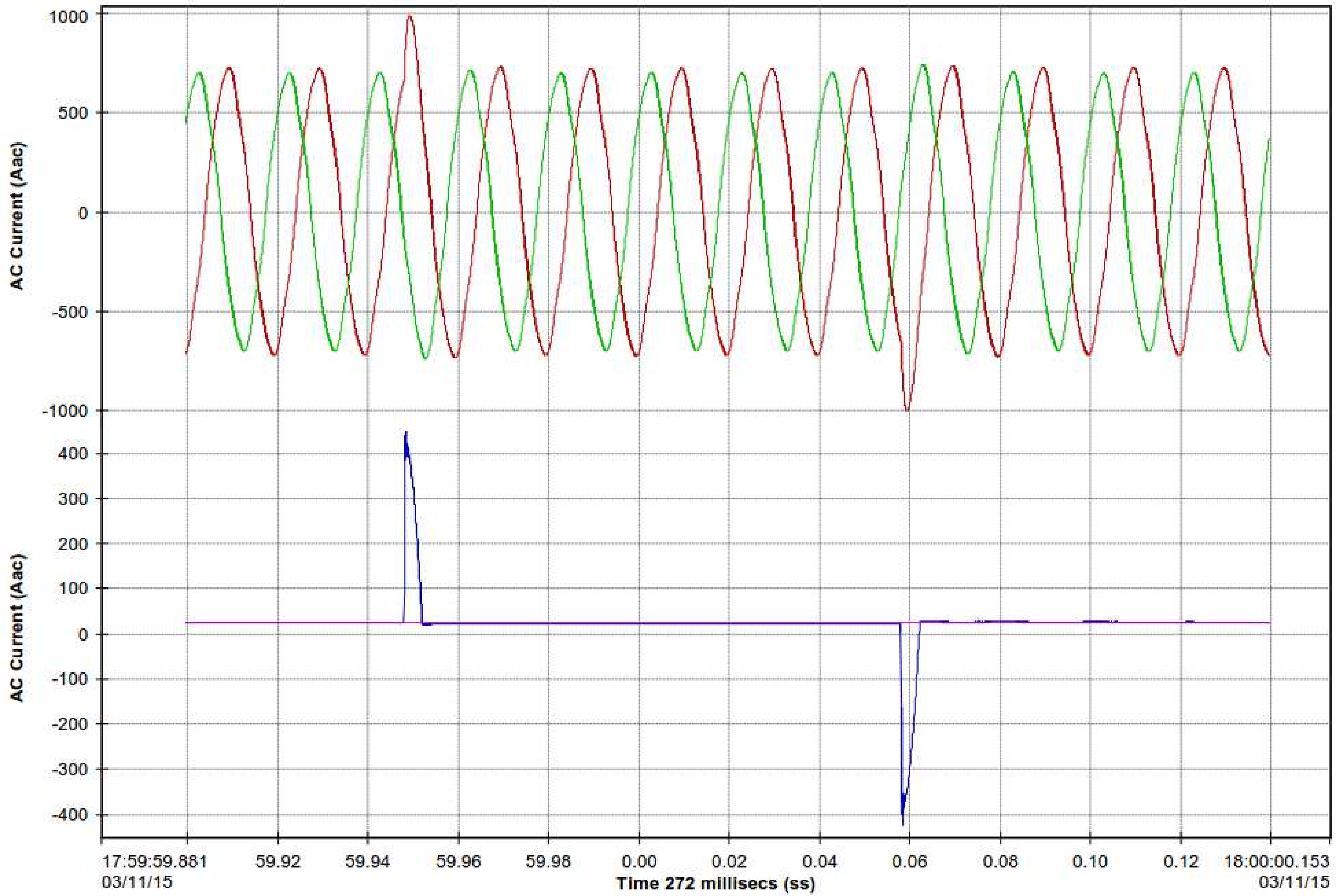
PM7000 Operations

- Three PM7000's used in the FlexDGrid FLM
- Dual Path device for calculating Total Fault Level and Upstream Fault Level Contribution
- Natural Combined device for determining upstream contribution for parallel transformers
- Parallel Detection device measures circulating current to determine if two networks are operating in parallel

Dual Path PM7000 FLM

- Device uses voltage and current input from transformer breaker and FLM feeder breaker
- Monitors Red and Blue Phases
- Measures the disturbance on both to estimate total 11kV fault level and upstream (through Primary Transformer) contribution to the fault level

Dual Path PM7000 FLM Waveform

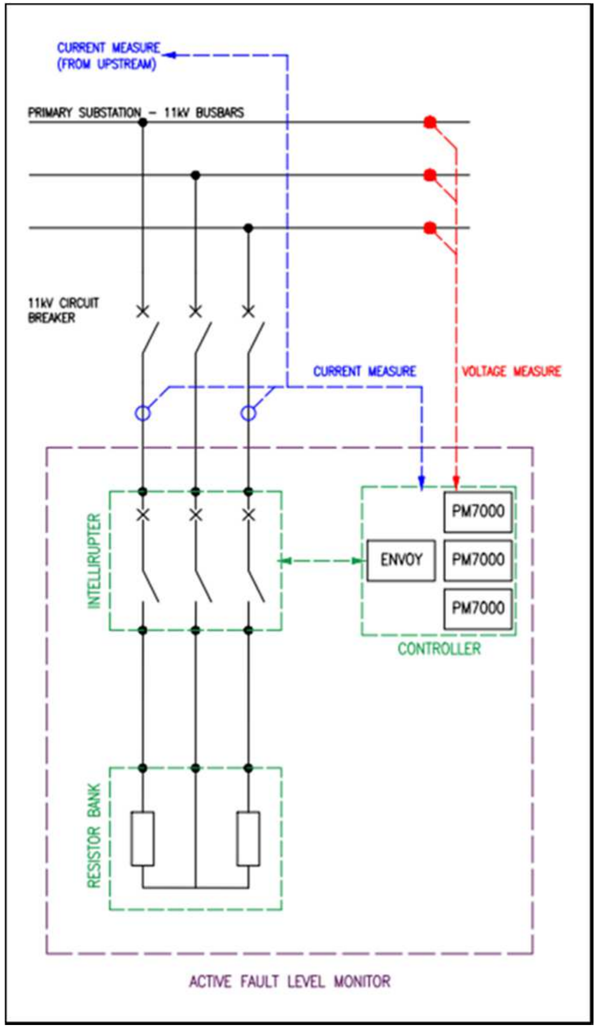


Nortech Envoy

Envoy

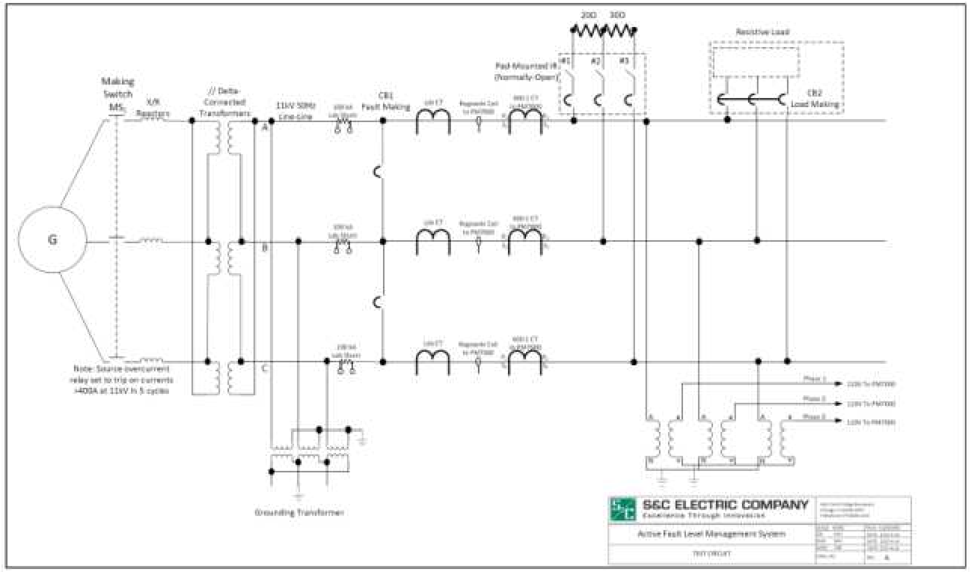
- Responsible for control of FLM operation and collection/transmission of data
- Pre-programmed schedule for operation of FLM (3 or 6 hour interval)
- PM7000 data and operation history stored in iHost for remote download and analysis
- Real time data available in NMS
- Control Engineer can trigger an operation at any time through the standard NMS interface

Single Line Diagram of the FLM



Testing – Chicago May 2015

- Fault Level Prediction Accuracy tests carried out at S&C's Laboratory
- Prove accuracy of FLM to within 5% for a variety of system conditions



Testing – Chicago May 2015

- 3ϕ Bolted Fault applied first to test network
- Operation of FLM using 20Ω, 30Ω and 50Ω resistor values
- Three network arrangements tested varying X/R and maximum fault level to simulate differing network conditions

Test #	Test Type	Test Circuit	Test Type	Controller	Impedance (Ω)	Purpose
1	A	CKT1	3Ø Bolted Fault	Lab	N/A	To gather reference fault level data
2	B	CKT1	Natural disturbance replication	Lab	Res Load	To provide data to produce 90ms Break data for Artificial disturbance calculations
3	C	CKT1	Artificial disturbance - pulse close	Envoy	20	To provide Peak, RMS and Break FL monitored data from FLM
4	C	CKT1	Artificial disturbance - pulse close	Envoy	30	To provide Peak, RMS and Break FL monitored data from FLM
5	C	CKT1	Artificial disturbance - pulse close	Envoy	50	To provide Peak, RMS and Break FL monitored data from FLM
6	A	CKT2	3Ø Bolted Fault	Lab	N/A	To gather reference fault level data
7	B	CKT2	Natural disturbance replication	Lab	Res Load	To provide data to produce 90ms Break data for Artificial disturbance calculations
8	C	CKT2	Artificial disturbance - pulse close	Envoy	20	To provide Peak, RMS and Break FL monitored data from FLM
9	C	CKT2	Artificial disturbance - pulse close	Envoy	30	To provide Peak, RMS and Break FL monitored data from FLM
10	C	CKT2	Artificial disturbance - pulse close	Envoy	50	To provide Peak, RMS and Break FL monitored data from FLM
11	A	CKT3	3Ø Bolted Fault	Lab	N/A	To gather reference fault level data
12	B	CKT3	Natural disturbance replication	Lab	Res Load	To provide data to produce 90ms Break data for Artificial disturbance calculations
13	C	CKT3	Artificial disturbance - pulse close	Envoy	20	To provide Peak, RMS and Break FL monitored data from FLM
14	C	CKT3	Artificial disturbance - pulse close	Envoy	30	To provide Peak, RMS and Break FL monitored data from FLM
15	C	CKT3	Artificial disturbance - pulse close	Envoy	50	To provide Peak, RMS and Break FL monitored data from FLM

Testing – Chicago May 2015

Test #	Lab Trace ID	Peak I (10ms) error (%)	RMS I (90ms) error (%)
4	90	4.4%	-2.3%
3	92	1.9%	-2.8%
4	93	2.1%	-4.6%
3	95	4.6%	-2.8%
4	96	-2.5%	-8.6%
4	100	3.9%	-8.2%
3	102	2.1%	-4.4%
		2.4%	-4.8%
8	107	3.4%	-0.9%
9	108	6.9%	-2.8%
8	110	3.4%	-1.8%
8	118	2.4%	-4.8%
9	119	-3.8%	-8.7%
8	121	4.9%	-1.9%
9	122	-1.1%	-5.7%
8	124	5.2%	-0.8%
9	125	-1.1%	-6.6%
		2.2%	-3.8%
13	130	0.6%	0.0%
14	131	12.1%	3.6%
13	133	1.6%	-0.9%
14	134	10.8%	-2.3%
13	136	1.5%	-0.9%
14	137	3.4%	-2.6%
14	140	2.6%	-2.6%
13	142	3.5%	-1.1%
14	143	3.7%	-0.6%
		4.2%	-0.8%

– Average accuracy across all tests within 5% target for both Peak and RMS

– 50Ω impedance gave poor results, smaller disturbance

– Red values are outside accuracy target

– Detailed analysis showed cause was frequency drop due to laboratory set up. Would not be repeated on real network

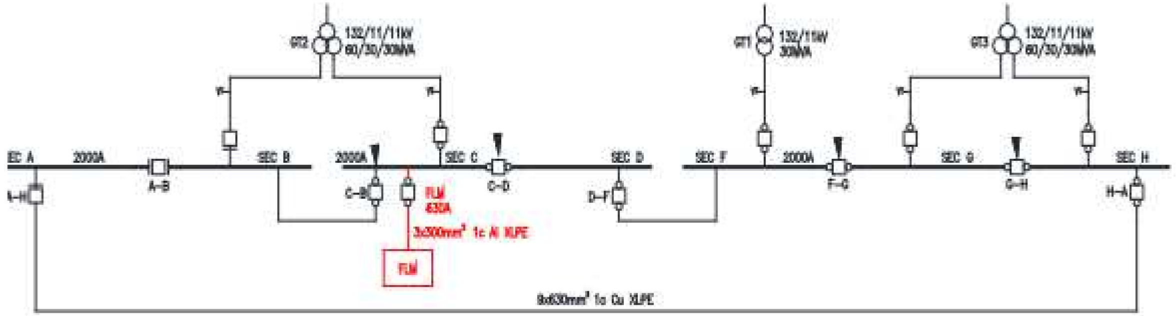
Site Installation

Commissioning Dates

Substation	Commissioning Date
Elmdon 132/11kV	22/10/2014
Chad Valley 132/11kV	02/12/2014
Castle Bromwich 132/11kV	12/02/2015
Kitts Green 132/11kV	04/03/2015
Shirley 132/11kV	04/03/2015
Hall Green 132/11kV	01/04/2015
Nechells West 132/11kV	29/07/2015
Chester Street 132/11kV	13/08/2015
Bartley Green 132/11kV	03/09/2015
Bournville 132/11kV	28/10/2015

Elmdon

- First FlexDGrid FLM to be installed and commissioned
- Connection via spare circuit breaker on existing switchboard



- IntelliRupter and Resistor placed in corner of 132kV Compound

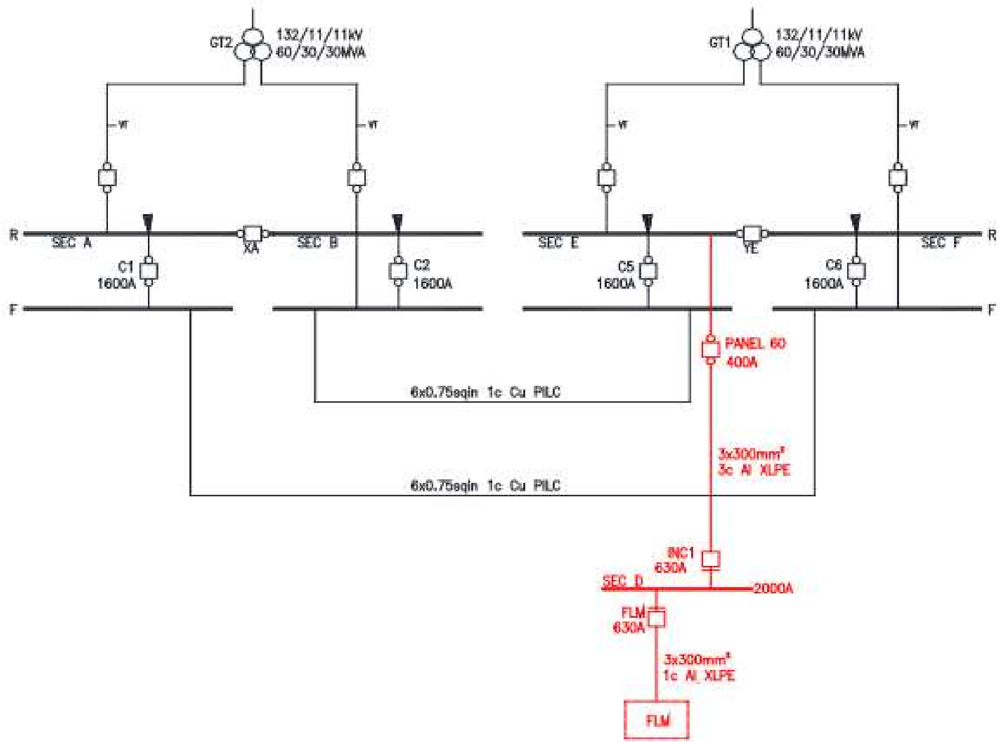
Elmdon

Elmdon

- Many lessons learnt and carried forward to all other sites
  - Rodent proof fiber optic cable
  - Modified foundation design for ease of construction
  - Prototype site for correcting communications issues experienced
  - Test site for equipment firmware upgrades

Chad Valley

– Connection via new two panel board connected to spare legacy circuit breaker on existing switchboard

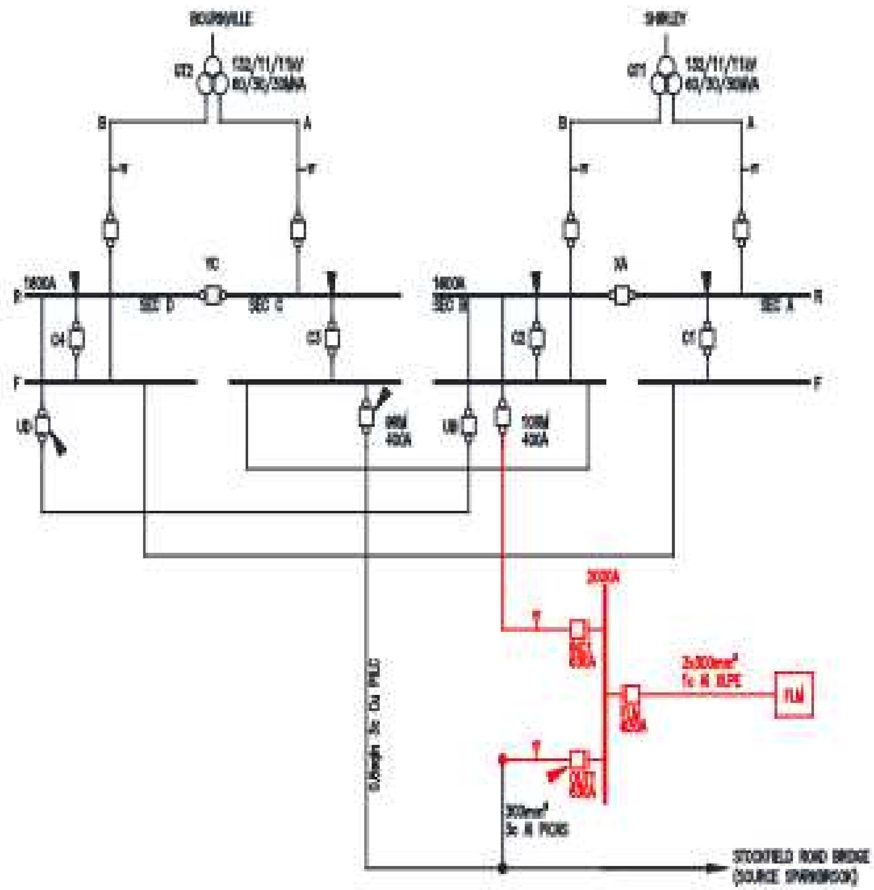


Chad Valley

- IntelliRupter and Resistor positioned on raised platform to allow bottom entry of cables
- Cables run through tunnel in adjacent store room, bent up through wall and then under device

Hall Green

- Connection via new three panel board moving existing normally open point
- New switchboard positioned in spare switchroom at far end of top floor
- IntelliRupter and Resistor placed in 132kV compound on ground floor



Hall Green

Pictures from Other Installations

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions?

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

COFFEE BREAK

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Technical Dissemination

FCLs: Design and Implementation

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Introduction

- Overview of Method Gamma
- FCL Integration Options
- Site Selection Process
- FCL Technologies
- Site Installation

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 Overview

- 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

FlexDGrid – Method Gamma Overview

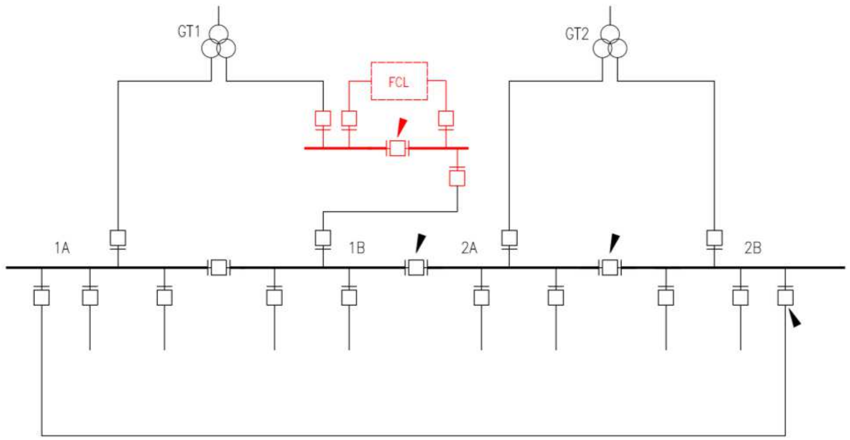
– Aims for Method Gamma

Aim
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

FCL Integration Options

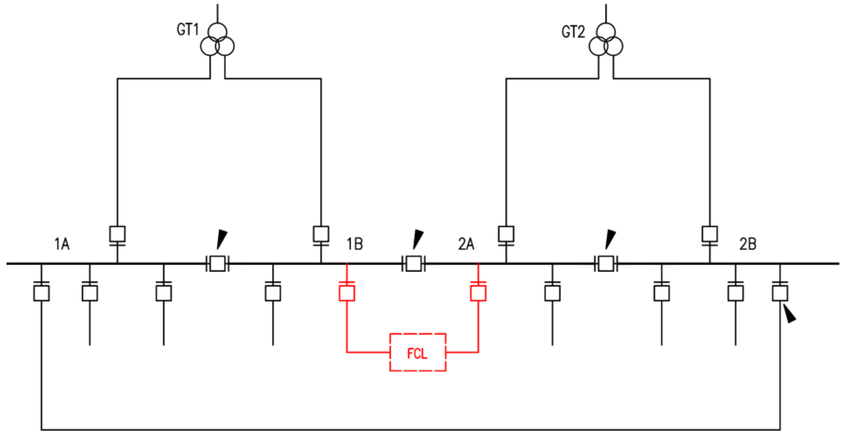
- Initial stage of FlexDGrid identified four integration options for FCLs:
    - In series with a secondary winding of a transformer
    - Across a bus-section
    - Within an interconnector
    - Between transformers

FCL Integration Option – in series with transformer



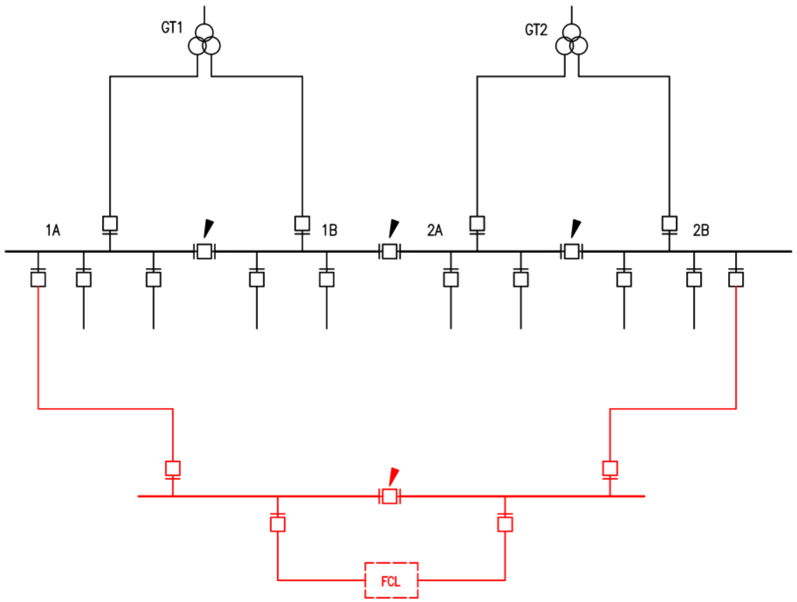
- Parallel of GT1A and GT1B
- Transformer protection has to be transferred
- FCL has to “ride-through faults”

FCL Integration Option – across bus-section



- Parallel of GT1B and GT2A
- Requirement to have spare CBs in existing switchboard

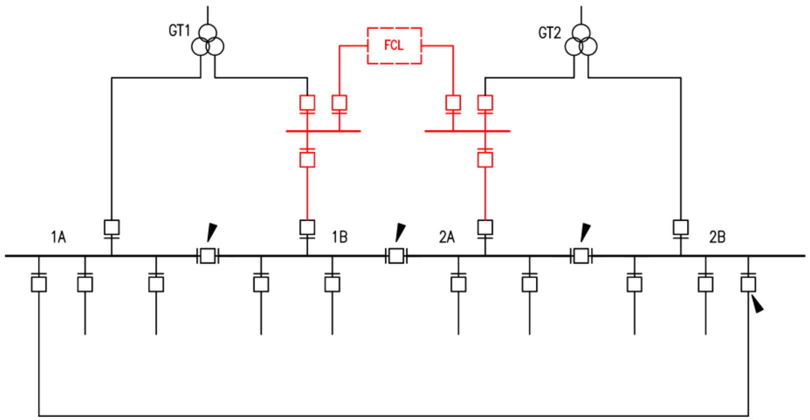
FCL Integration Option – within an interconnector



– Parallel of GT1B and GT2B

– Can be deployed across a normally open interconnector

FCL Integration Option – between transformers

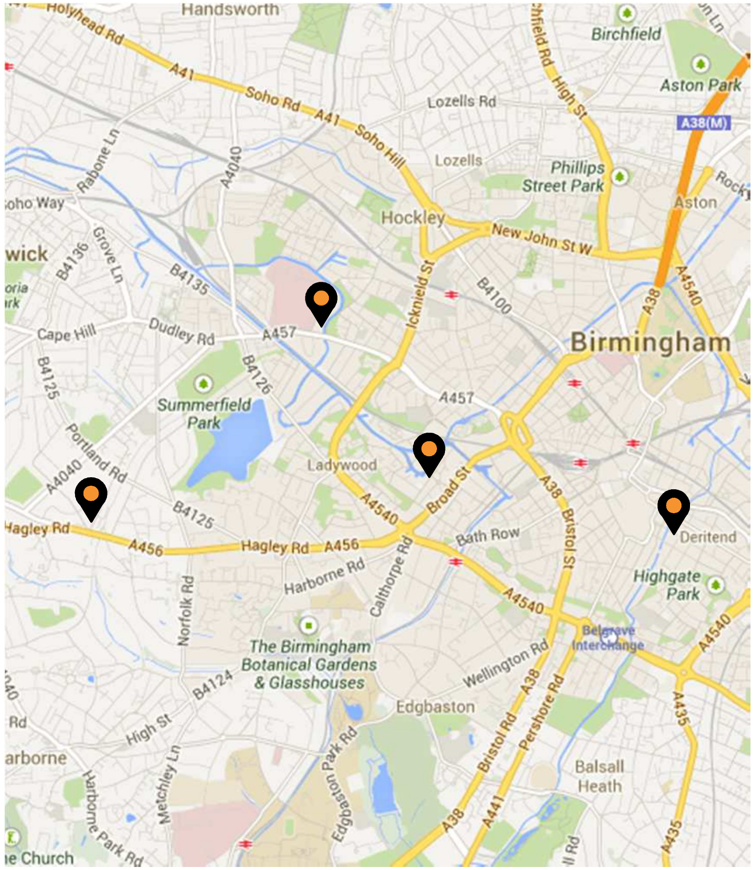


– Parallel of GT1B and GT2A

– Transformer protection has to be moved for two transformers

Site Selection Process

- 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

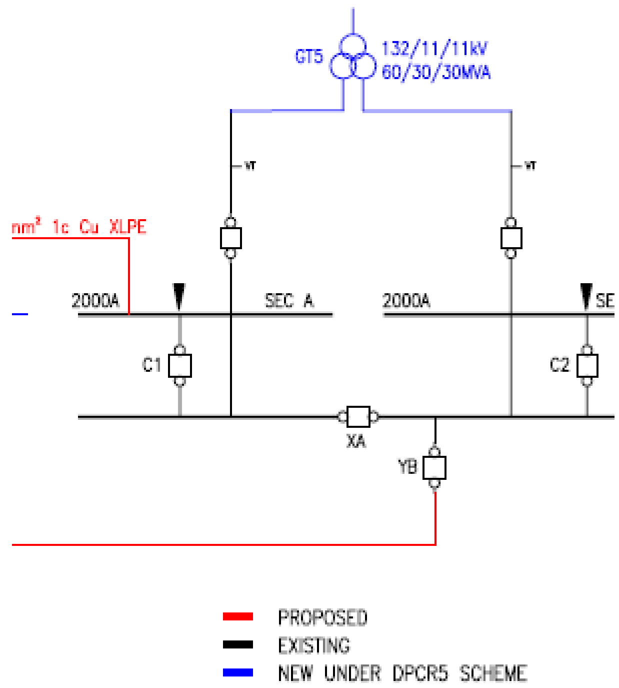
- Consider the complexity of connection to the 11kV network
- Where possible avoid extensive alterations to protection schemes
- Utilise existing switchgear where possible

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



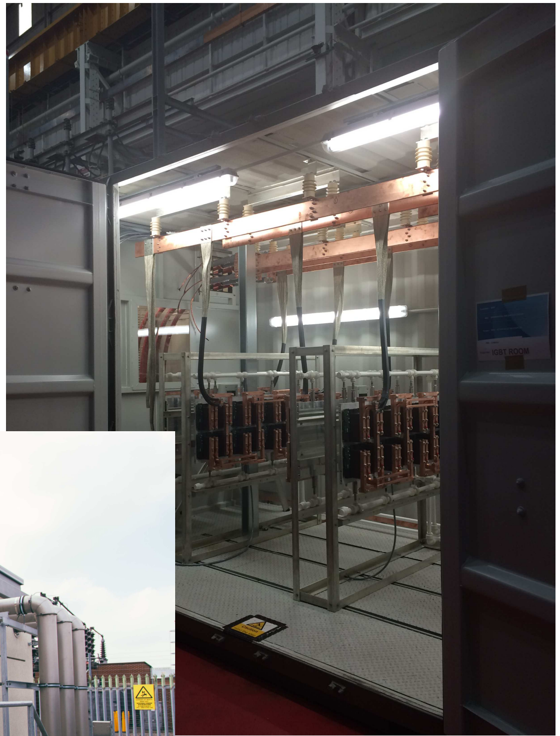
Auxiliaries

- 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

Sites Selected for FCL Installation

Substation	Technology	Manufacturer
Castle Bromwich 132/11kV	Pre-Saturated Core FCL	GridON
Chester Street 132/11kV	Resistive Superconducting FCL	Nexans
Bournville 132/11kV	Resistive Superconducting FCL	Nexans
Kitts Green 132/11kV	Power Electronic FCL	GE
Bartley Green 132/11kV	Power Electronic FCL	GE

FCL Technologies



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)

Pre-Saturated Core Fault Current Limiter

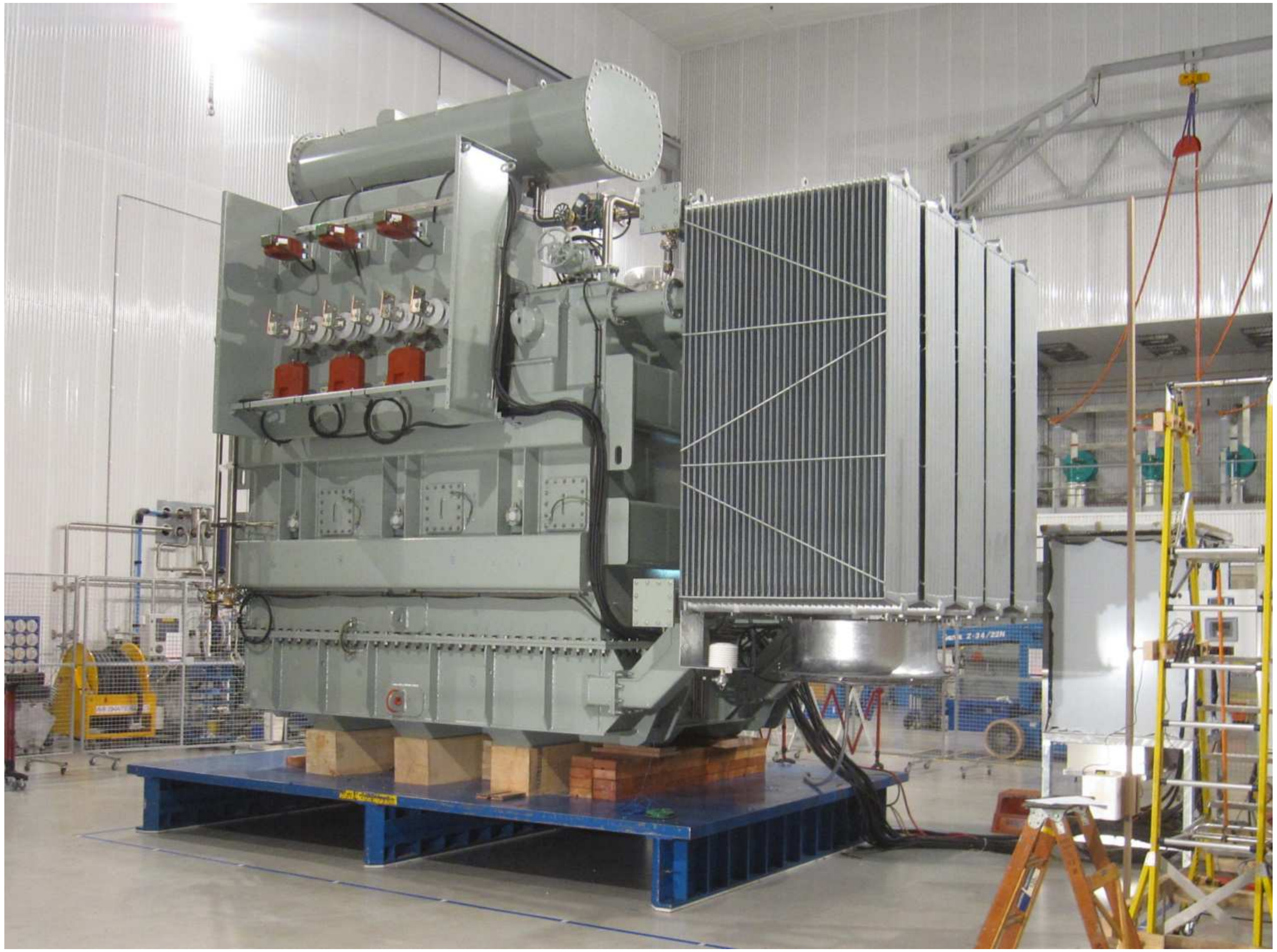
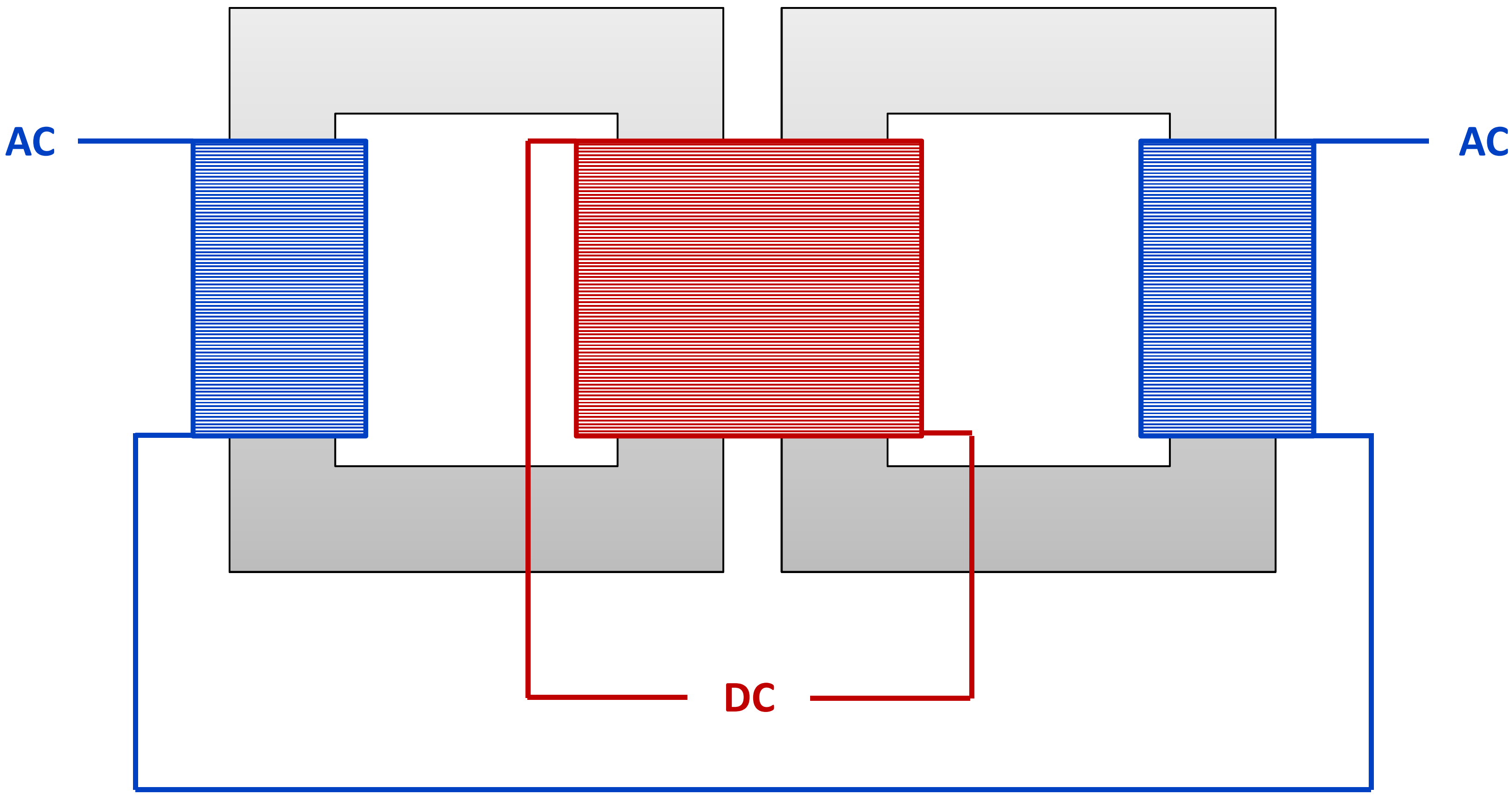
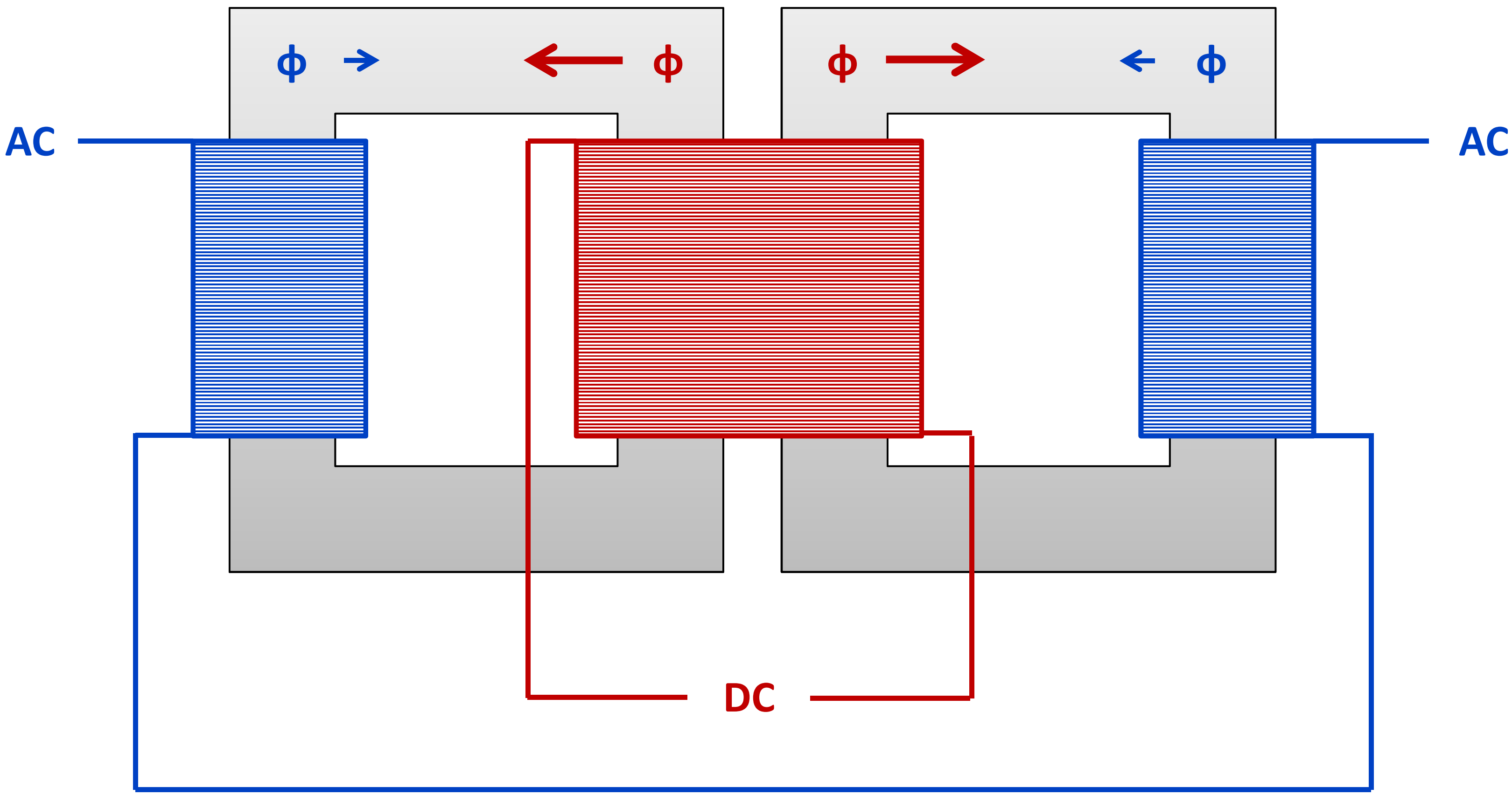


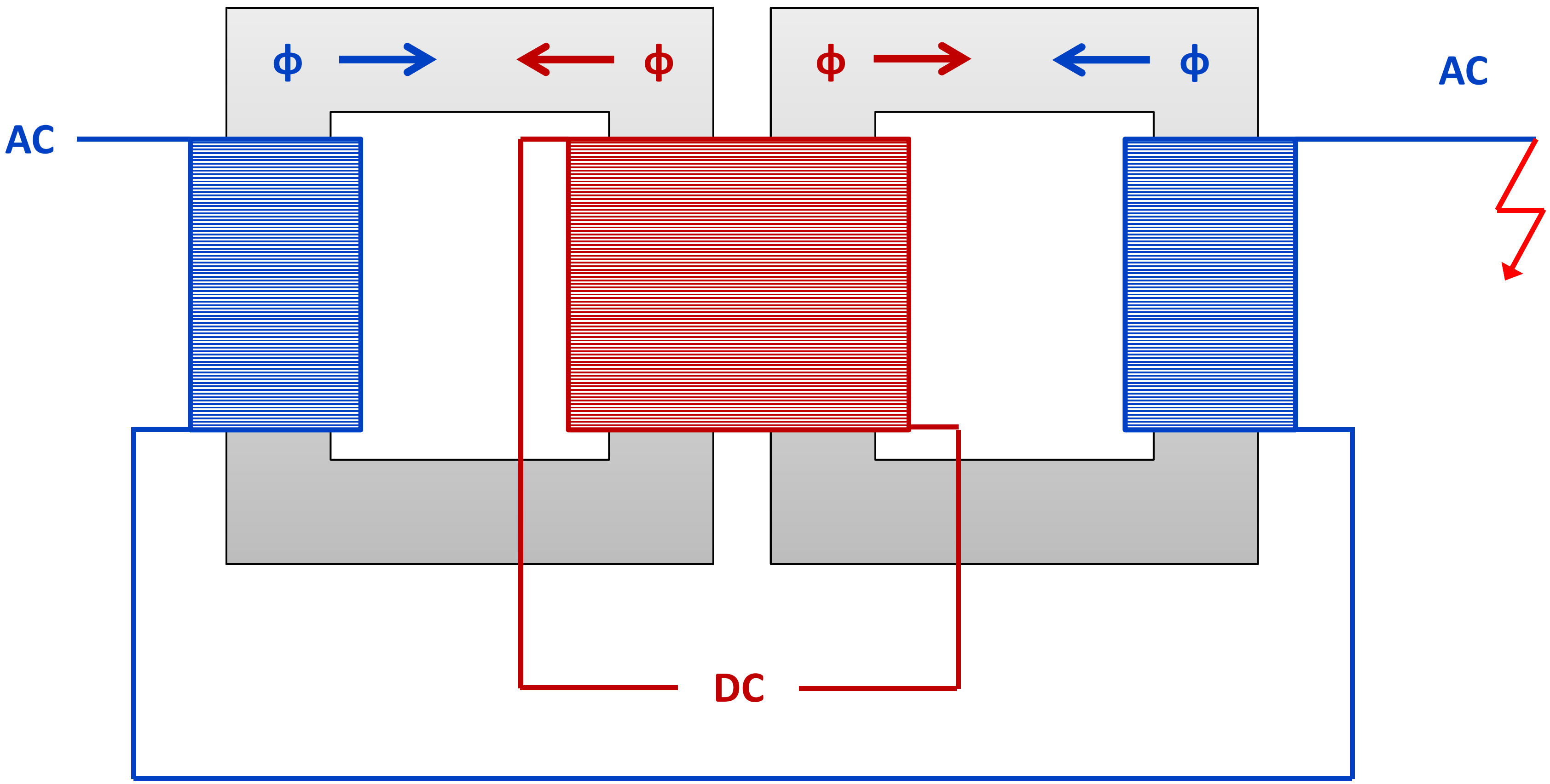
Diagram of PSCFCL



Normal Operation of PSCFCL



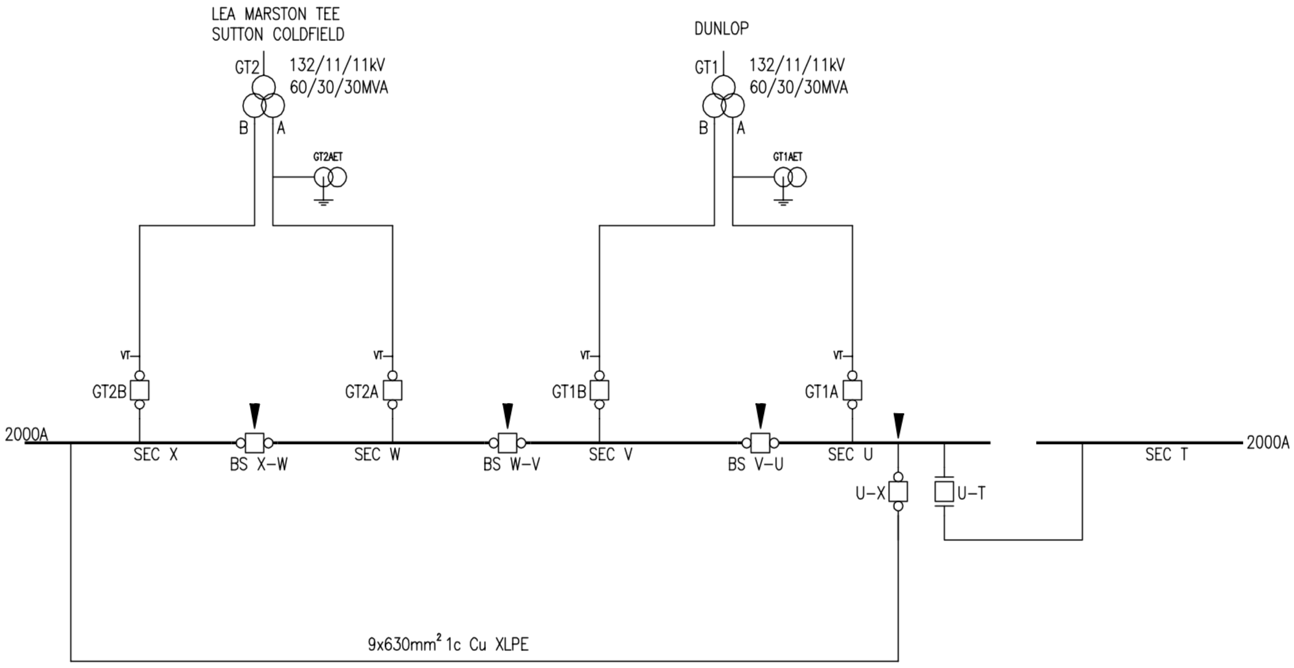
Operation of PSCFCL during a fault



Details for GridON PSCFCL for Castle Bromwich

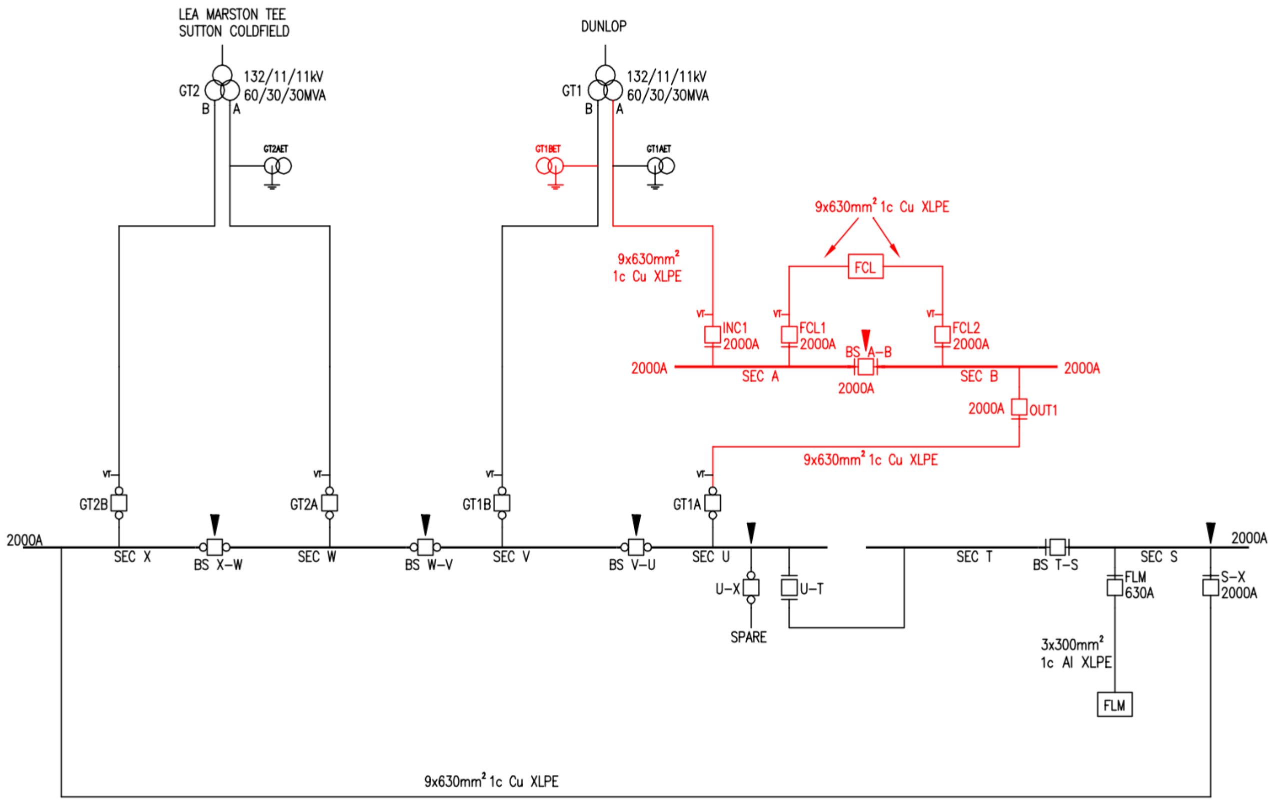
- Rating: 30MVA ONAN, 38MVA ONAF
- Break fault level reduction required: 44%
- Peak fault level reduction required: 53%
- Mass: 170 Tonnes
- Dimensions (LxWxH): 6.4 x 4.5 x 5.3 m

PSCFCL Integration – Castle Bromwich 132/11kV



EXISTING

PSCFCL Integration – SLD

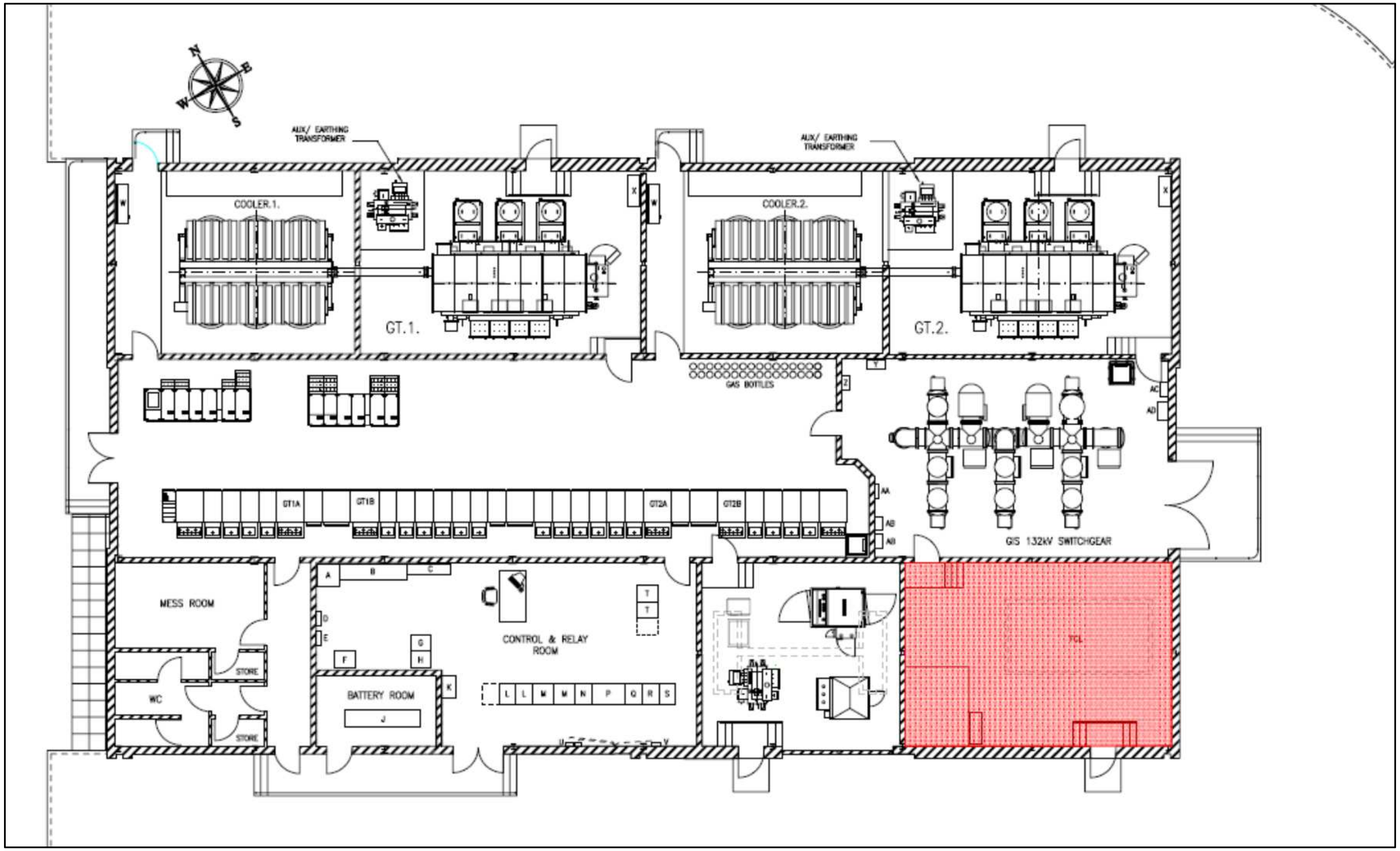


PROPOSED

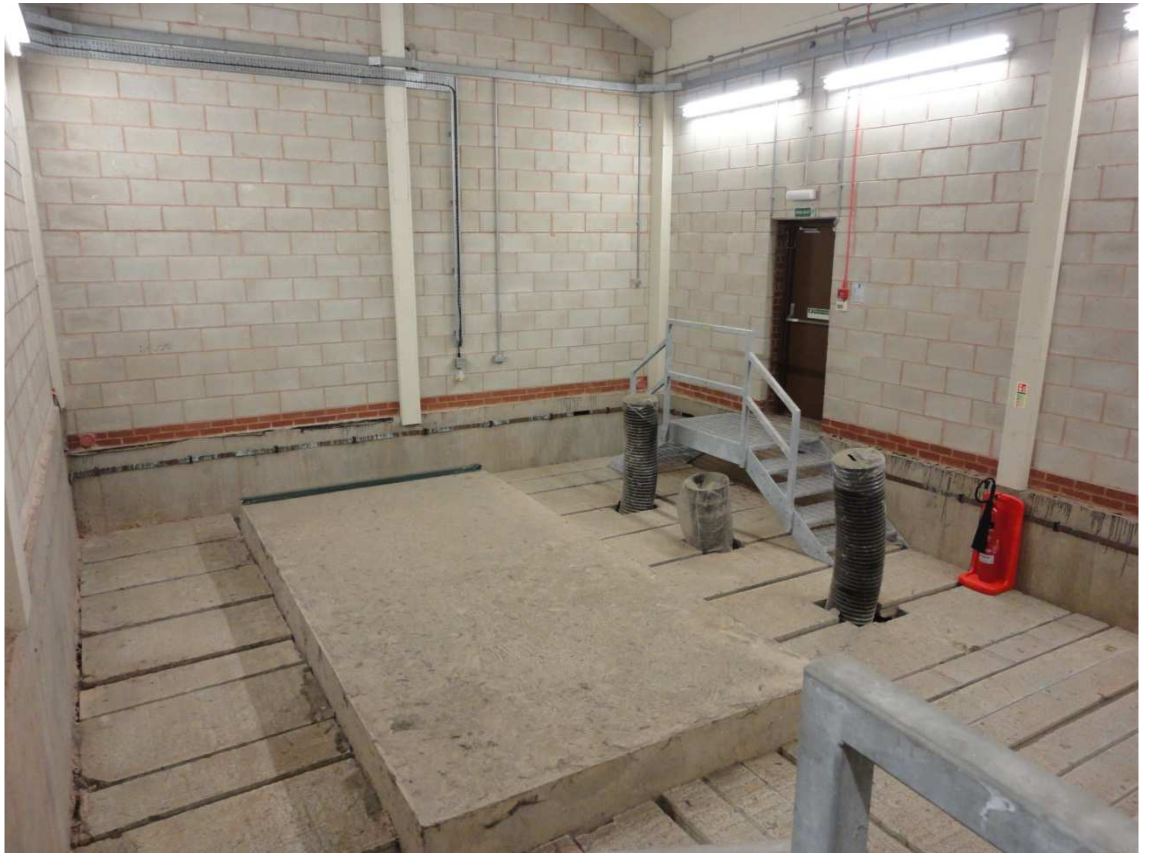
PSCFCL Integration – Main Points

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

PSCFCL Integration – Indoor Installation

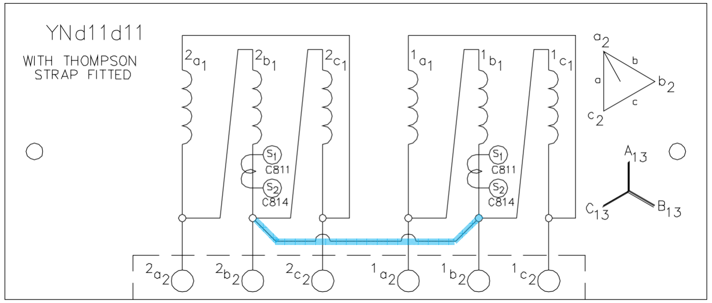


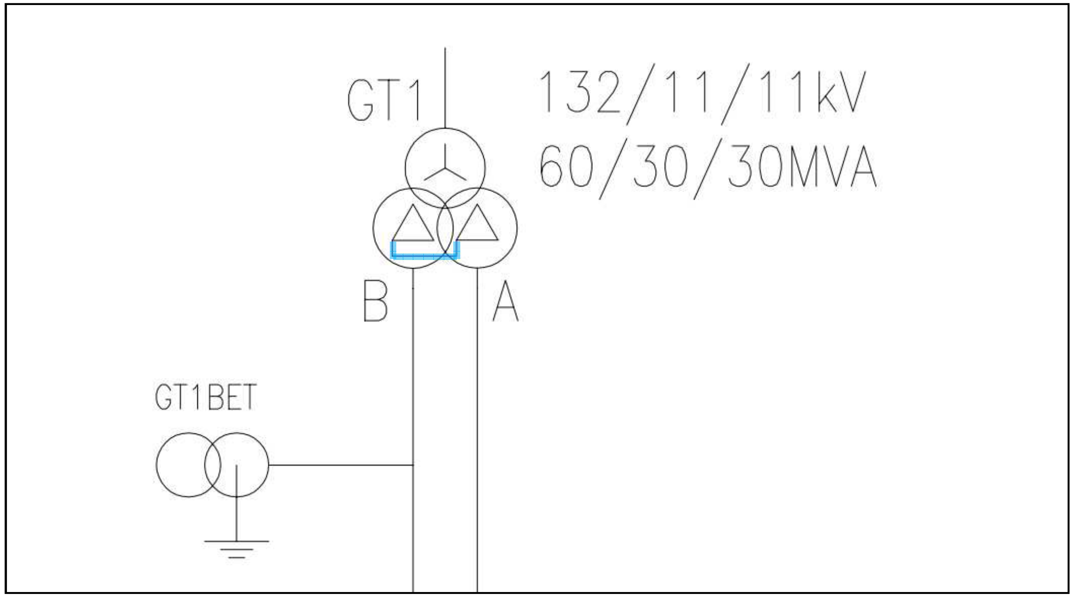
PSCFCL Integration – Indoor Installation



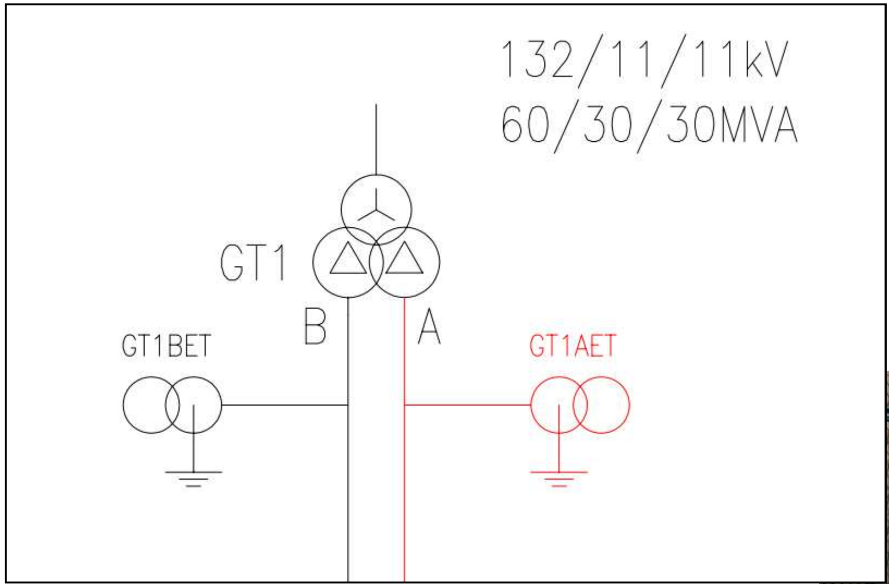
PSCFCL Integration – Indoor Installation

PSCFCL Integration – Thompson Strap





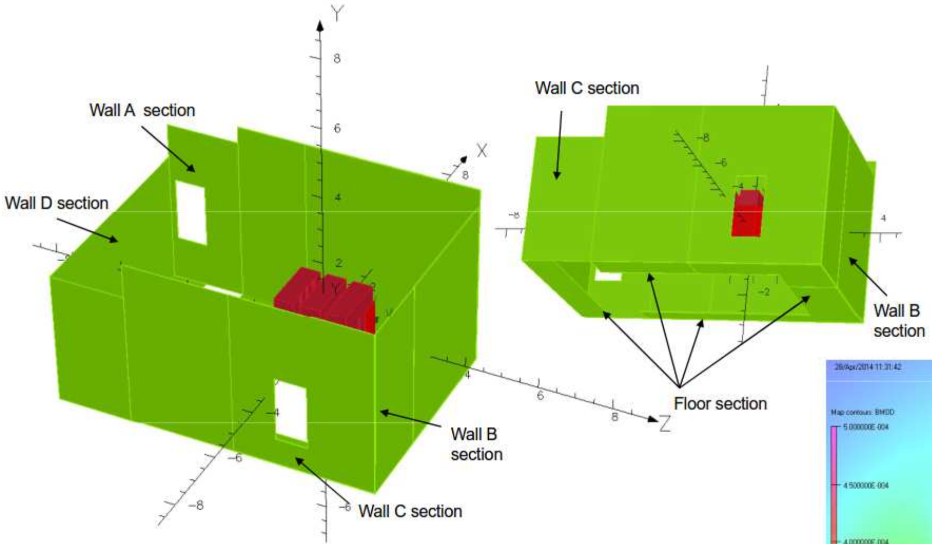
PSCFCL Integration – Thompson Strap

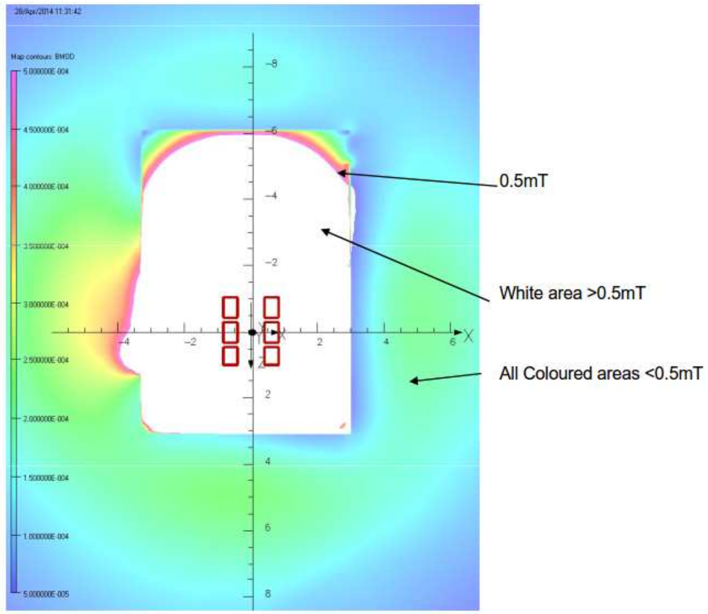


PSCFCL Integration – Magnetic Shielding

- 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 modelled and a shield design produced

PSCFCL Integration – Magnetic Shielding



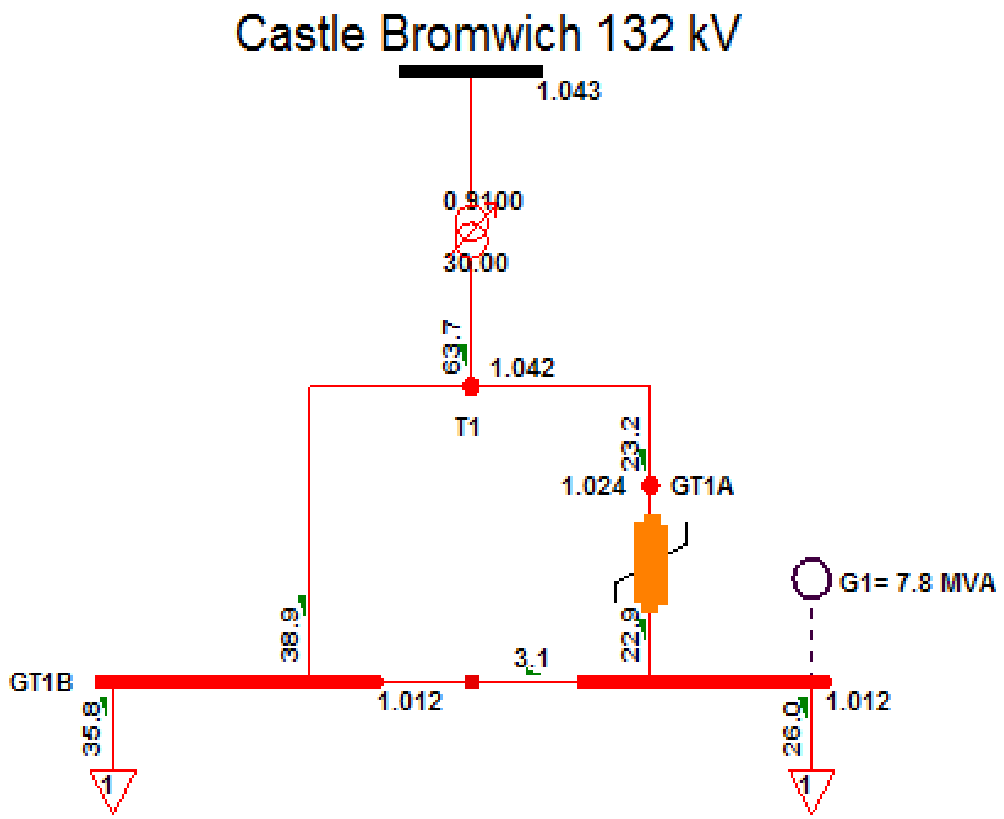


FCL Integration – Load Sharing

- 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

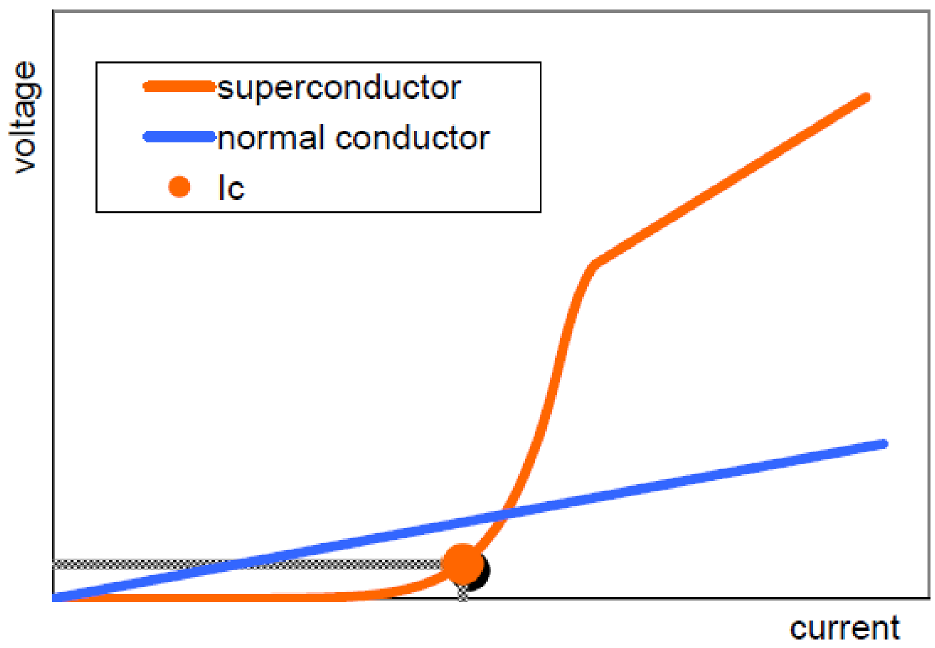
AC Load current RMS [A]	DC bias current [A]
400	130
800	220
1000	270
1250	320
1575	365
2000	490

FCL Integration – Load Sharing



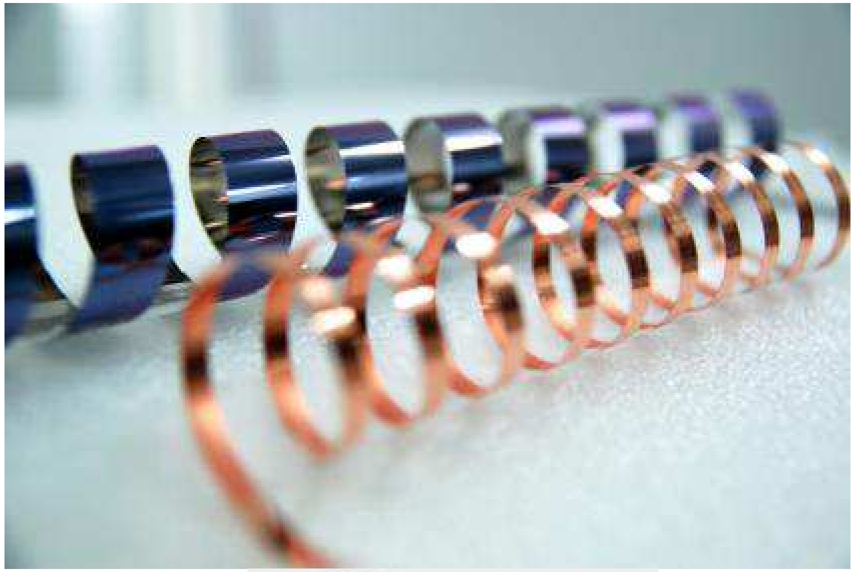
Resistive Superconducting Fault Current Limiter

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

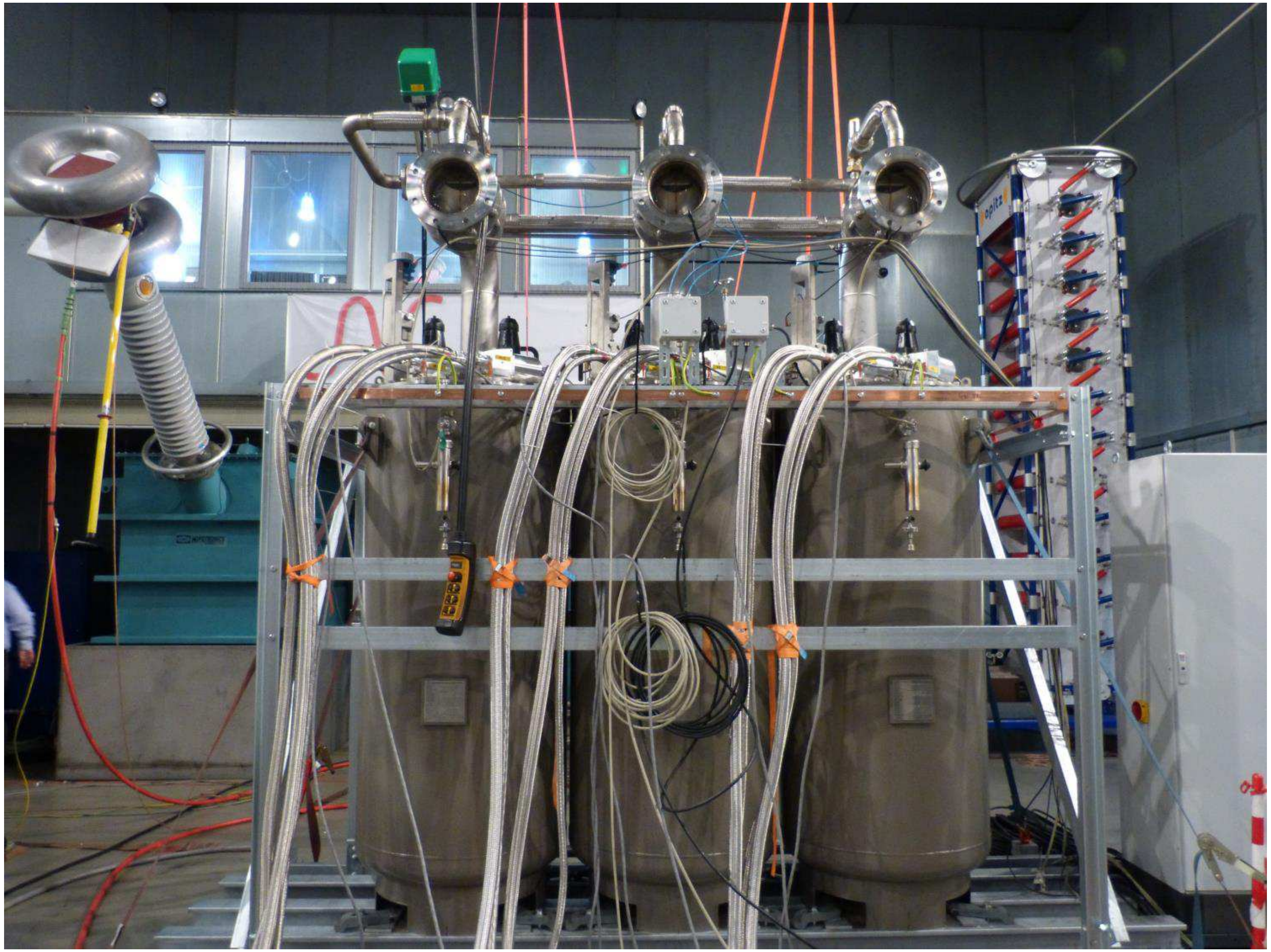


Resistive Superconducting Fault Current Limiter

- HTS material is supplied as a thin tape
- The tape is installed in a vacuum insulated pressure vessel which contains the cryogenic material
- The HTS tape length and construction determines the device rating

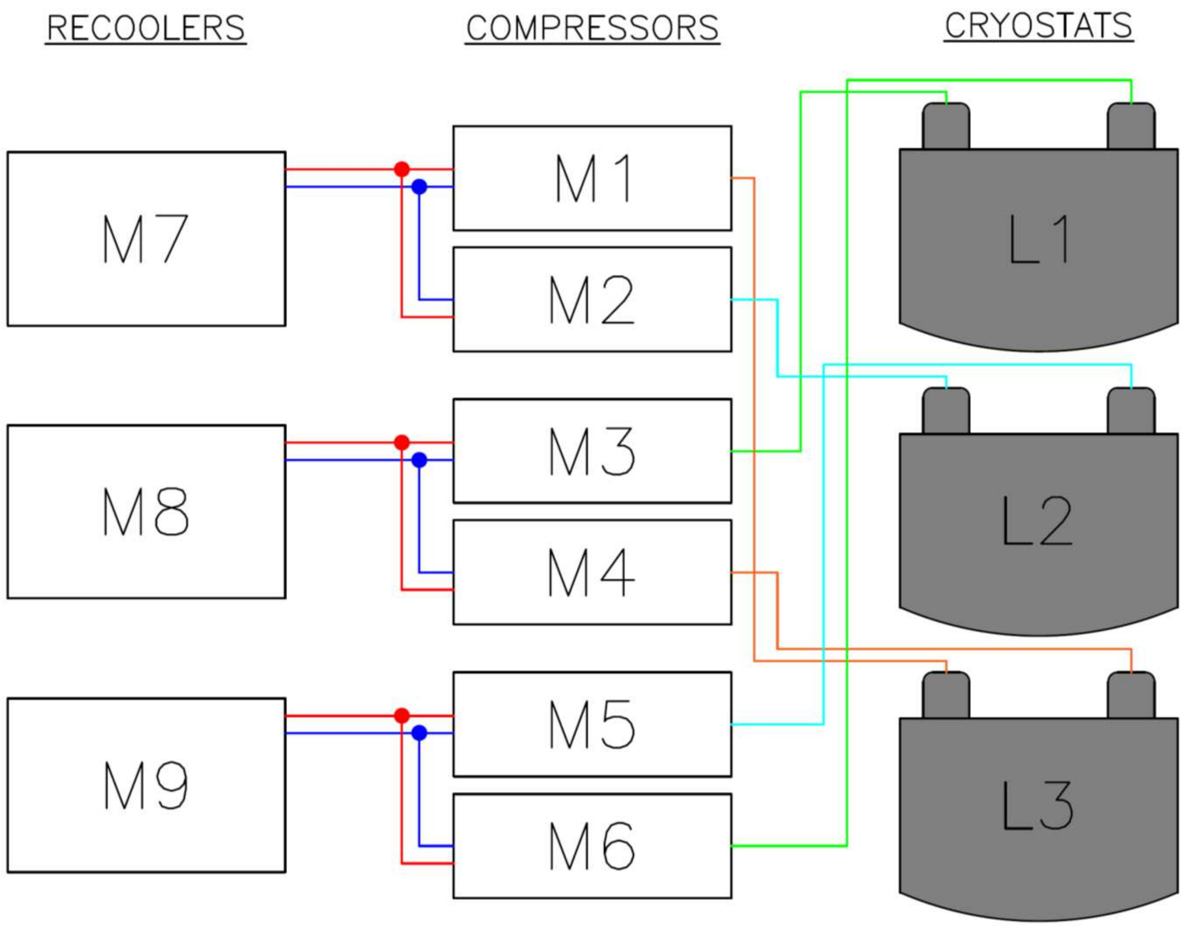


Resistive Superconducting Fault Current Limiter



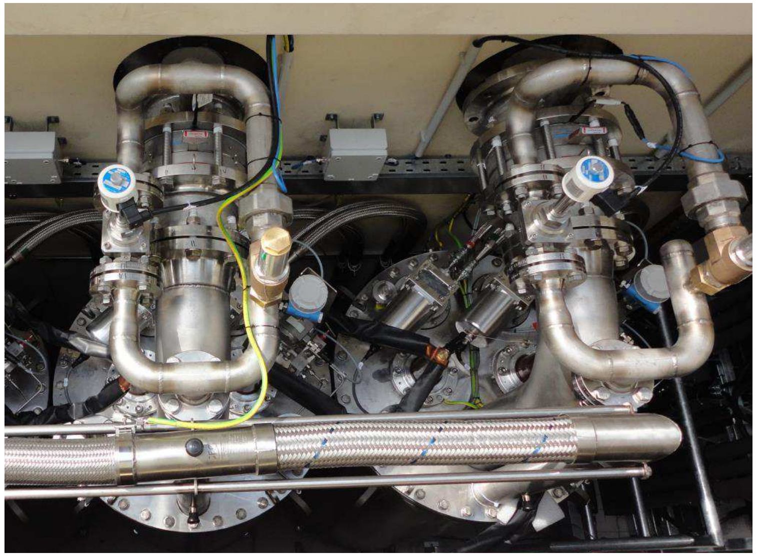
Cooling System

- 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



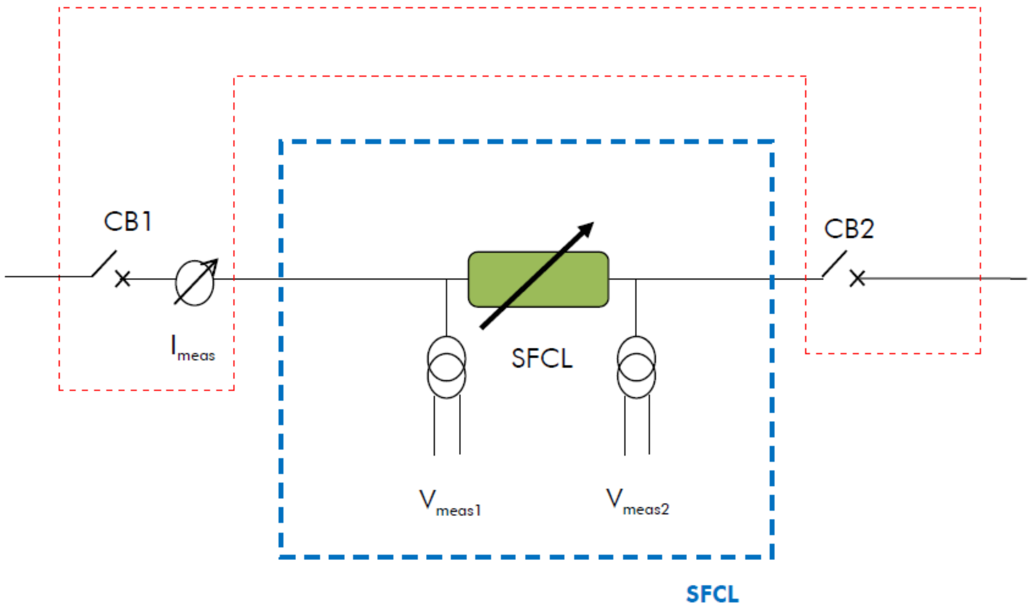
WESTERN POWER DISTRIBUTION
FLEXDGRID

FCLs: Design and Implementation

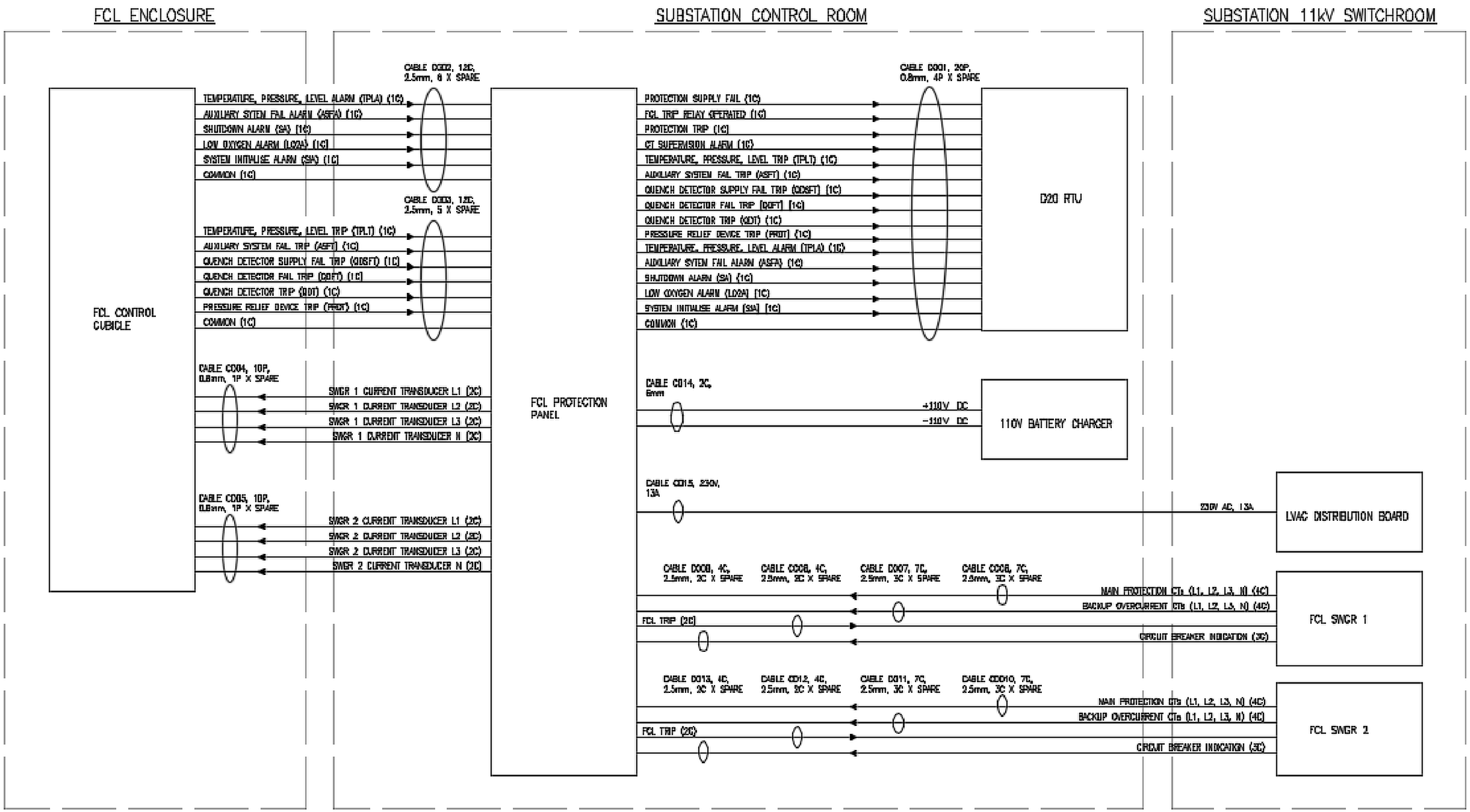


Protection and Control – Device Level

- 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:

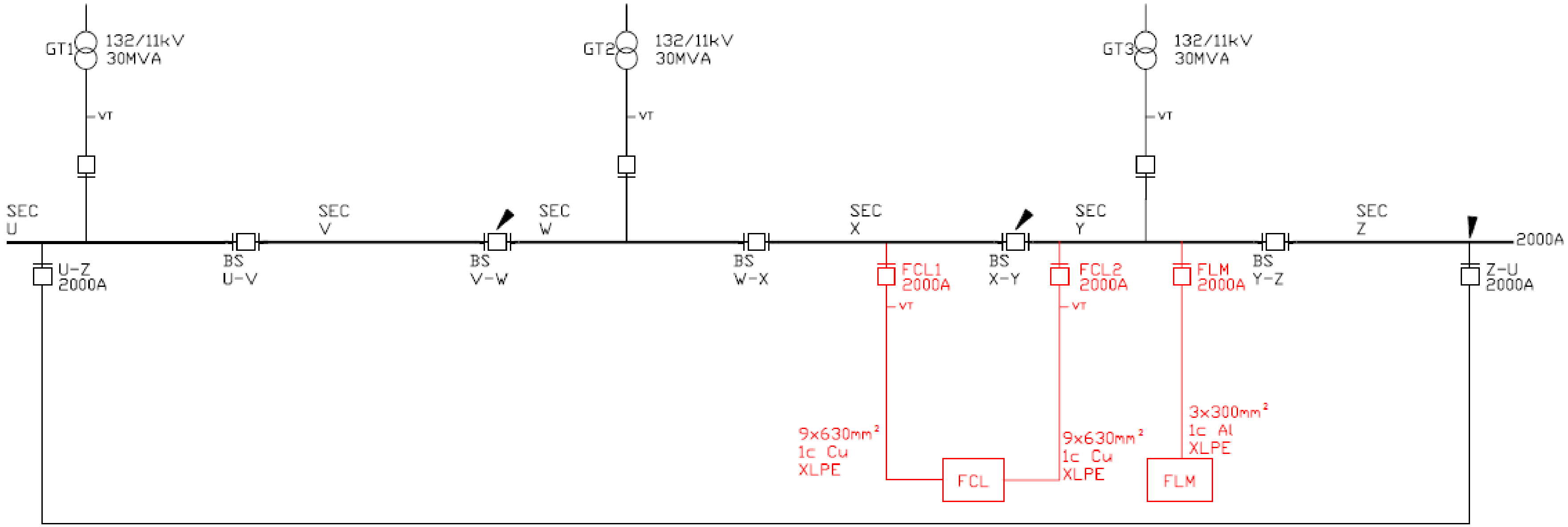
- 1600A rated
- Peak fault reduction (@10ms) 19.76kA to 9.90kA or below
- Peak fault reduction (@90ms) 7.03kA to 3.68kA or below
- 33.4kA short circuit current withstand capability

Bournville 132/11kV Substation:

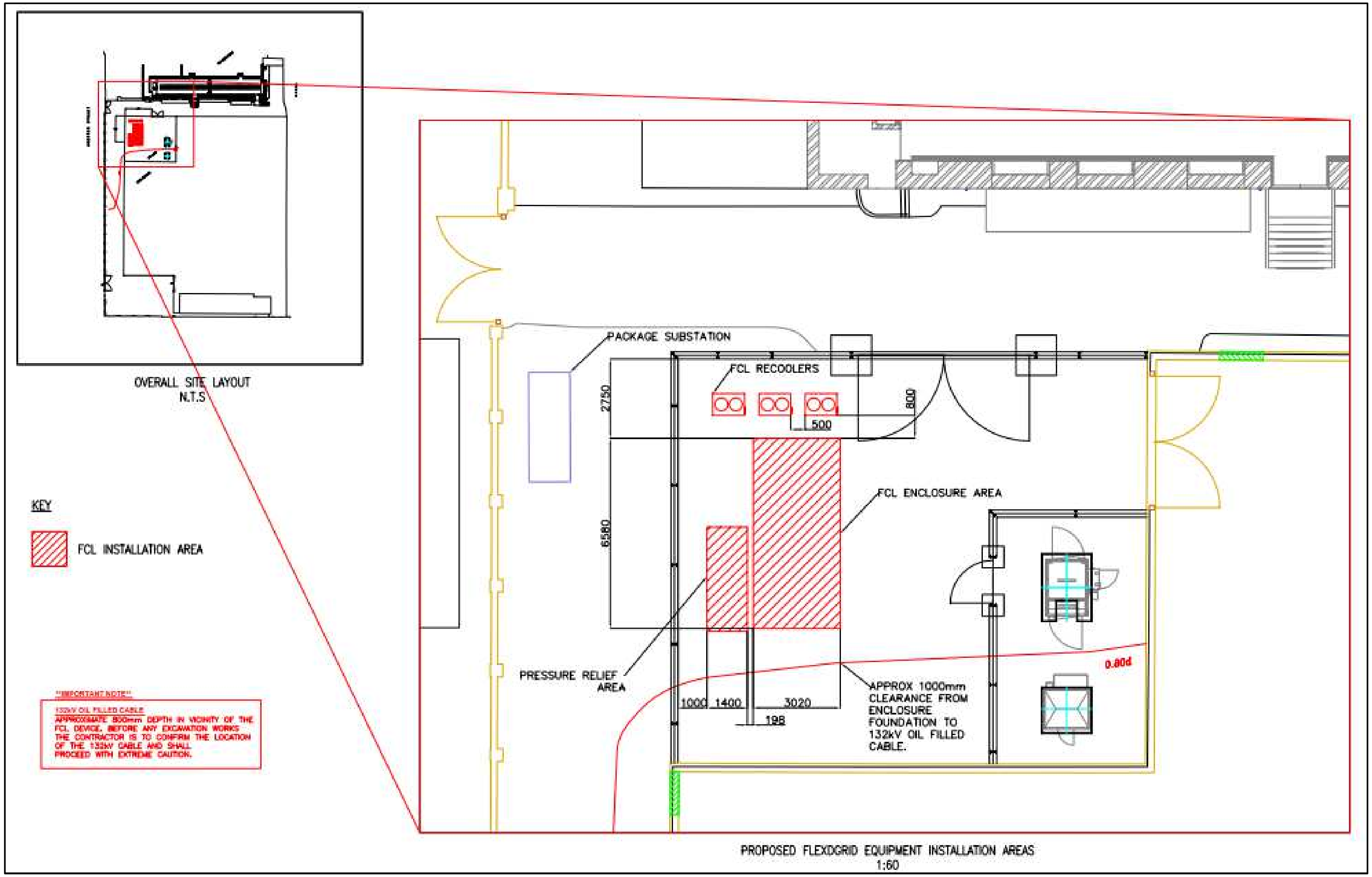
- 1050A rated
- Peak fault reduction (@10ms) 21.97kA to 7.70kA or below
- Peak fault reduction (@90ms) 7.66kA to 3.05kA or below
- 33.4kA short circuit current withstand capability

Chester Street FCL Network Connection

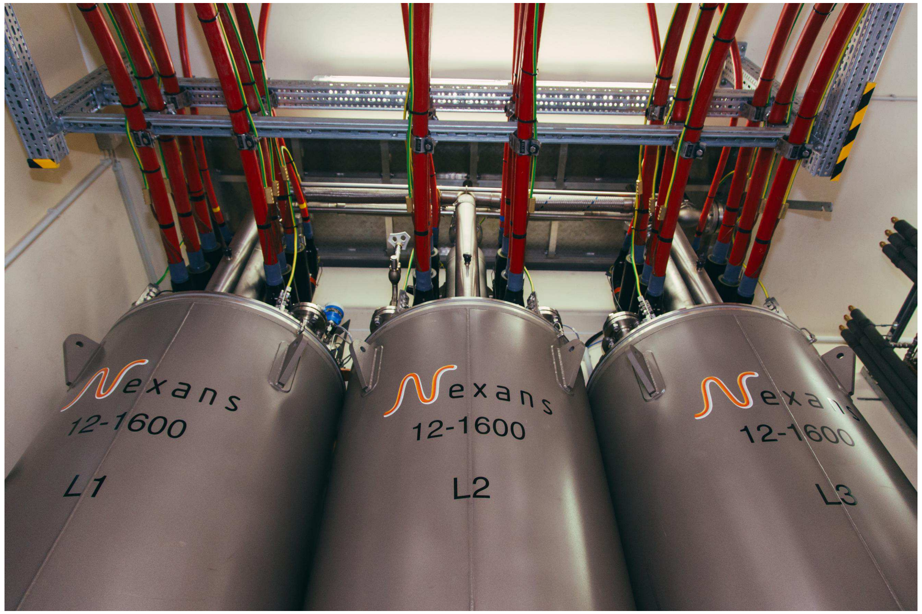
- Three Grid Transformers run in split configuration
- RSFCL connected across the bus-section
- Circuit breaker fail scheme installed:
  - FCL1 trips Bus-section W-X (250ms delay)
  - FCL2 trips GT3 (250ms delay)



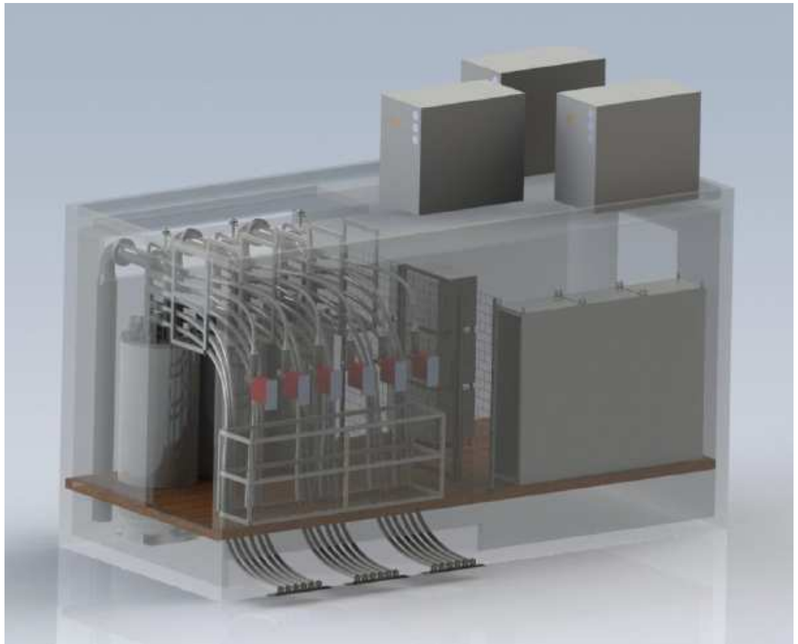
Chester Street RSFCL Installation



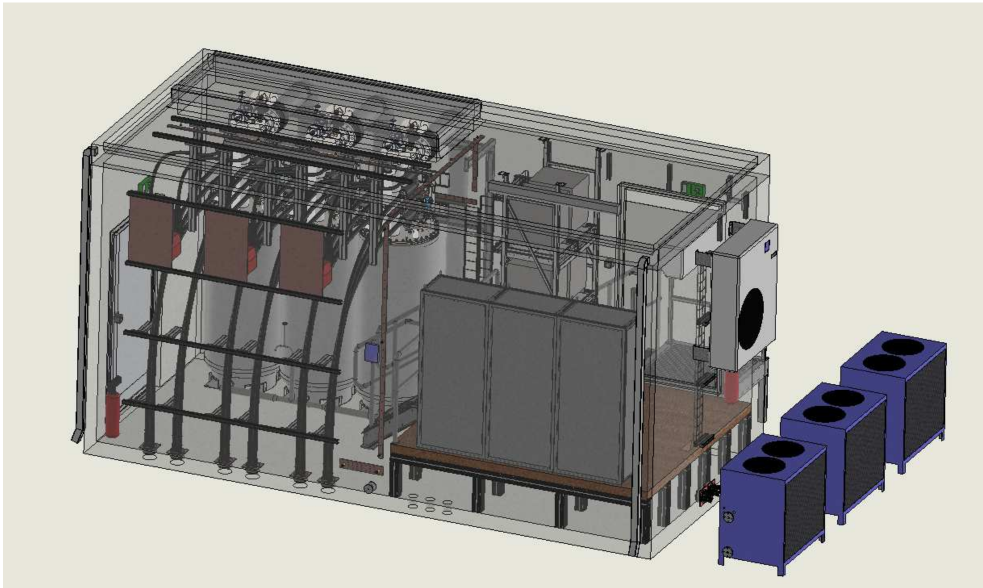
Chester Street RSFCL Installation



Design - Enclosure



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



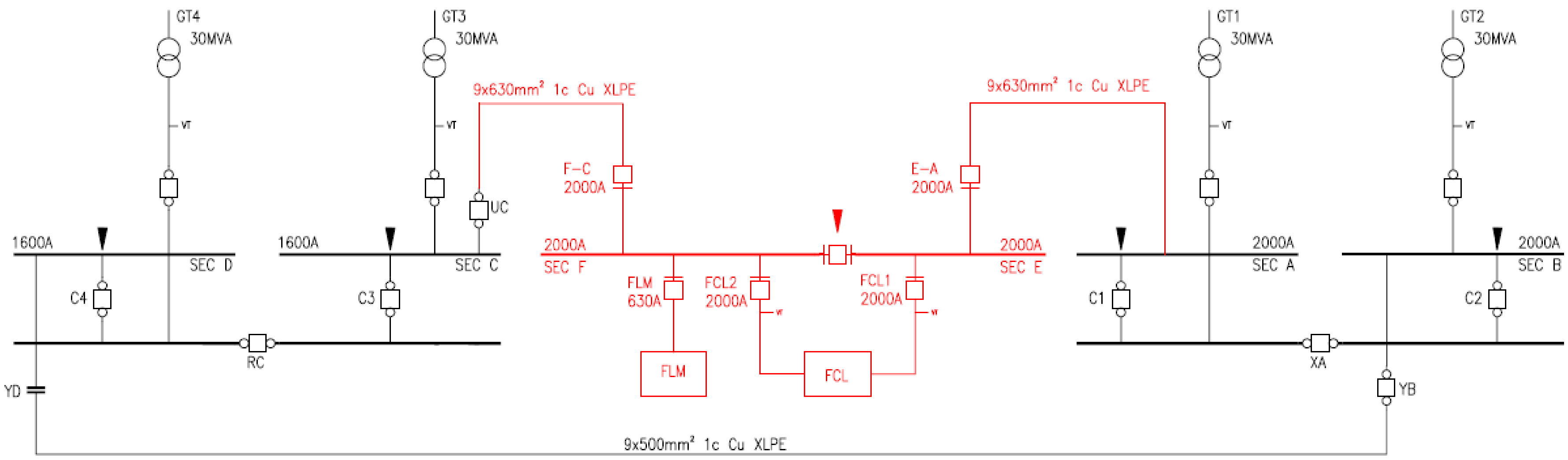
FCL Protection Panel

Provides:

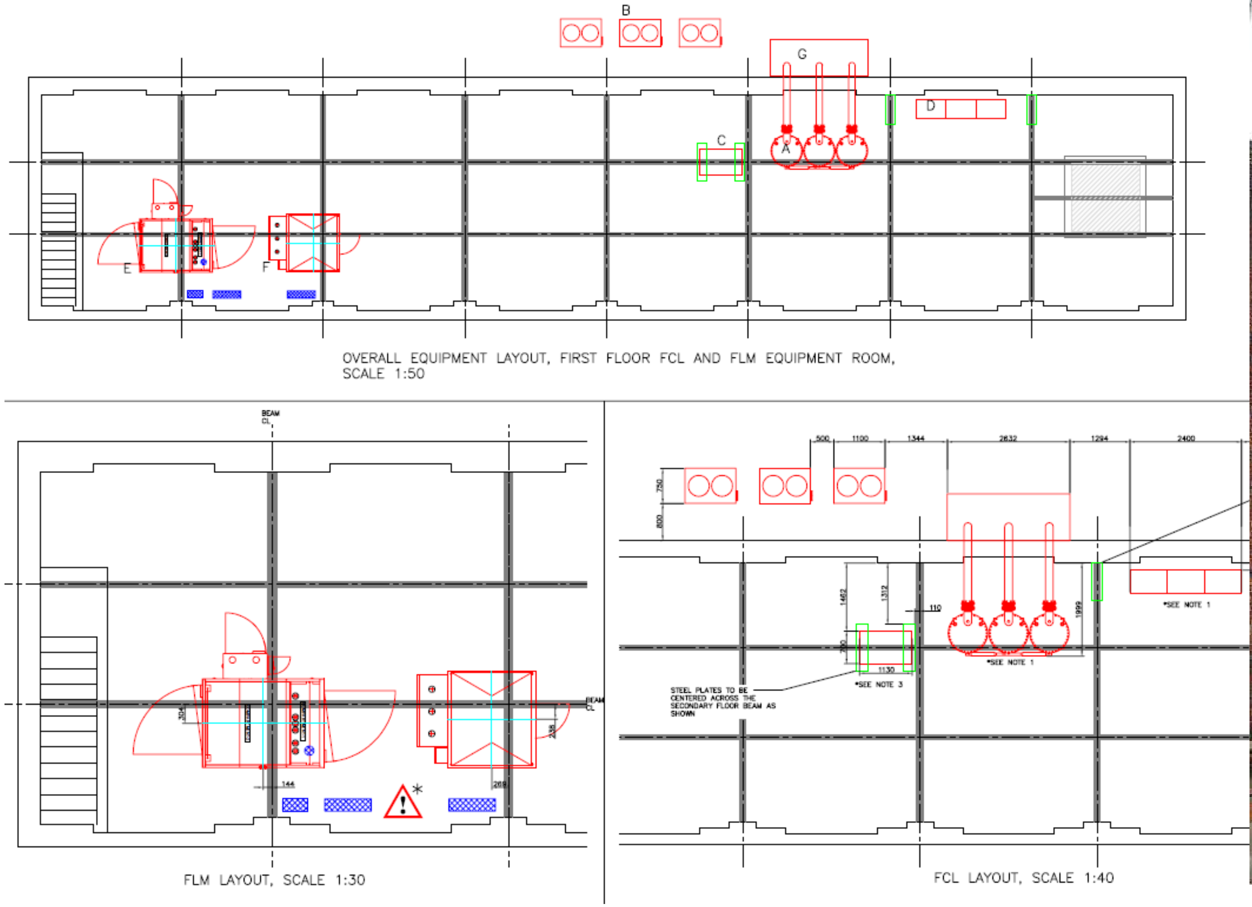
- Unit protection scheme across the FCL
- Initiates trip signal to FCL feeder circuit breakers
- Alarm and trip indication
- Control/indications to/from WPD control

Bournville FCL Network Connection

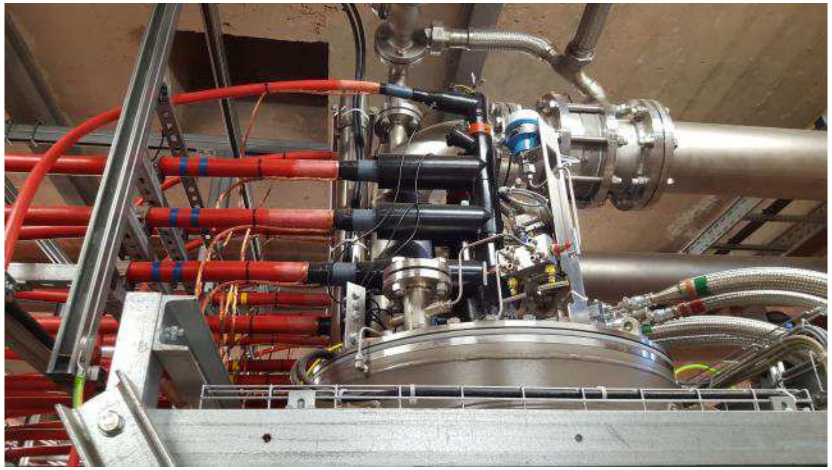
- New 6 panel switchboard installed
- RSFCL connected in the interconnector A-C
- Circuit breaker fail scheme installed:
    - FCL1 trips Interconnector E-A (250ms delay)
    - FCL2 trips Interconnector F-C (250ms delay)

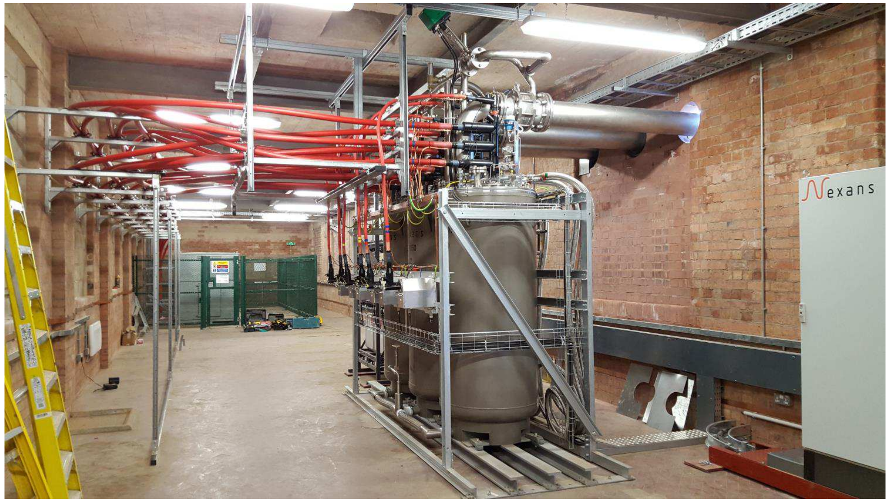


Bournville RSFCL Installation



Bournville RSFCL Installation





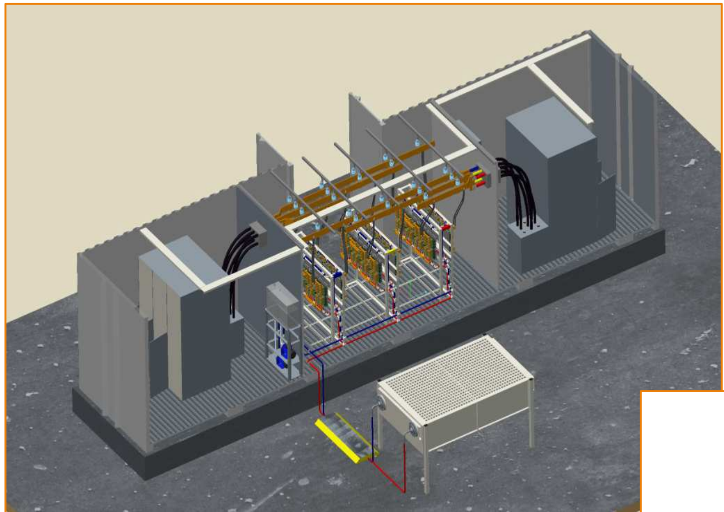
Safety Considerations

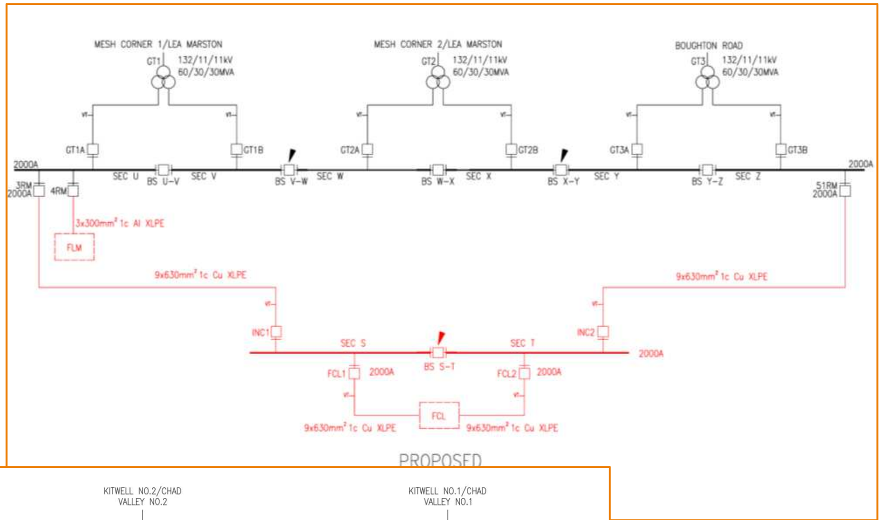
- Bund for safe containment of liquid nitrogen
- Oxygen sensor for detection of low oxygen levels
- Access/Egress

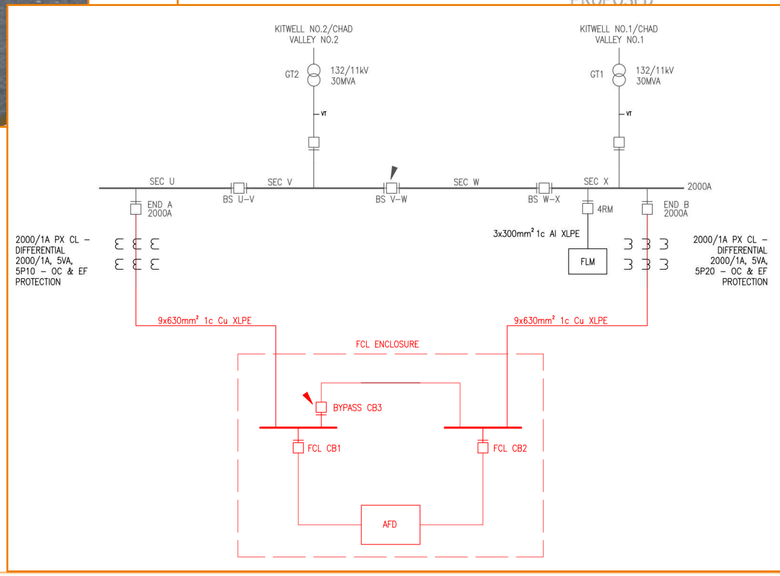
Power Electronic Fault Current Limiter

- GE were contracted to build two 11kV PEFCLs for installation at Kitts Green and Bartley Green substations
- Unfortunately, due to issues with the design integrity of the PEFCL it was not able to be completed in time for the end of the project
- The main issues are highlighted in the following slides

PEFCL - Connection







PEFCL – Main Issues

Issue	Description
General Arrangement	The PEFCL GA did not have sufficient detail to allow WPD/GE to check clearances and positioning of equipment
Insulation Level	– Cooling system not adequately insulated from HV – Phase-Earth clearances not sufficient – DC power supplies not isolated
Current Chopping	Surge arrestors not adequately sized for the energy dissipated during switch-off
Voltage Sharing	Snubber circuits were not included therefore IGBTs would not share voltage equally

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions?

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

LUNCH

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Technical Dissemination

FLMs: Enhanced Modelling Practices

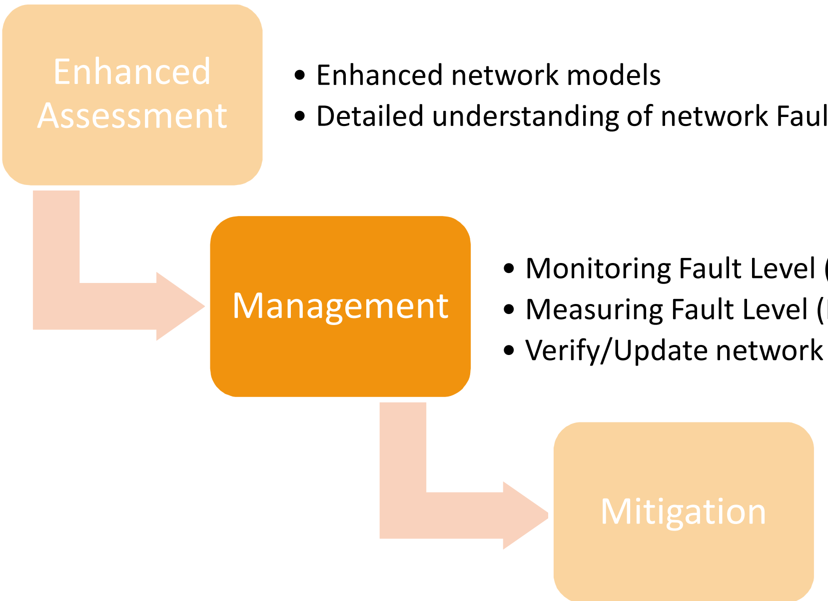
LCN Fund Low Carbon Networks   THE UNIVERSITY OF WARWICK   PARSONS BRINCKERHOFF

Introduction

- Overview of Method Beta
- Aims for FLM Data
- Fault Level Comparison
- MVA/MVA Template Creation
- FL Alternative Connections

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 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 Beta Overview

- Method Beta: Fault Level Measurement Technology
  - Build on knowledge learned through previous Projects
  - Install an FLM technology in 10 separate WPD substations
  - Use results from trials to inform changes to Modelling policy (Method Alpha)
  - Customer control based on Fault Level Contribution

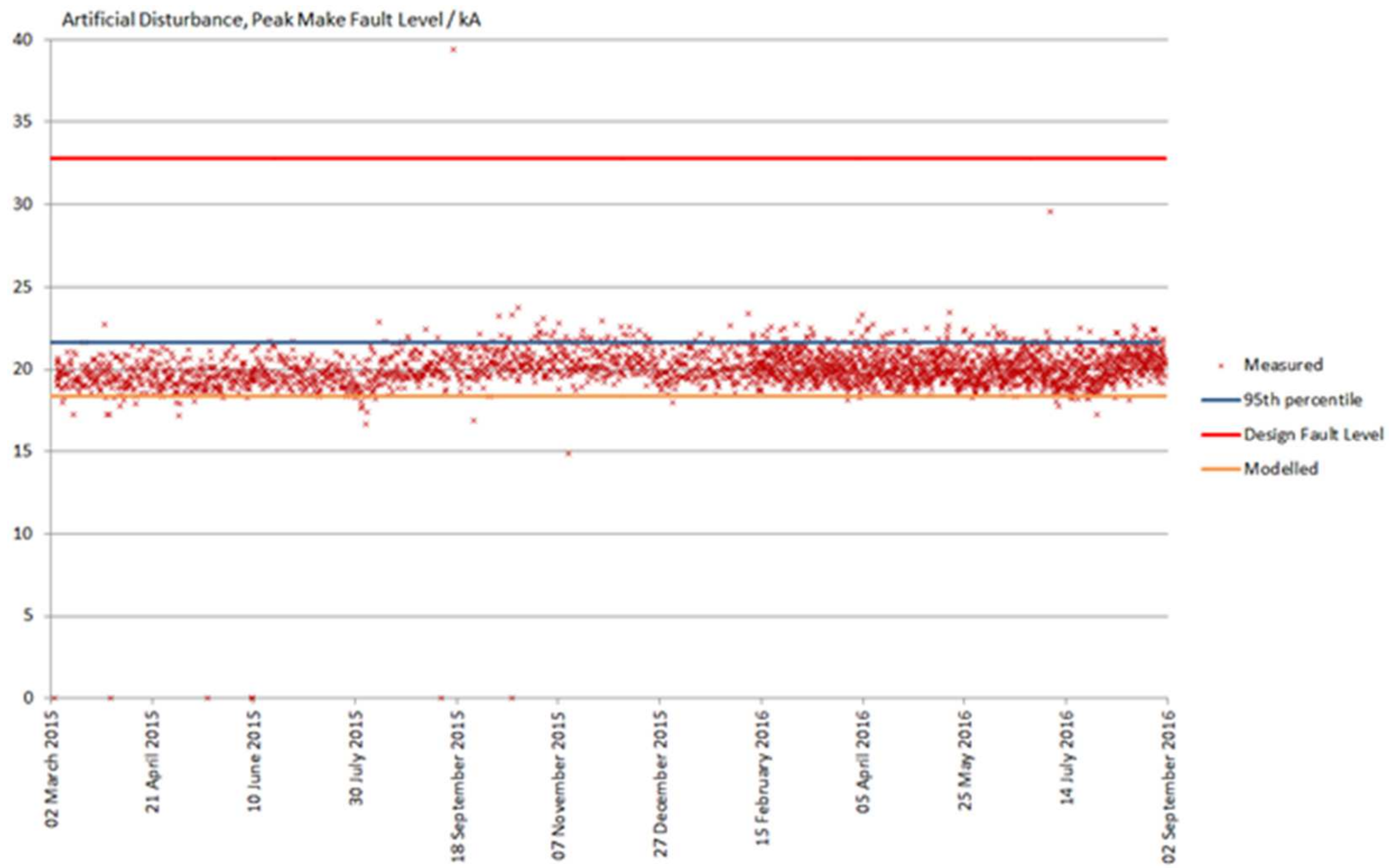
Aims

- Compare FLM results to current modelled values
- Generate new Fault Level headroom for each substation
- Use FLM to inform network configuration changes
- Develop Fault Level infeed template
  - New MVA/MVA infeed value based on load type
  - New value for application at non FlexDGrid substation

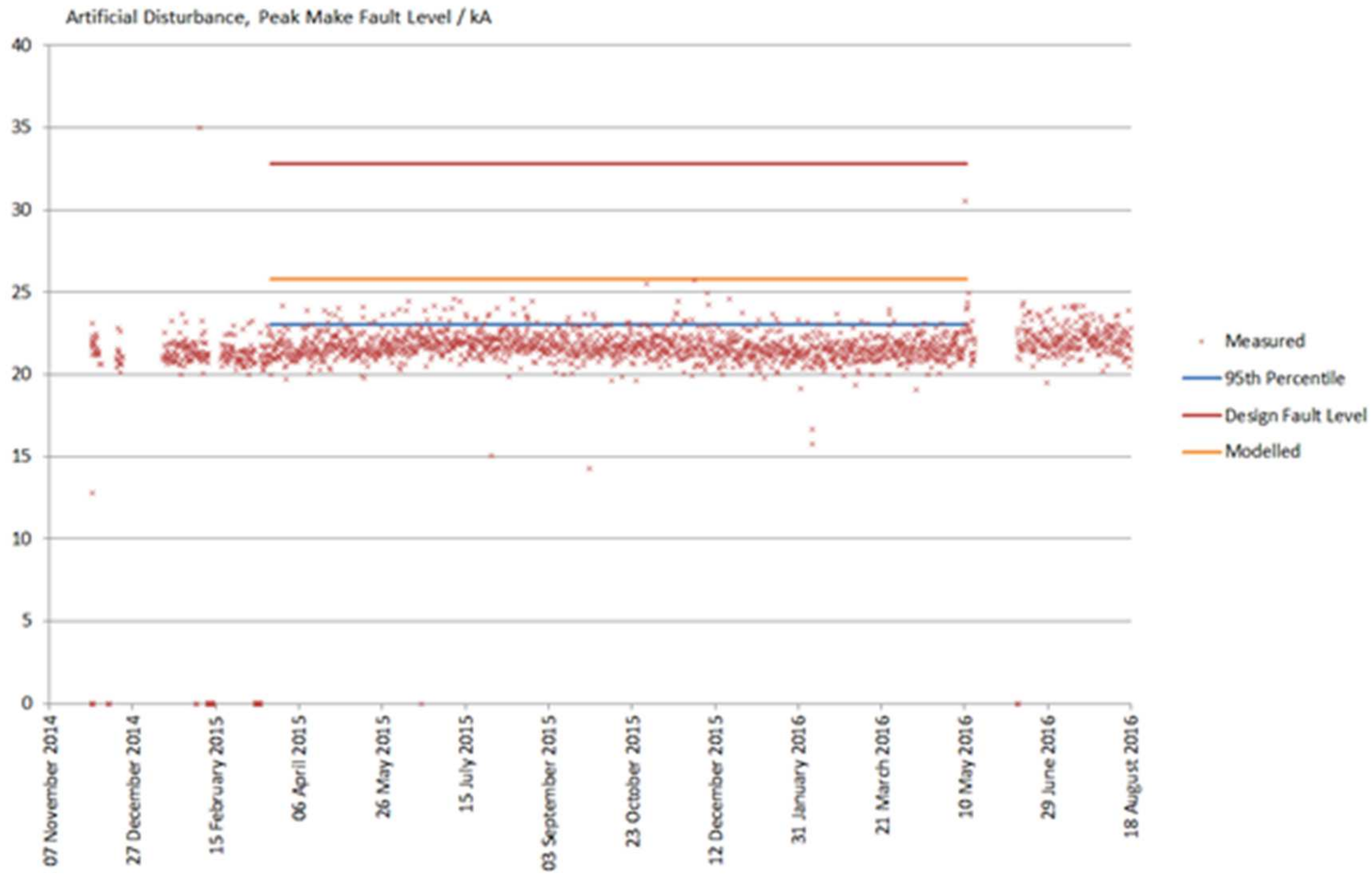
Fault Level Comparison

- Using 12 months of fault level data from FLMs
- 95th percentile fault level was calculated for each FLM
  - Provides a conservative value for maximum fault level
- Comparison made to design fault level and existing modelled fault level
- % available headroom calculated at each substation based on FLM result

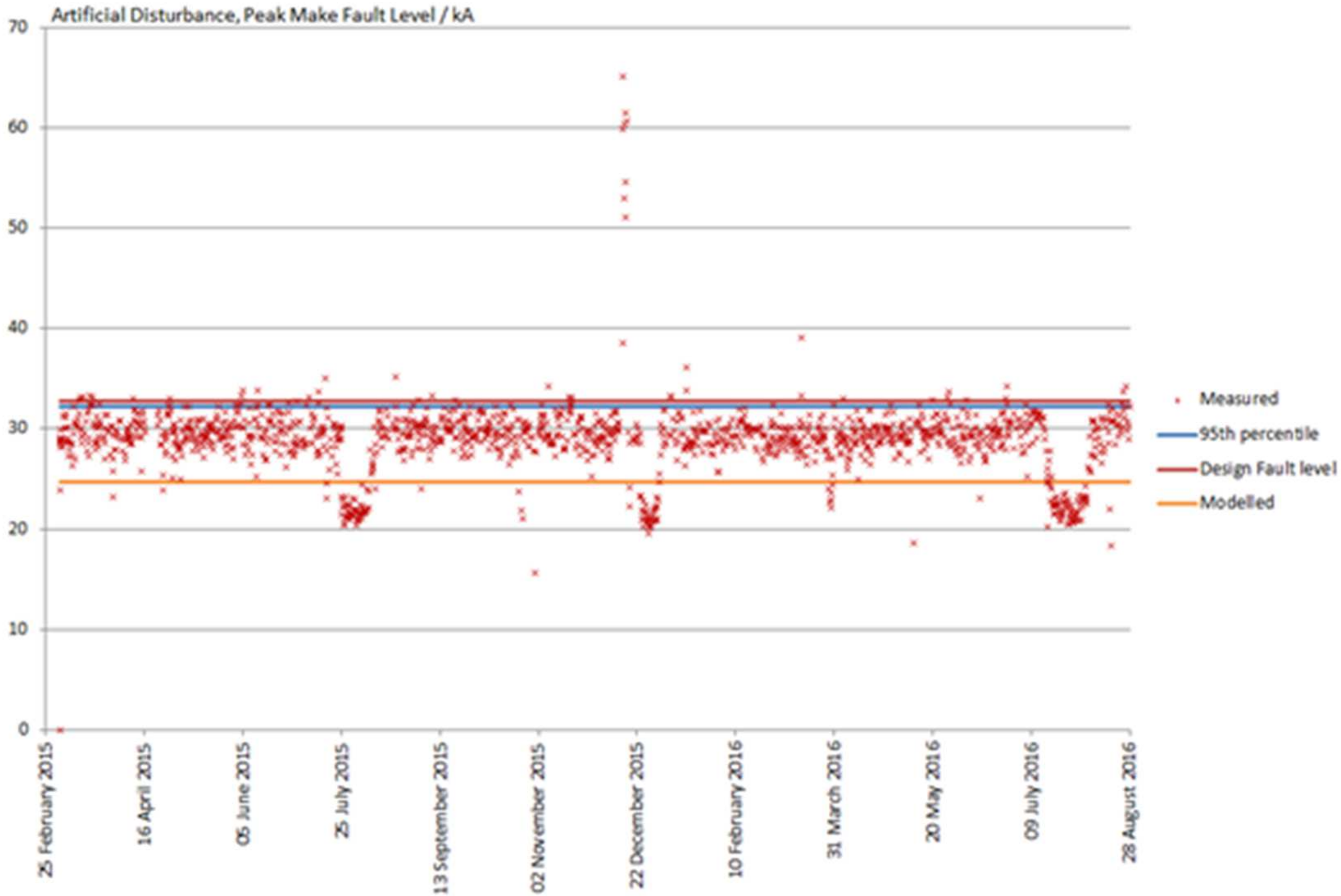
Fault Level Comparison - Elmdon



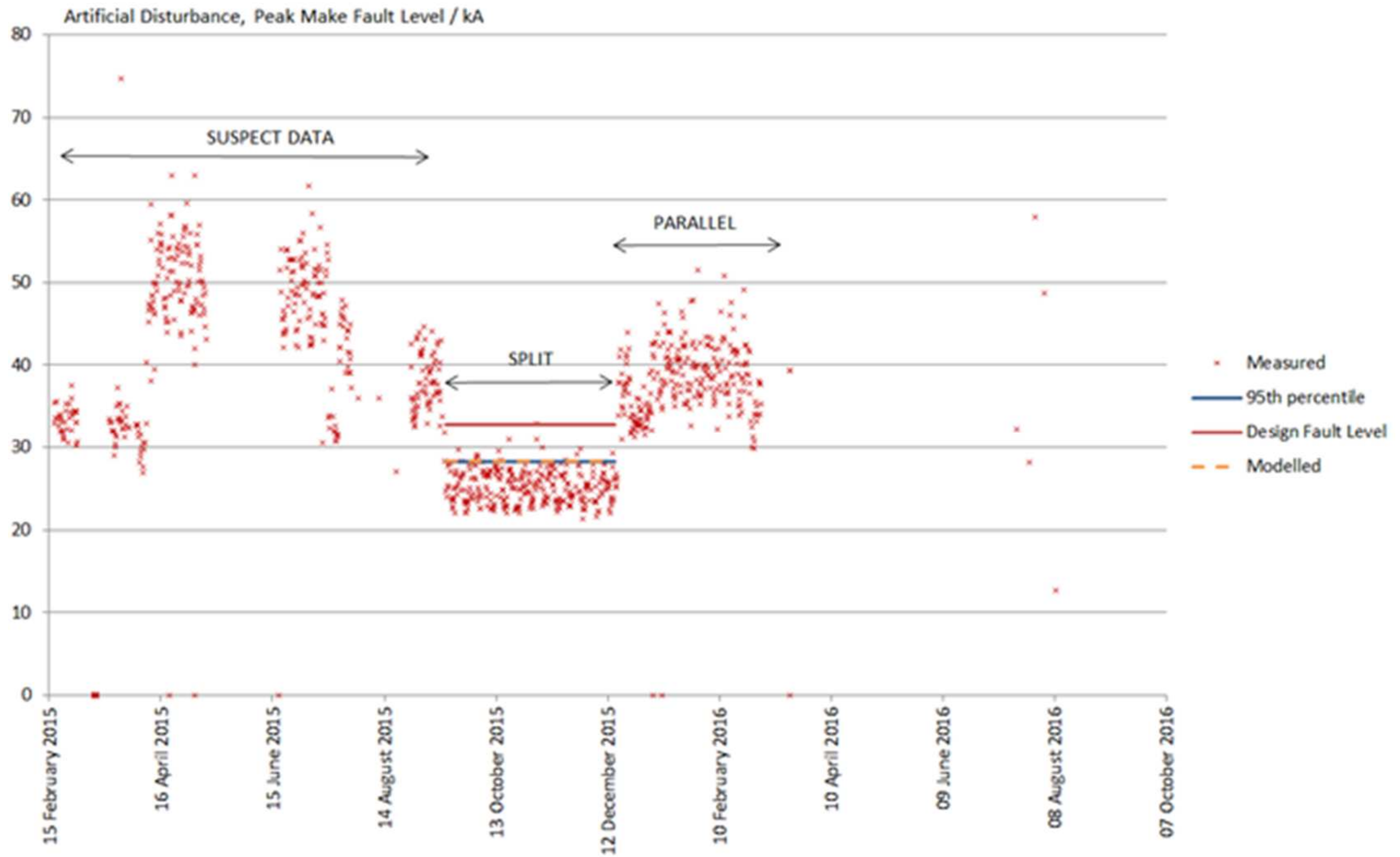
Fault Level Comparison – Chad Valley



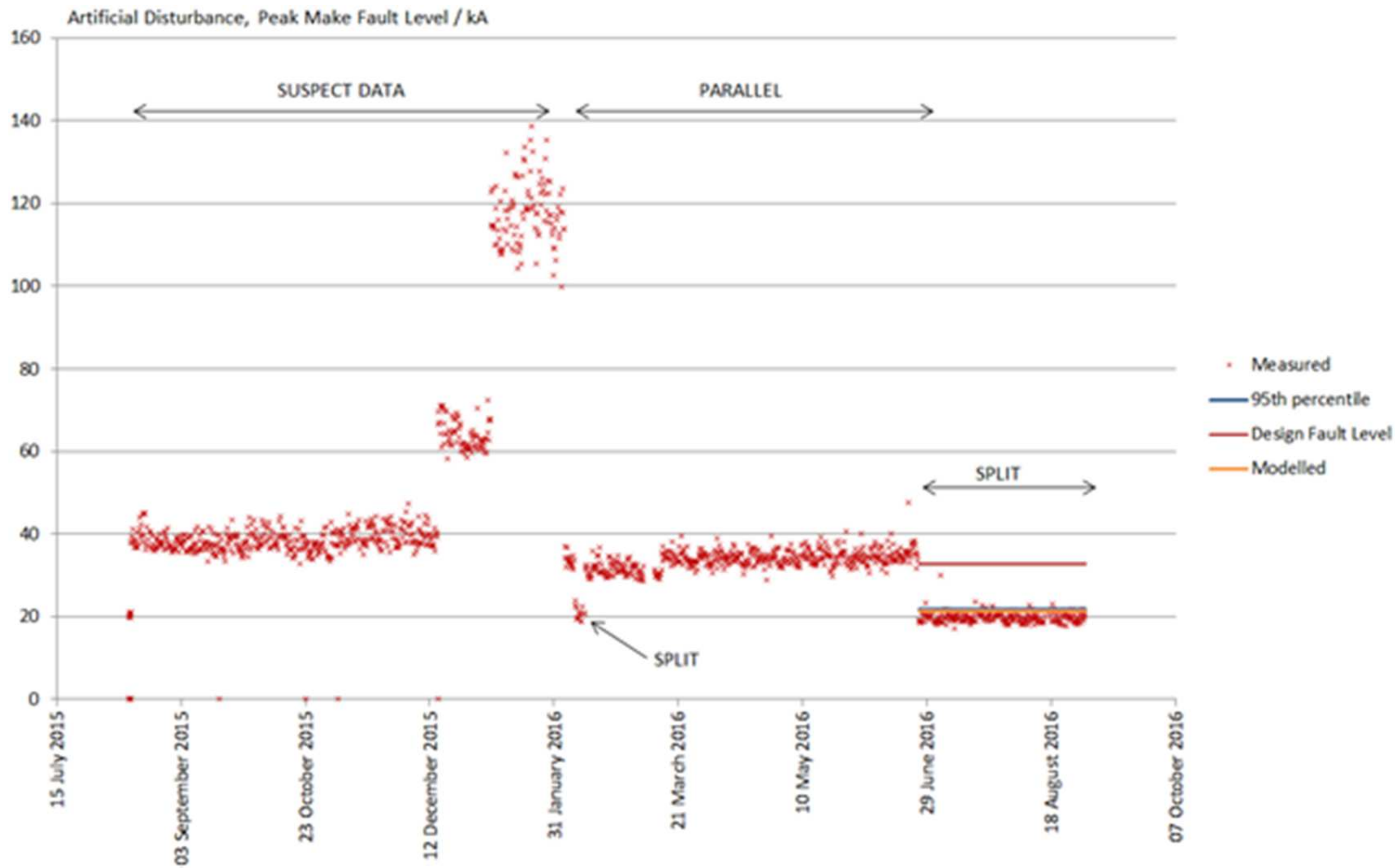
Fault Level Comparison – Kitts Green



Fault Level Comparison – Castle Bromwich



Fault Level Comparison – Chester Street



Fault Level Comparison - Peak Make

	Modelled / kA	Measured Mean / kA	Measured 95th percentile / kA
Bartley Green	21.7	19.3	21.3
Bournville	24.8	22.2	23.8
Castle Bromwich	28.3	25.3	28.3
Chad Valley	25.8	21.8	23.1
Chester Street	21.4	19.8	21.8
Elmdon	18.4	19.8	21.6
Hall Green	22.6	20.1	21.7
Kitts Green	24.7	29.1	32.2
Nechells West	34.8	32.9	37.0
Shirley	17.6	17.9	18.9

Available Headroom – Peak Make

	Current Headroom /%	FLM Headroom / %	% Change
Bartley Green	35.0%	36.2%	1.2%
Bournville	25.7%	28.7%	3.0%
Castle Bromwich	15.3%	15.3%	0.0%
Chad Valley	22.8%	30.8%	8.1%
Chester Street	35.9%	34.7%	-1.2%
Elmdon	44.9%	35.3%	-9.6%
Hall Green	32.3%	35.0%	2.7%
Kitts Green	26.0%	3.6%	-22.5%
Nechells West	-4.2%	-10.8%	-6.6%
Shirley	47.3%	43.4%	-3.9%

Fault Level Comparison – RMS Break

	Modelled / kA	Measured Mean / kA	Measured 95th percentile / kA
Bartley Green	7.6	7.7	8.4
Bournville	8.7	8.1	8.7
Castle Bromwich	9.9	10.0	11.4
Chad Valley	9.0	9.1	9.4
Chester Street	7.9	9.2	10.0
Elmdon	6.5	7.3	7.8
Hall Green	8.0	8.0	8.5
Kitts Green	8.5	11.3	12.5
Nechells West	11.6	12.2	13.4
Shirley	6.2	9.2	9.6

Available Headroom – RMS Break

	Current Headroom /%	FLM Headroom / %	% Change
Bartley Green	42.0%	35.9%	-6.1%
Bournville	33.6%	33.6%	0.0%
Castle Bromwich	24.4%	13.0%	-11.5%
Chad Valley	31.3%	28.2%	-3.1%
Chester Street	39.7%	23.7%	-16.0%
Elmdon	50.4%	40.5%	-9.9%
Hall Green	38.9%	35.1%	-3.8%
Kitts Green	35.1%	4.6%	-30.5%
Nechells West	11.5%	-2.3%	-13.7%
Shirley	52.7%	26.7%	-26.0%

MVA/MVA Template

G74 states:

For load connected to the supply network at:

- Low voltage allow 1.0 MVA per MVA of aggregate low-voltage network substation winter demand
- High voltage allow 2.6 MVA per MVA of aggregate winter demand

MVA/MVA Template

- Aim to use FLM Artificial and Natural Disturbance data with substation load information to calculate a substation specific MVA/MVA infeed value
- Combining value from all FlexDGrid FLMs is it possible to generate a template to determine a suitable MVA/MVA fault infeed value for any substation.

FLM MVA/MVA Calculation

- AD data and ND data compared and difference (11kV contribution) determined
- Total load at time of FLM operation calculated from PM7000 Volts and Amps
- Results averaged over time to provide a single figure

	Calculated MVA/MVA Infeed
Bartley Green	0.9
Bournville	1.0
Castle Bomwich	6.0
Chad Valley	0.8
Chester Street	5.5
Elmdon	2.8
Hall Green	1.3
Kitts Green	4.2
Nechalls West	5.8
Shirley	3.5

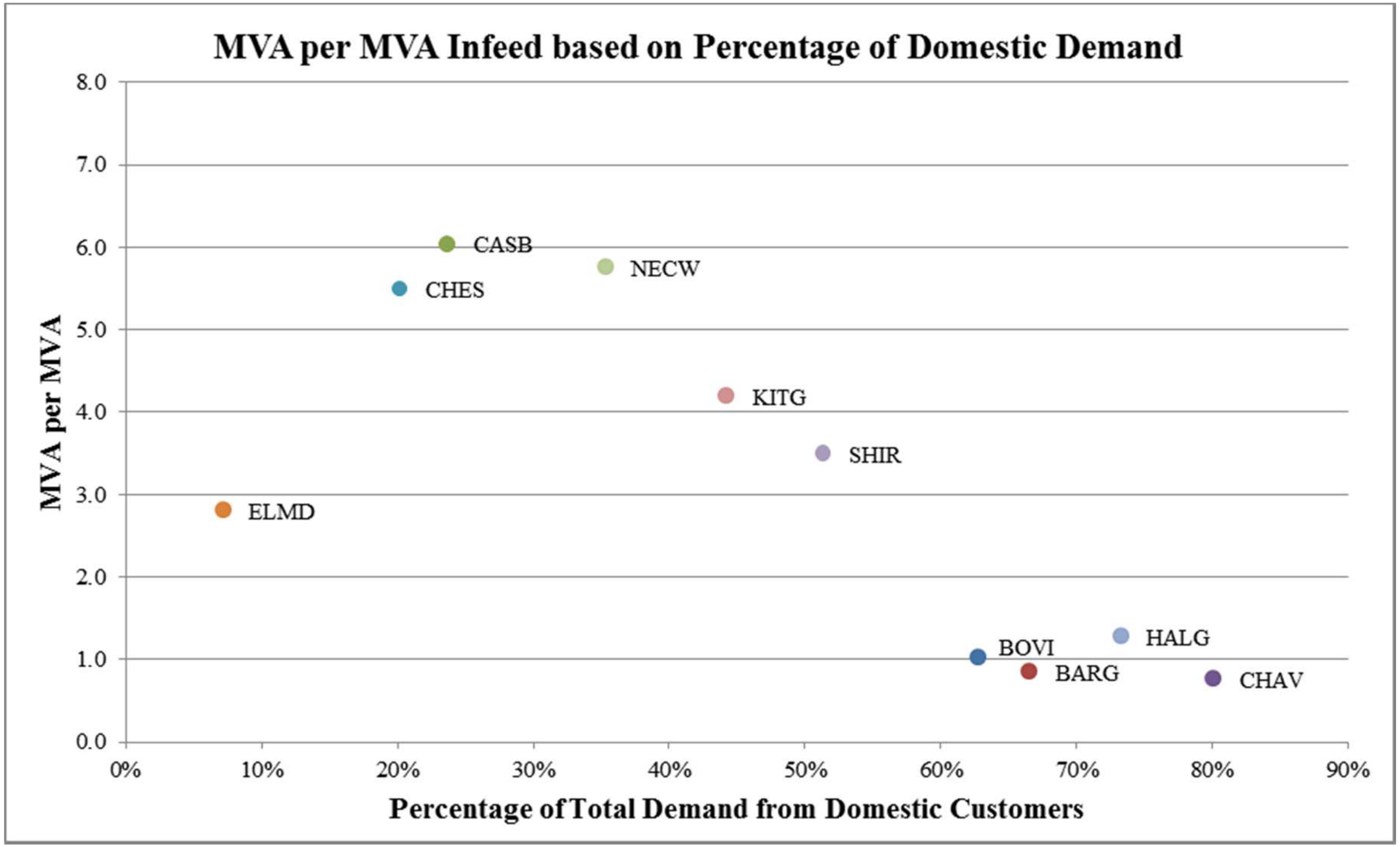
Substation Load Breakdown

– Available customer metering data from each substation amalgamated into three categories

– Further analysis of FLM network to determine load connected to that section of the substation

Substation	% Demand on AFLM Network		
	Domestic	Small Com/Ind	Large Com/Ind
Bartley Green	67%	20%	14%
Bournville	63%	14%	23%
Castle Bromwich	24%	10%	66%
Chad Valley	80%	11%	9%
Chester Street	20%	19%	61%
Elmdon	7%	7%	86%
Hall Green	73%	19%	7%
Kitts Green	44%	14%	42%
Nechalls West	35%	24%	41%
Shirley	51%	25%	23%

MVA/MVA Template



Proposed MVA/MVA Infeed Values

Load	G74 MVA per MVA Infeed
Majority Domestic	1.0
Split Domestic/Industrial	3.0
Majority Commercial	3.0
Majority Industrial	5.0

- Industrial substations showing values above 5.0 MVA/MVA. Decided to limit contribution to 5.0 as per typical contribution from synchronous generation
- Domestic dominated substations remain around 1.0 MVA/MVA contribution
- Commercial and substations with 50/50 split recommended 3.0 MVA/MVA

Template Trial

- Ladywood substation used for trial of template
- FLM installed as part of Tier 1 LCNF Project
- Load split
  - 15% Domestic
  - 20% Small Commercial/Industrial
  - 65% Large Commercial/Industrial
- Substation located in center of city. Mainly commercial rather than industrial
  - Recommend an MVA/MVA infeed of 3.0

Results

	MVA/MVA	11kV Fault Level
EFLA - G74	1.0	19.4 kA
EFLA - FlexDGrid	3.0	23.4 kA
FLM	2.7	21.5 kA

- FLM MVA/MVA result very close to the recommended value
- Discrepancy in Fault level between EFLA and FLM due to 1kA difference in upstream contribution
- Further analysis and research of the 132kV network required to determine difference in upstream contributions

Lessons

- FlexDGrid has shown that 1.0 MVA/MVA general load fault infeed value at 11kV is no longer valid at all substations

- Further analysis at a wider range of substations required to come to a definitive conclusion
  - Further development of FLM required to enable easier installation
  - Reduction of ±5% accuracy of device

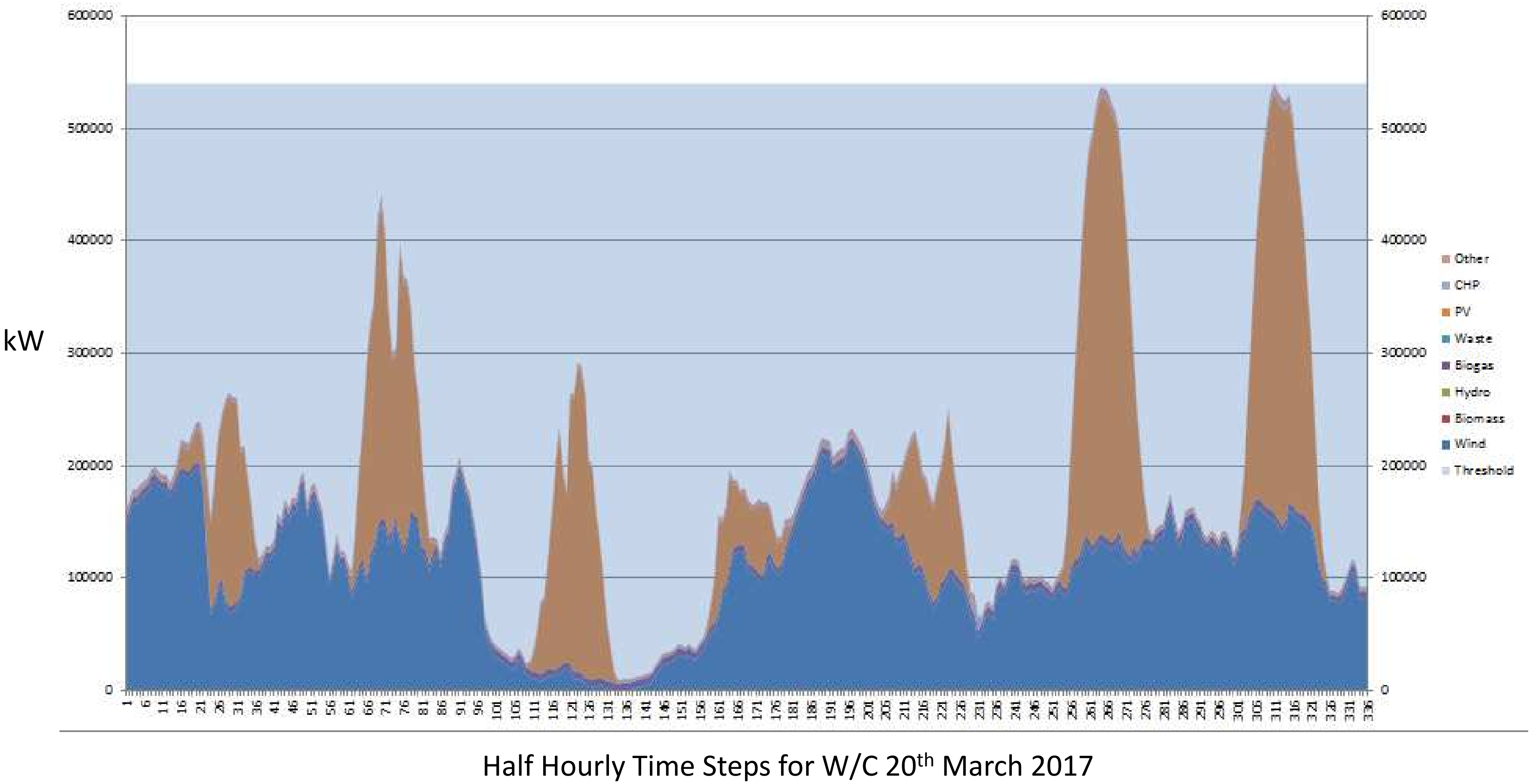
FL Alternative Connections - Overview

- Alternative Connections Background
- Comparison with Existing Offerings and Key Decision Points
- Fault Level Soft-Intertrip Development
- Final Key Points

Alternative Connections

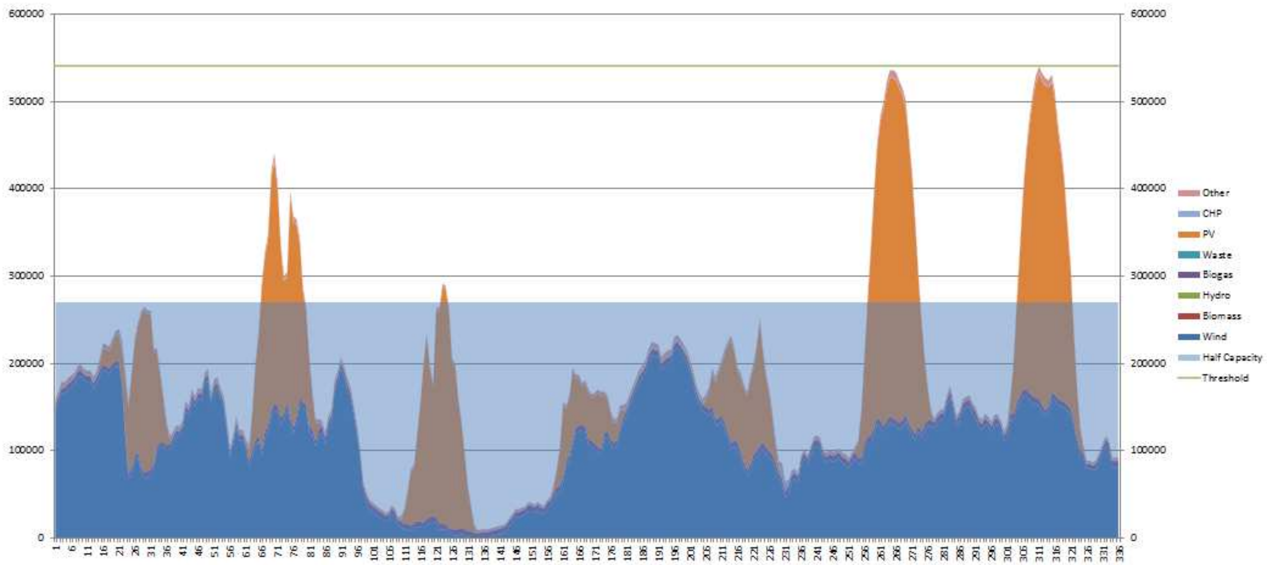
- Developed as parts of the network became ‘full’
- ‘Full’ = Limitations from Thermal, Voltage, Protection or Fault Level
- Customers must be willing to accept some level of curtailment in return for a saving in reinforcement costs and timescales
- Level of curtailment can be fixed or dynamic
- WPD currently has four options of increasing technicality

Alternative Connections



Alternative Connections

kW



Half Hourly Time Steps for W/C 20th March 2017

- 50% capacity available 85% of the time

Alternative Connections – Export Limiting

- Measures Apparent Power at Exit Point of connection
- Uses information to restrict the generation and/or balance the customer demand in order to prevent agreed ASC being exceeded
- Suitable for all capacities & voltage levels
- Reduces generators contribution to thermal or voltage infringements (Fault Level Restrictions may still apply)

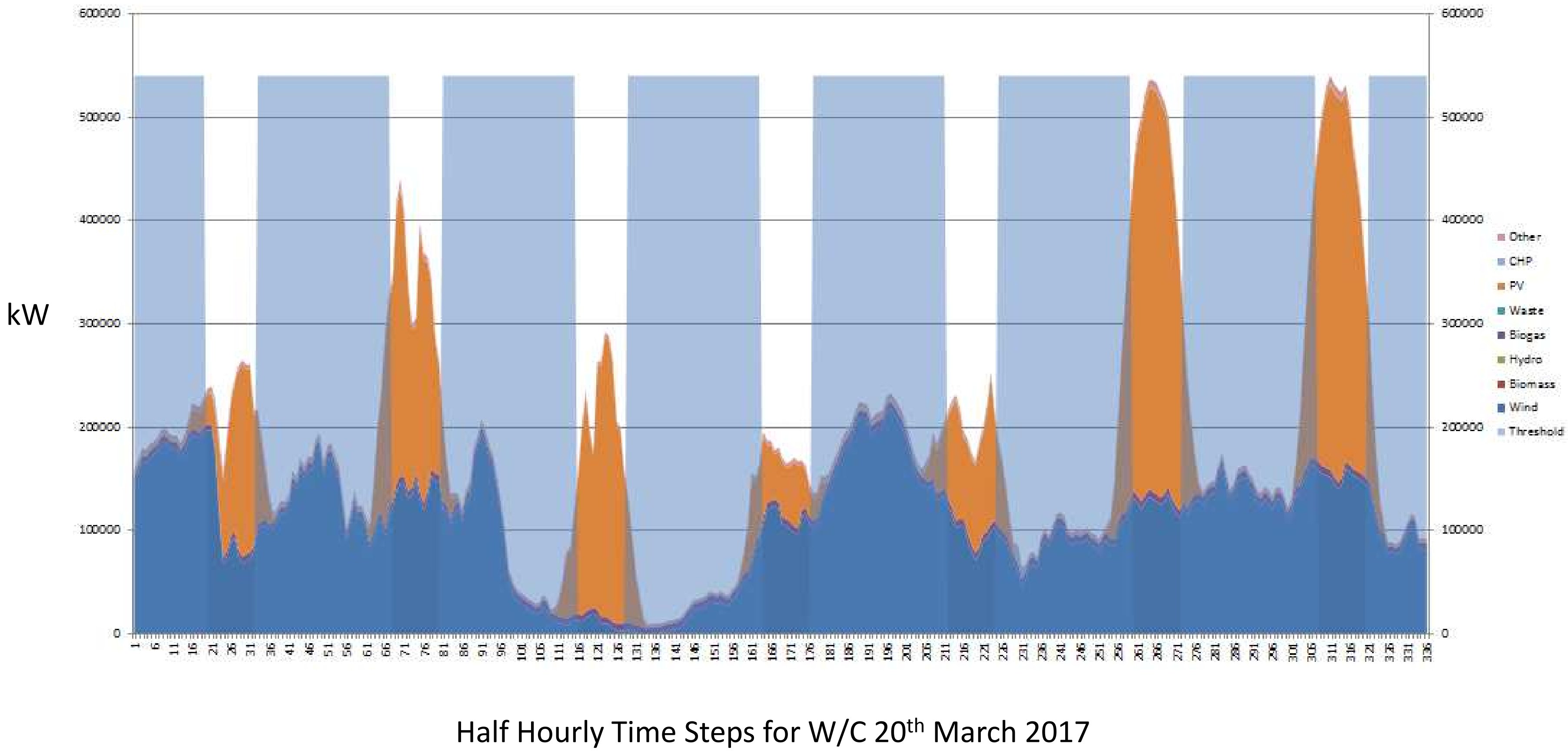
Alternative Connections - Timed

- Achievable where we have predictable load and generation patterns
- Connections will be given an operating schedule which will define times and levels of capacity available
- Typical constraint times;

Period	10am to 4pm	4pm to 10am
October to March	No Constraint	No Constraint
April to September	30% of full output	No Constraint
May to August	0% of full output	No Constraint

- Method of curtailment provided by WPD or customer
- Suitable for sub 1MVA generation installs

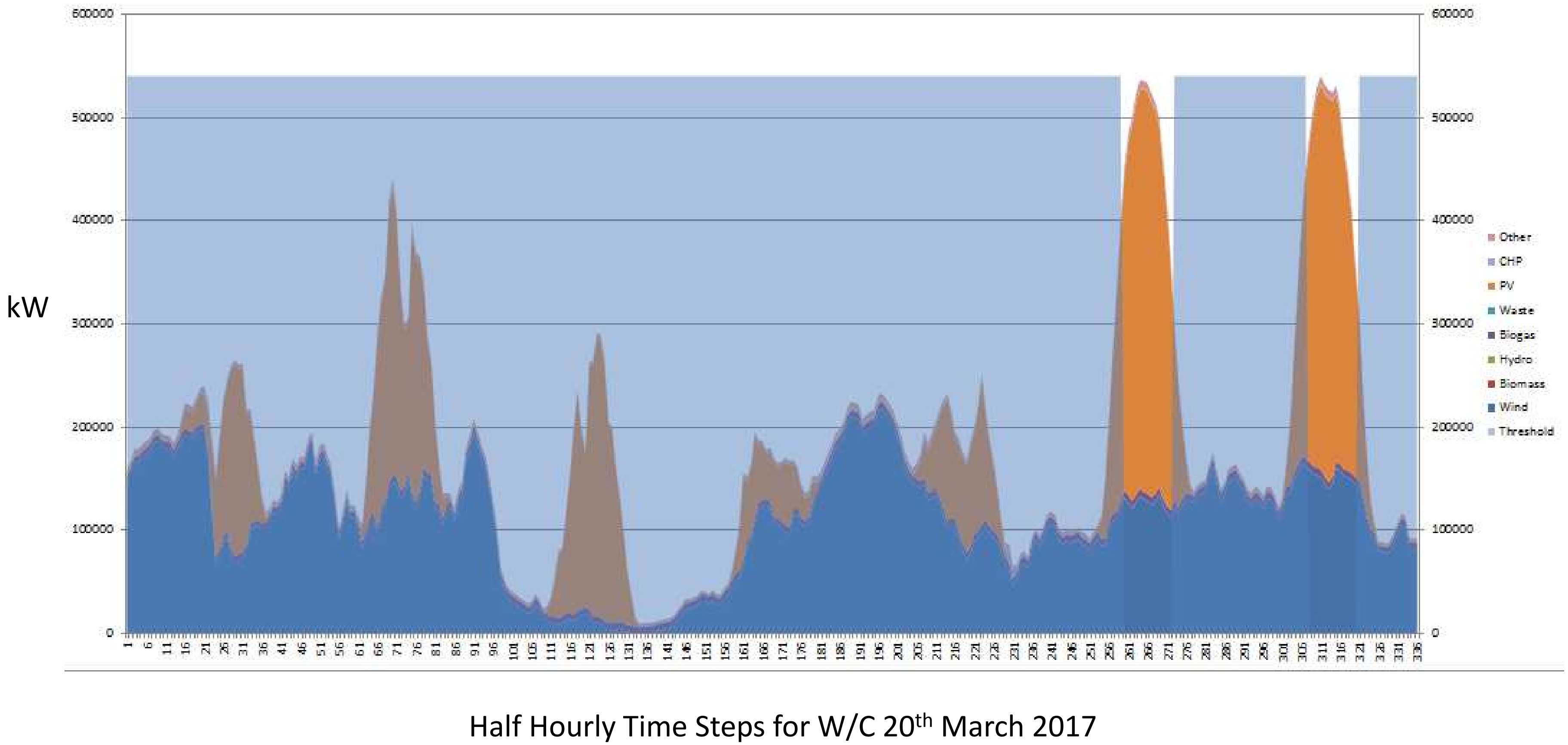
Alternative Connections - Timed



Alternative Connections – Soft-Intertrip

- Network Constrained by a single upstream asset requiring reinforcement
- Through monitoring these conditions using the network management system, further capacity can be released when these limits or assets are within normal operating parameters
- On-site WPD RTU issues two stages of constraint – 30% total output and 0% total output
- Suitable for all generator applications connecting at HV or with an export level of 250kW and above
- Limited participants per area
- Can monitor Transformer Reverse Power, (N-1) Constraints, Voltage Constraints, Thermal Constraints

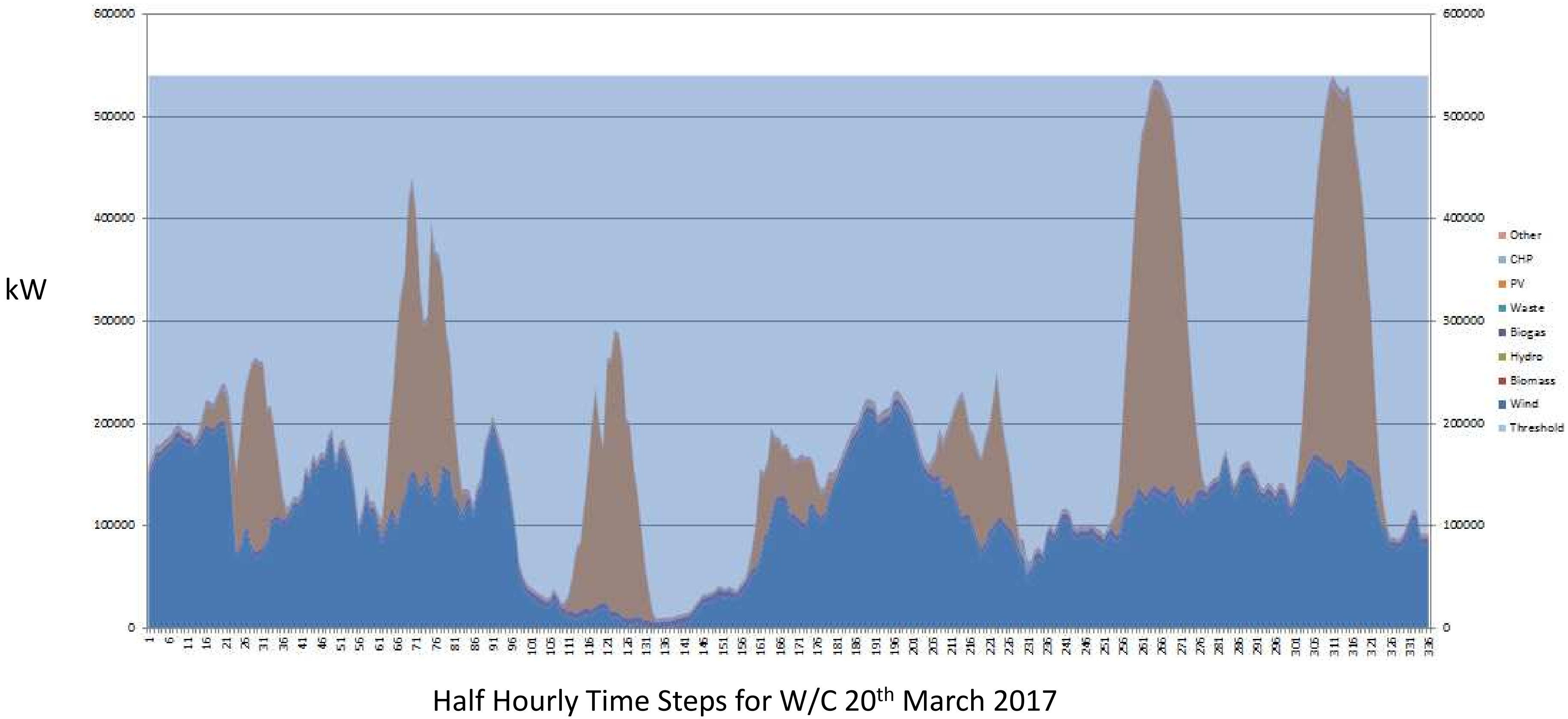
Alternative Connections – Soft-Intertrip



Alternative Connections – ANM

- 'Active Network Management'
- Multiple complex constraints affecting a number of customers
- Distributed control systems continually monitor all limits on the network then allocate the maximum capacity to customers in that area
- New ANM 'Zone' being rolled out every six months with a view to making the whole network available for customers to apply for an ANM connection by 2021

Alternative Connections – ANM



Alternative Connections – Fault Level

Aims

- Use the Fault Level Monitoring data to provide 'Quicker & Cheaper' connections for customers currently restricted by Fault Level constraints
- Takes advantage of real-time data to understand actual not worst-case fault level
- Ensure any solution is easy to roll-out to both customers and the business; both commercially and operationally.
- Trial with a customer

Alternative Connections – Comparisons to Existing

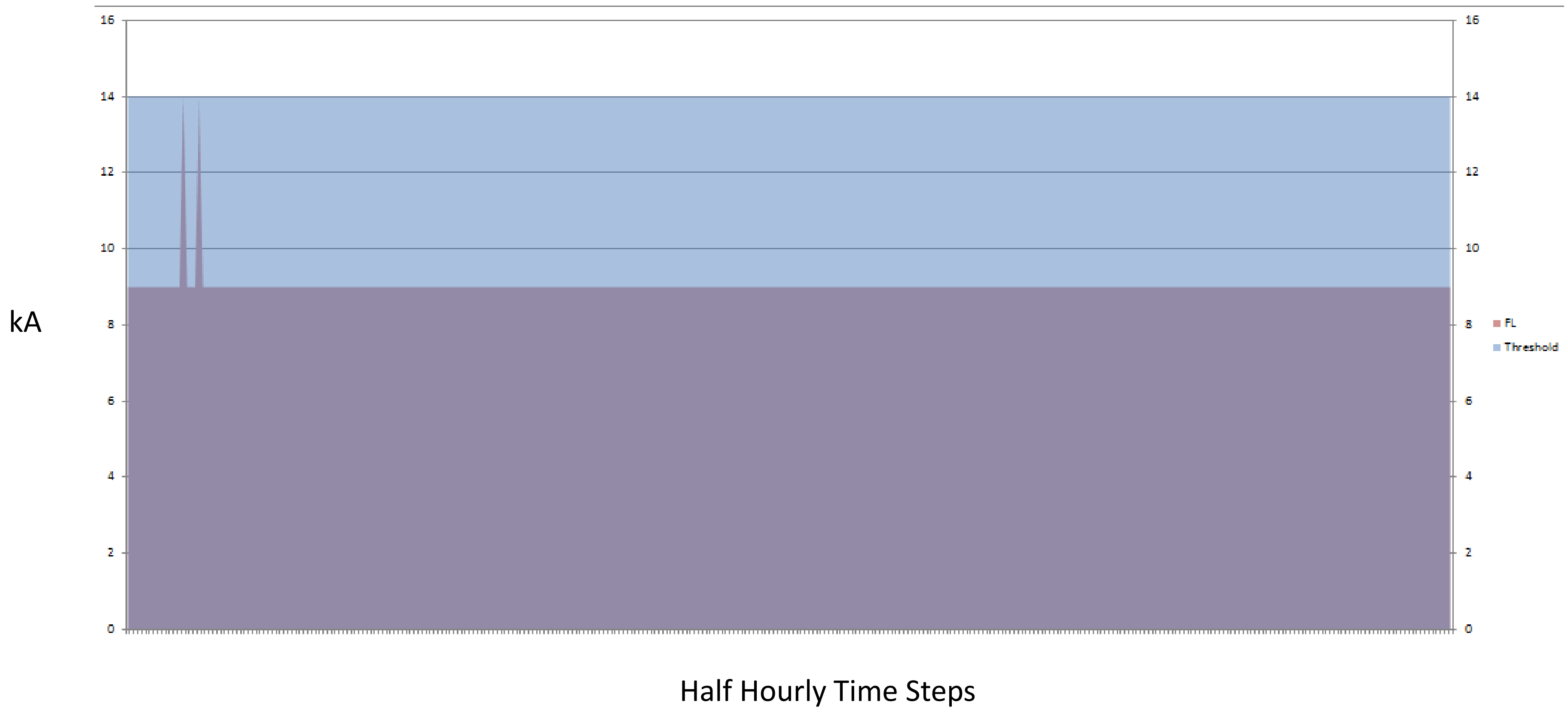
Limitations

- Constraints not seasonal or with any specific day / week patterns
- Export can not be limited – Must be totally disconnected
- Measurements not instantanious 'Real-Time' values
- No fall back protection operation

Strengths

- Periods of potential curtailment well understood in advance

Alternative Connections – Comparisons



Fault Level – Potential Solution

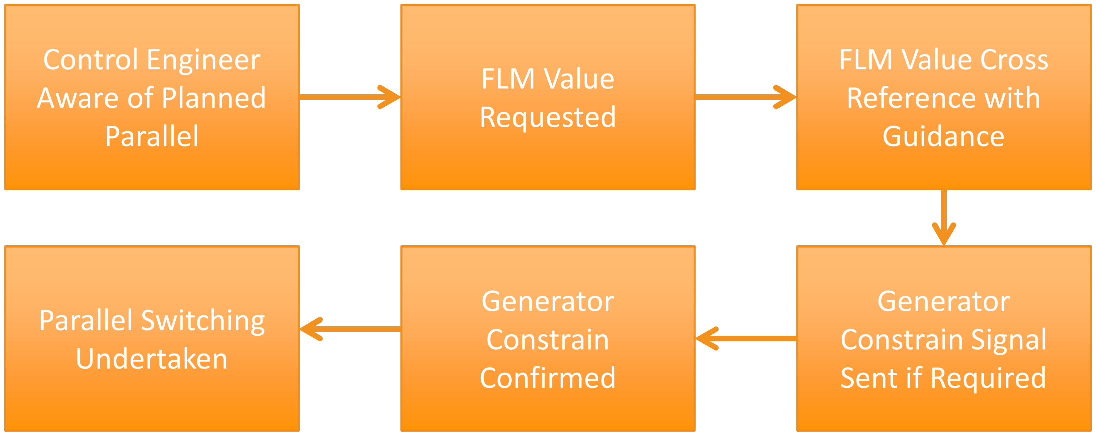
ANM

- Ideal scenario
- Nature of 'Real-Time' data makes conventional implementation not possible
- Costs associated with full ANM integration ruled it out as part of the project
- However, Fault Level Soft-Intertrip principles will need integrating in to ANM to cater for the possibility of both Fault Level and thermal constraints

Fault Level – Proposed Solution

Soft-Intertrip

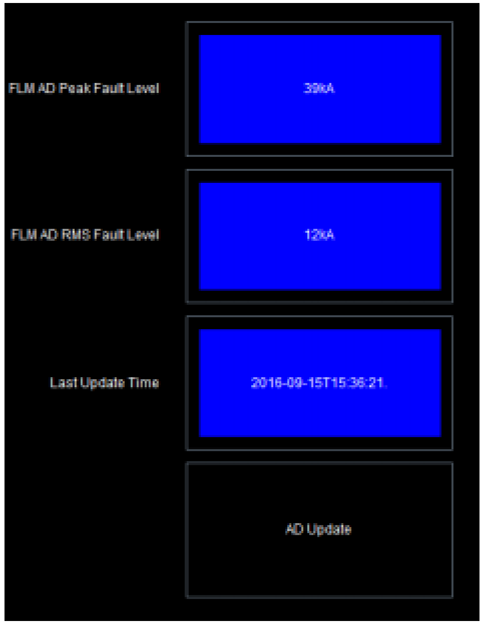
- Simpler and Cheaper installation
- Existing Soft-Intertrip coding can be altered internally to include an operator in the loop for the final decision



Fault Level Soft Intertrip - Development

Power-On Integration

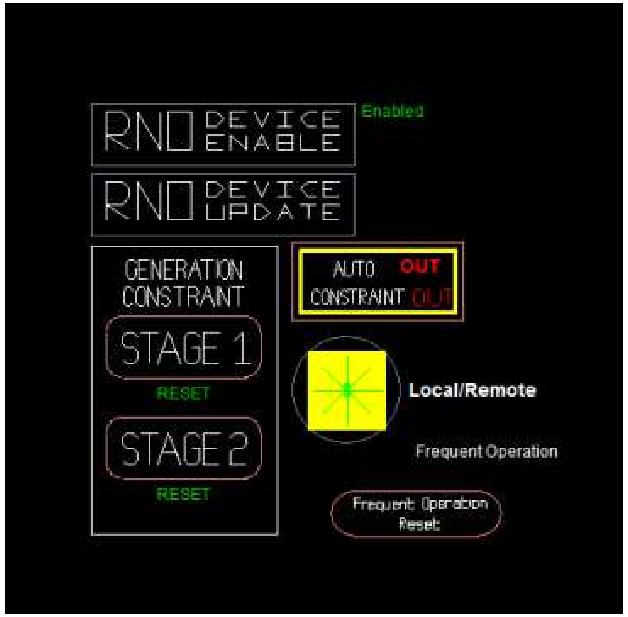
- Routed FLM data in to the WPD corporate network
- Created FLM PoF interface
- Developed 'On-Demand' Intellirupter control



Fault Level Soft Intertrip - Development

Generator End RTU

- Generator constraint panel already capable of opening and return status of G59 breaker; settings amendments required.



Fault Level Soft Intertrip - Development

Trial Customer

- Nechells West
- Existing on-site Is Limiter at the end of its useful working life. Two large CHP and One 800kVA Gas Generator
- Interested to understand the impact on their business
- Installed solution up to the generator to prove and provide visual indication

Fault Level Soft Intertrip -

Trial Customer

- Off-Line calculations to establish thresholds

FLM Value (kA)	Mitigating Actions
≥12.705	No Acceptable Mitigating Actions Available
12.190 to 12.704	800kVA Gas Generator Disconnected 4.7MVA CHP Disconnected Bus-Section Z-Y Open
10.675 to 12.189	4.7MVA CHP Disconnected Bus-Section Z-Y Open
≤10.674	Bus-Section Z-Y Open

Fault Level Soft Intertrip -

Trial Customer

- Curtailment

Mitigating Action	Av. No. of Actions per Year	Average Length of Action (Minutes)	Typical Times When Action May be Required	
800kVA Gas Generator Disconnected	1.16	3	9.30am	2.30pm to 4.30pm
4.7MVA CHP Disconnected	2.52			

- Costs

  FLM Solution = £91k

  Conventional = Approx. £300k and three years

- Updated policies, offer letter, connection agreement and curtailment studies

Fault Level Soft-Intertrip – Final Key Points

- Two types of Fault-Level Soft-Intertrip available – with and without FLM infeed

Mitigating Action	Av. No. of Actions per Year	Average Length of Action (Minutes)	Typical Times When Action May be Required	
800kVA Gas Generator Disconnected	4	3	9.30am	2.30pm to 4.30pm
4.7MVA CHP Disconnected	4			

- Customer potentially saves an additional £66k by accepting a couple more curtailments a year; depending on process criticality.
- Requirements to integrate with ANM solutions in the future for the scenarios where multiple constraints exist
- Currently 56 similar size sites with the potential for similar Fault Level based savings.

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Questions?

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

COFFEE BREAK

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Technical Dissemination

FCLs: Operation and Benefits

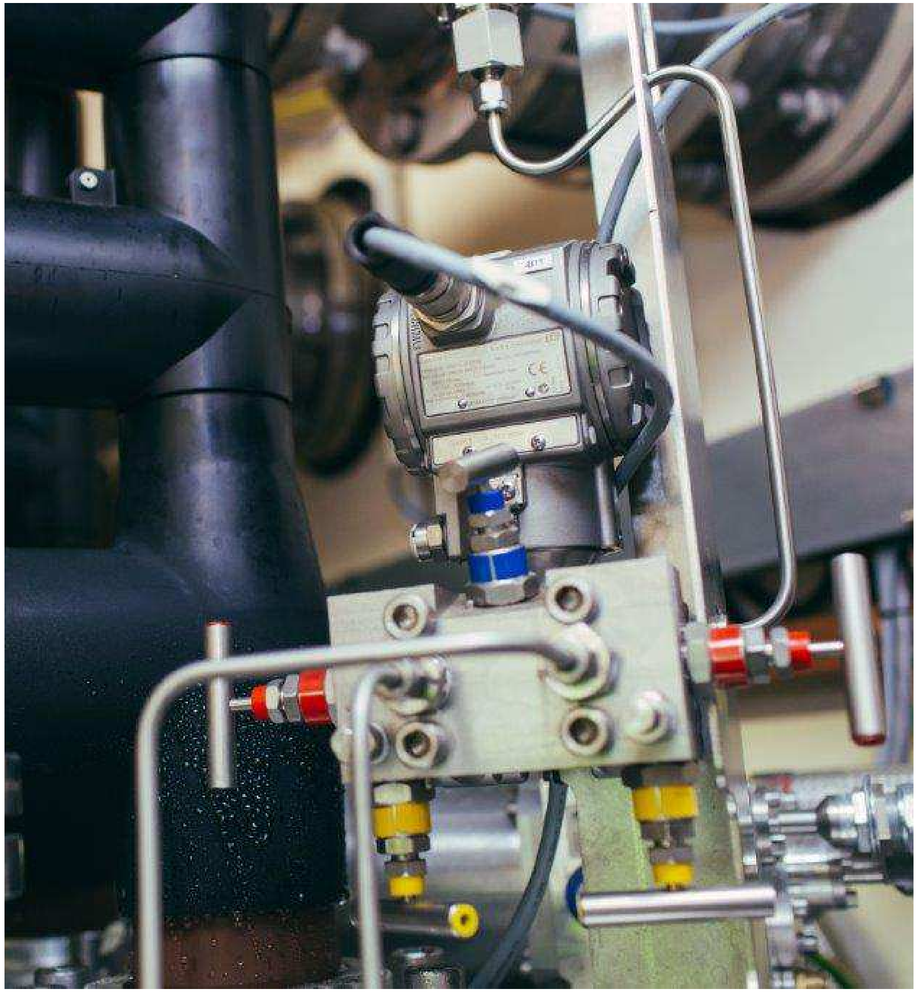
LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Introduction

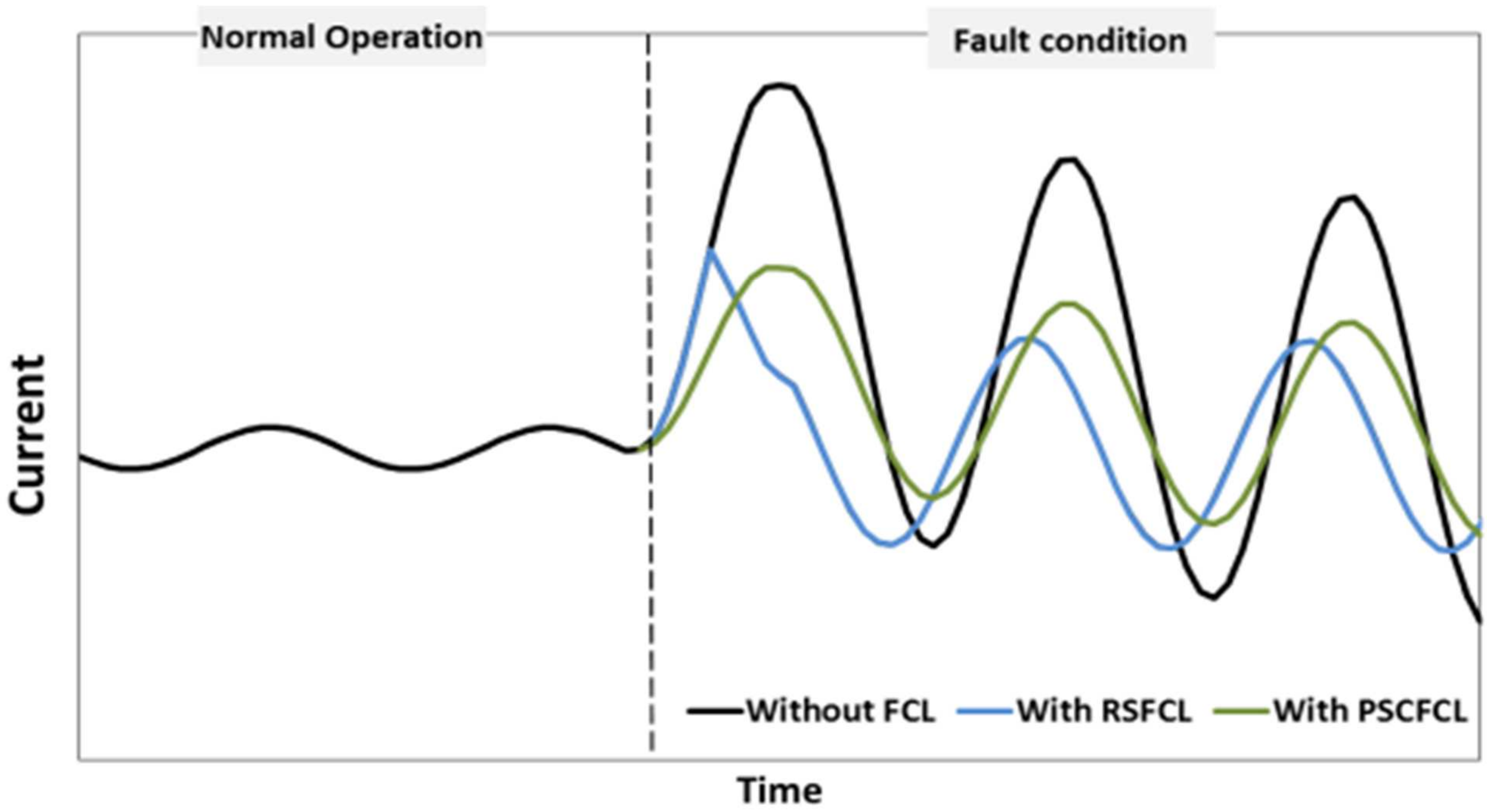
- FCL Modelling
- Policy documentation
- Power Consumption
- PSCFCL and RSFCL
    - —Fault level reduction
    - —Technology operation
    - —Learning points
- Benefits



FCL modelling - PSCFCL and RSFCL

- Detailed parameters of the device were not provided by the manufacturers due to confidentiality issues;
- Transient models could not be constructed using conventional power system analysis tools; and
- Detailed technical knowledge for transient modelling and analysis of the device was required.

FCL Modelling - Transient behaviour



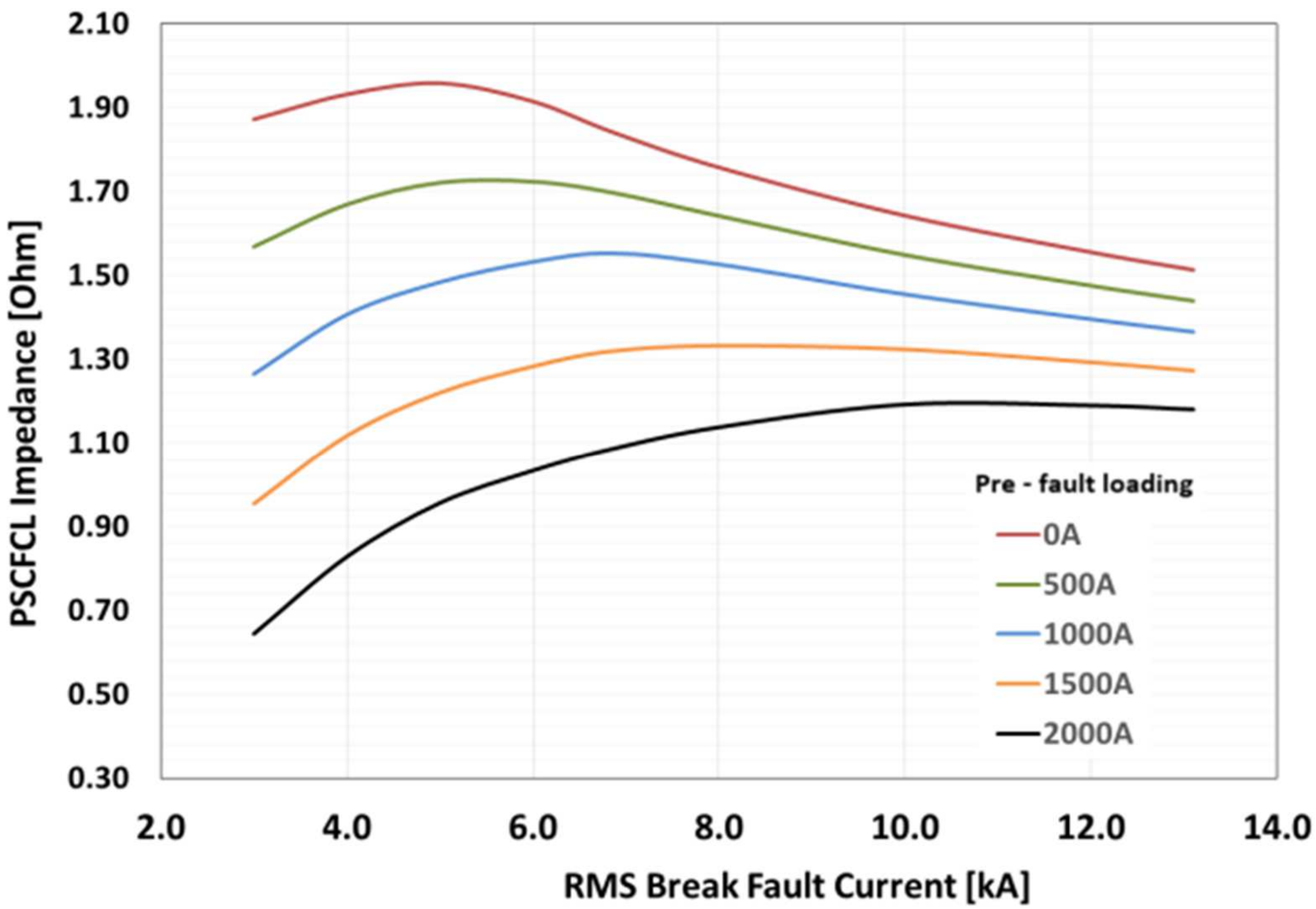
FCL Modelling – Static modelling

A fit-for-purpose computer model for FCLs may only include their behaviour at specific snapshots of the fault period e.g. Making and Breaking fault times

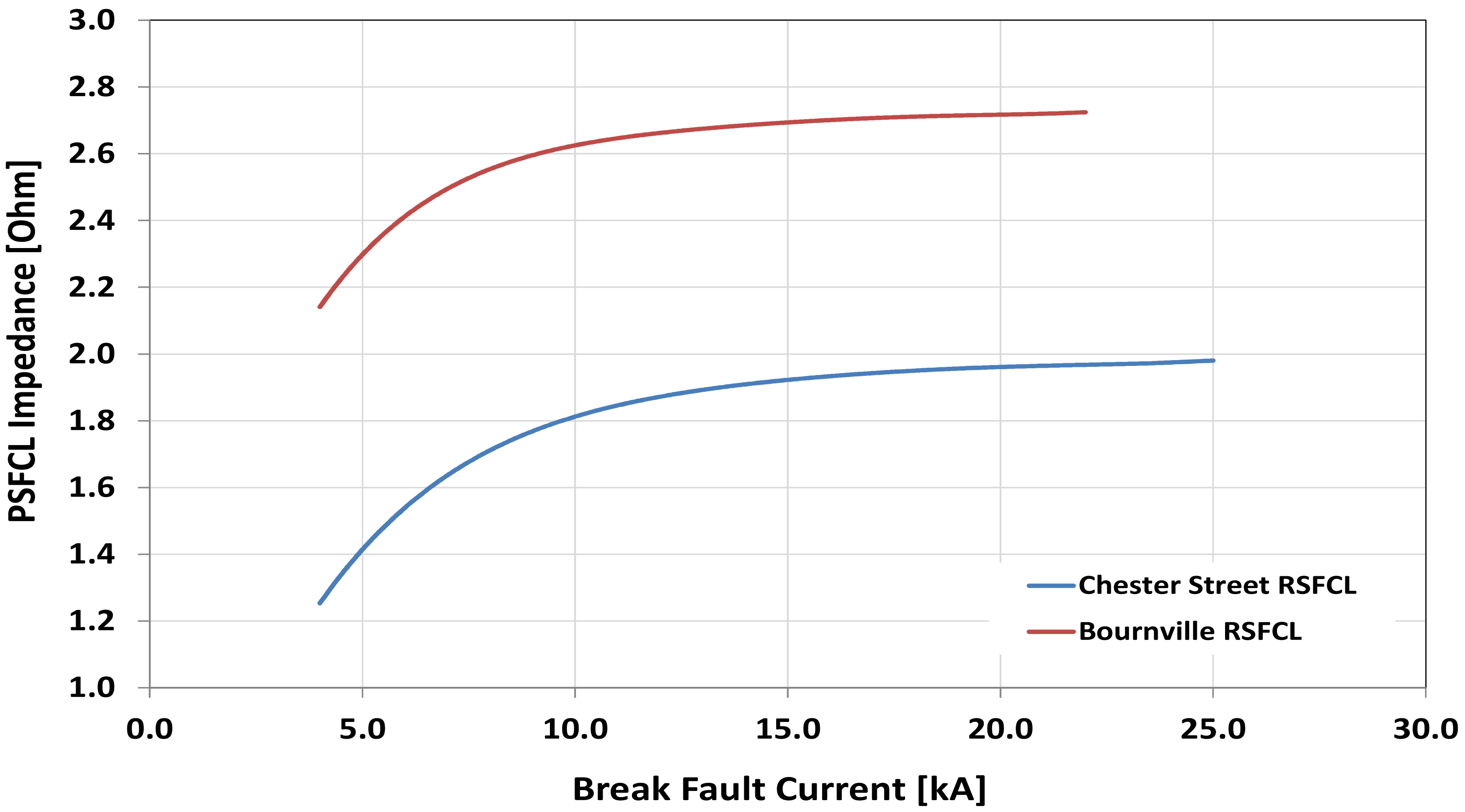
Stage I – Obtain device specific impedance data and create impedance look-up tables for prospective Make and Break fault currents.

Stage II – Deploy the FCL impedance look-up table in static short-circuit calculations.

Impedance at Breaking time (70ms) - PSCFCL



Impedance at Breaking time (70ms) - RSFCL

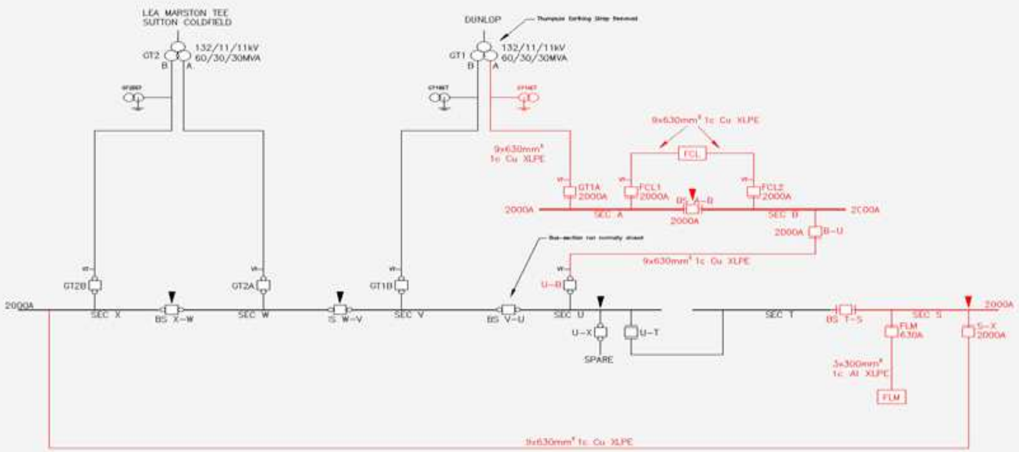


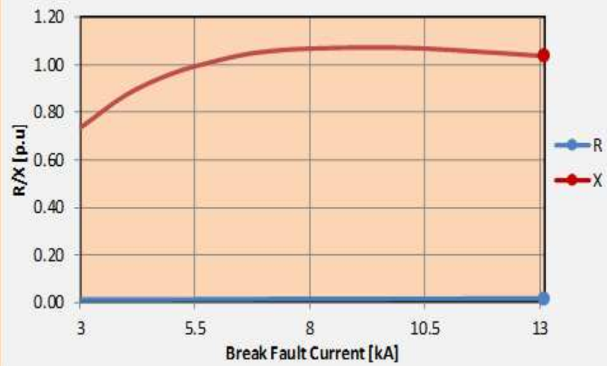
FCL Modelling

Fault current limiter technology

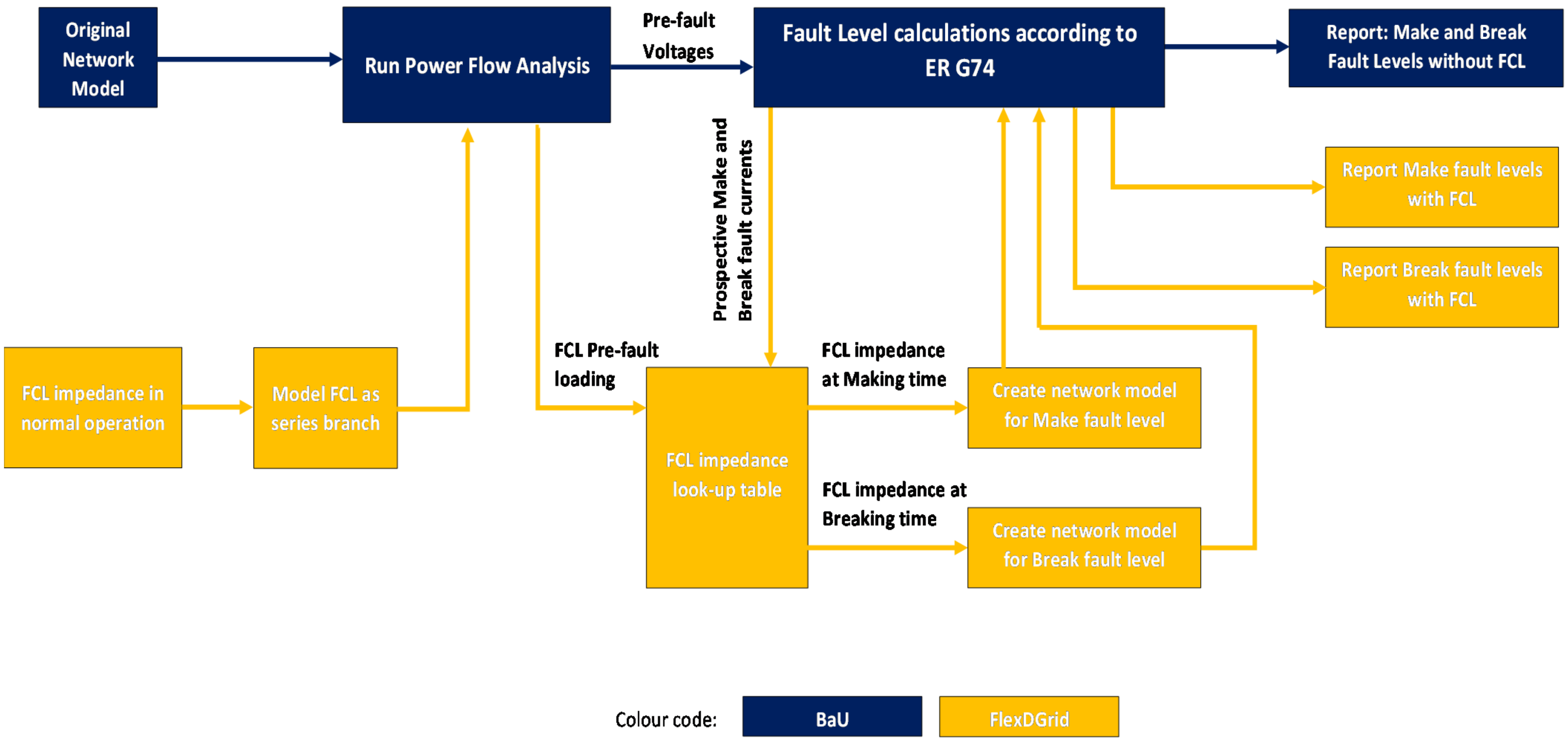
Pre saturated Core FCL Castle Bromwhich

Network conditions			R[p.u]	X[p.u]	R[Ohm]	X[Ohm]	Base Units	
Pre-fault FCL Loading	1600	A					Sb[MVA]	100
Prospective Make Fault Current	15.0	kA	0.01	0.88	0.02	1.06	Vb[kV]	11
Prospective Break Fault Current	13.1	kA	0.01	1.04	0.02	1.25	Zb[Ohm]	1.21

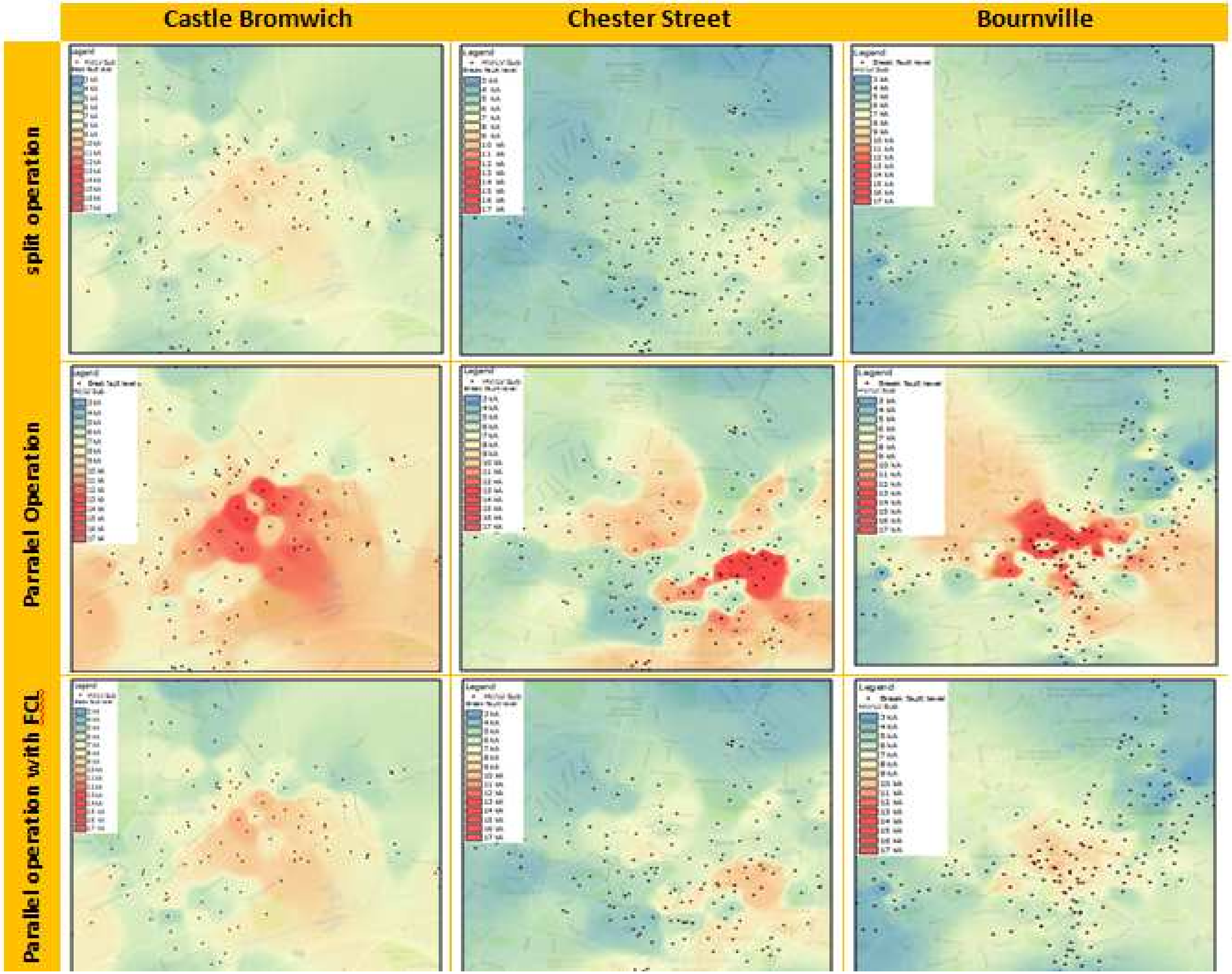




FCL Modelling - Methodology



Fault level heat maps



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	Phil Davies 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.

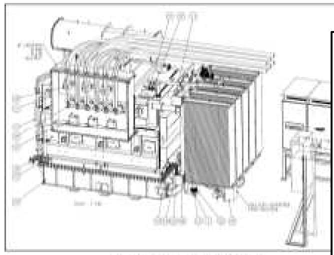


Figure 3-2: General Arrangement of FCL

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 adjacen… 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 (3… 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.

ST:OC1W June 2015 - 7 of 19 -

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.

ST:OC1W June 2015 - 12 of 19 -

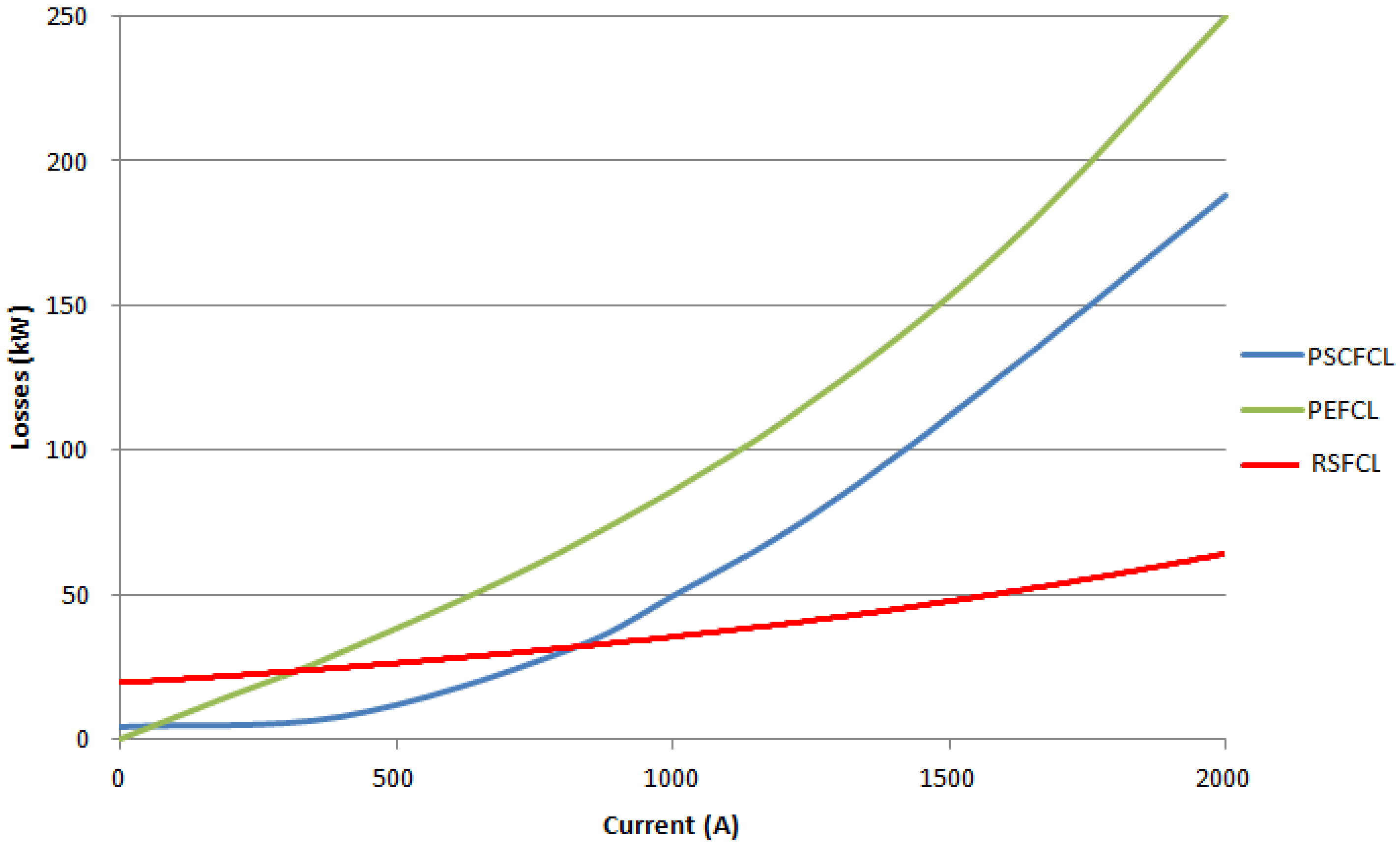
FCL Losses

– Losses associated with the PEFCL and RSFCL are mainly due to the mechanisms used for keeping the devices at their optimum operating temperature

– The PSCFCL 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


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

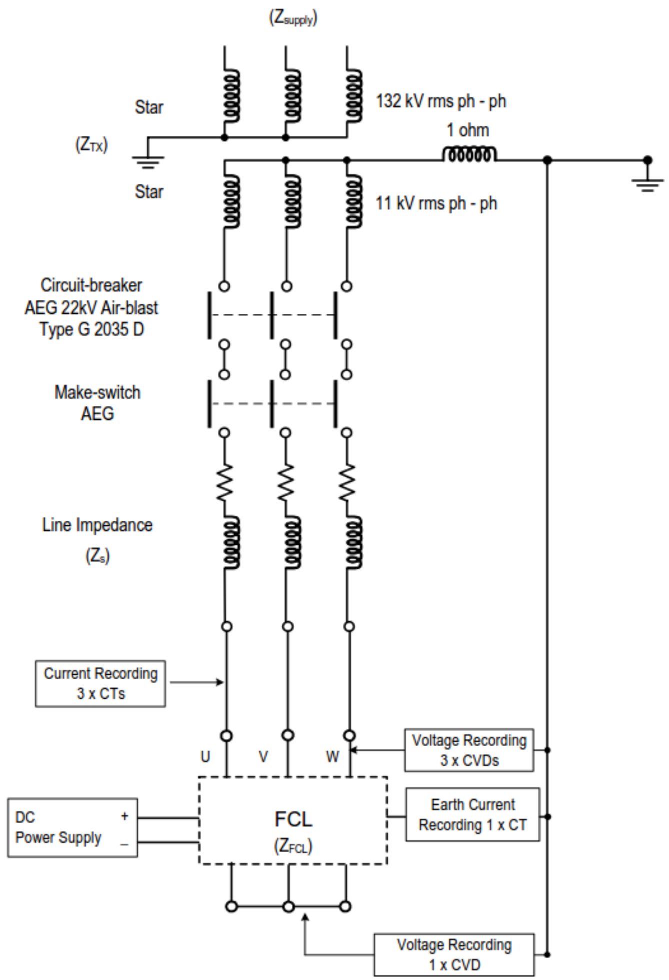
Fault Level Reduction

- Unfortunately, no significant faults have occurred to verify the performance of the FCLs
- However, thorough HV testing has demonstrated the performance of the FCLs
- The following slides explain the short circuit testing of the FCLs

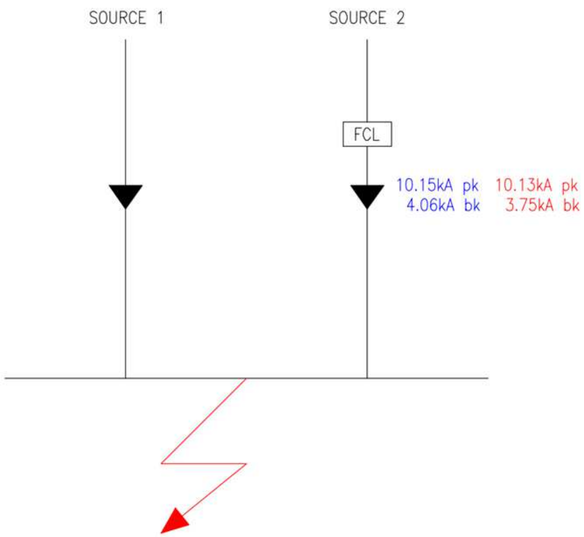
Fault Level Reduction – GridON FCL

- 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

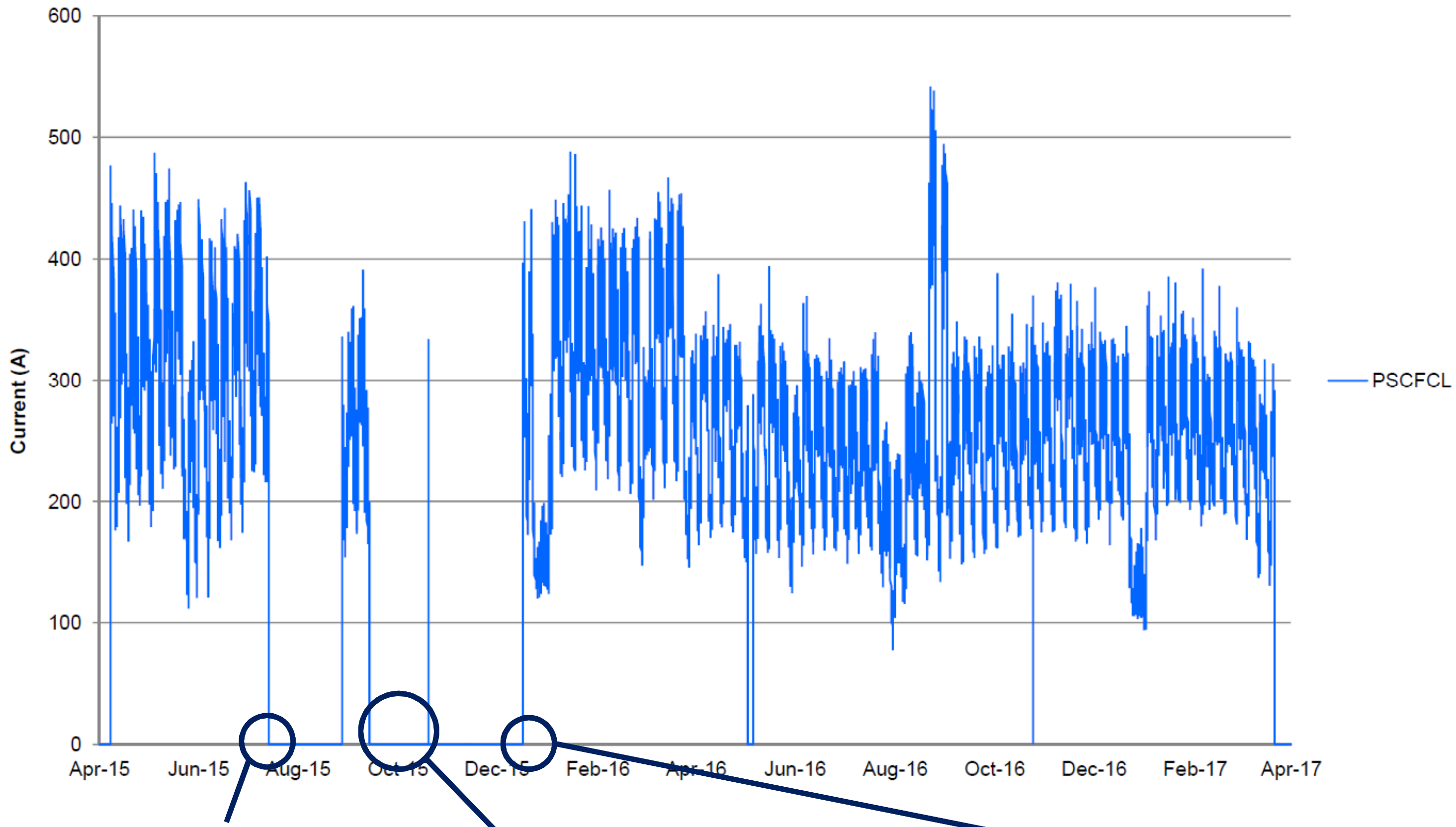


Scenario	Prospective Current	Required Limitation	Actual Limitation	Margin
Peak Make (nom. DC Bias)	20.2kA	10.15kA	10.13kA	+0.1%
RMS Break (nom. DC Bias)	6.85kA	4.06kA	3.71kA	+8.6%
RMS Break (min. DC Bias)	6.85kA	4.06kA	3.75kA	+7.6%

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

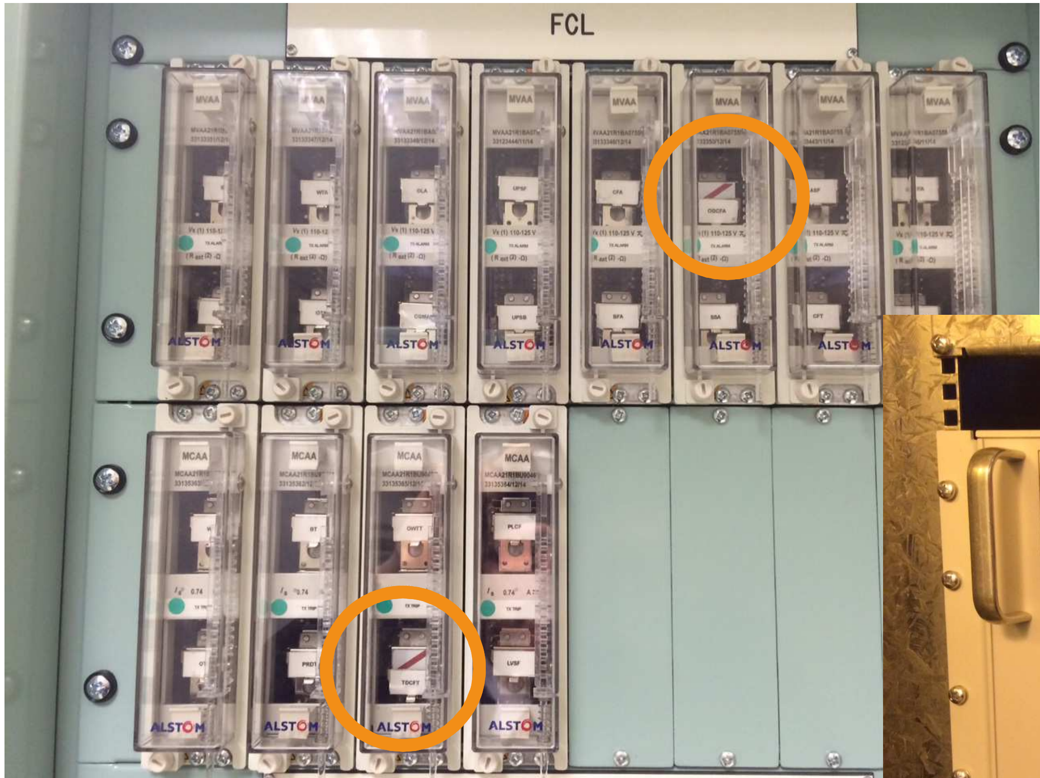
– Initial alarm received for "One DC Supply Failed", FCL switched off for GridON investigation

– 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

<u>Magnetic Shield</u>

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

<u>Carefully consider installation of shield in overall design</u>

Learning – GridON FCL

Short circuit testing

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

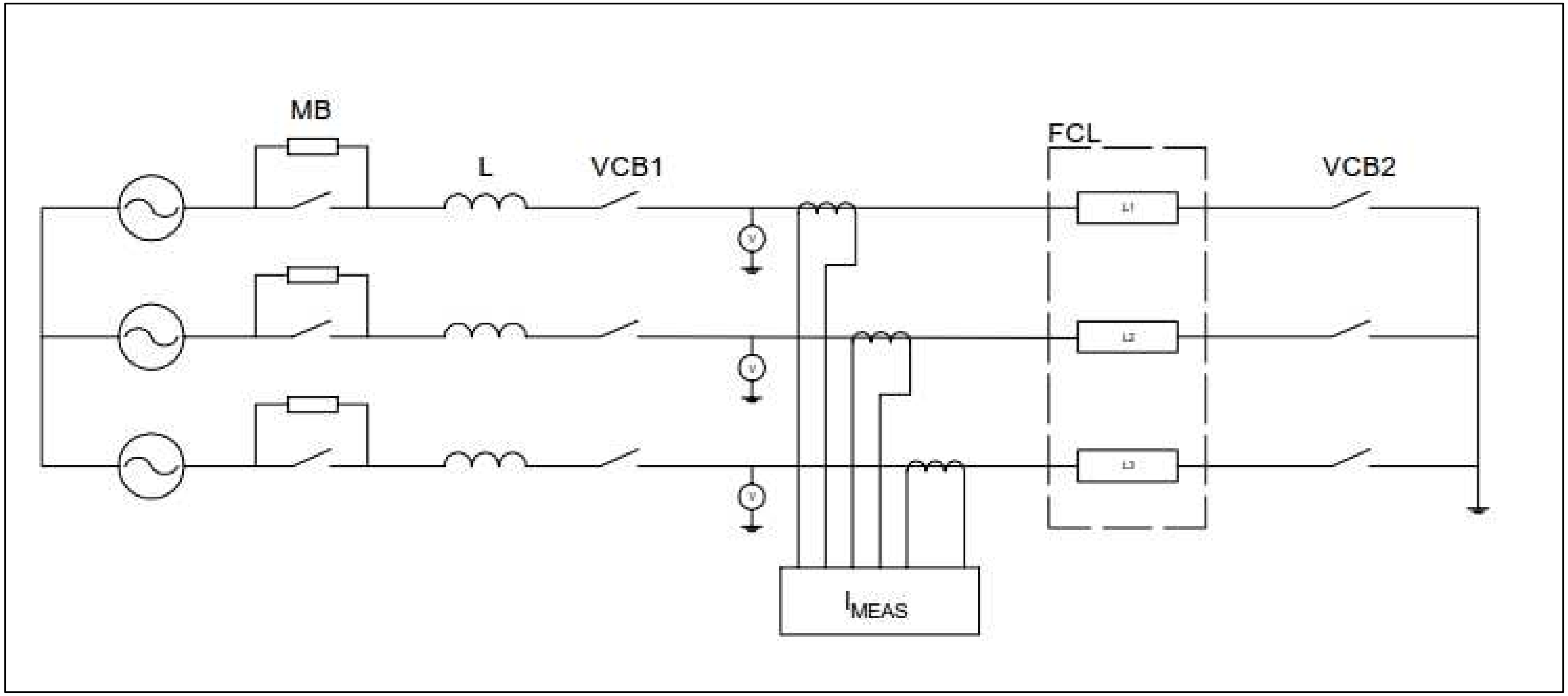
- Operation of buchholz relay
- Alarm from de-hydrating breather
- Alarm from Calisto Gas Monitor

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

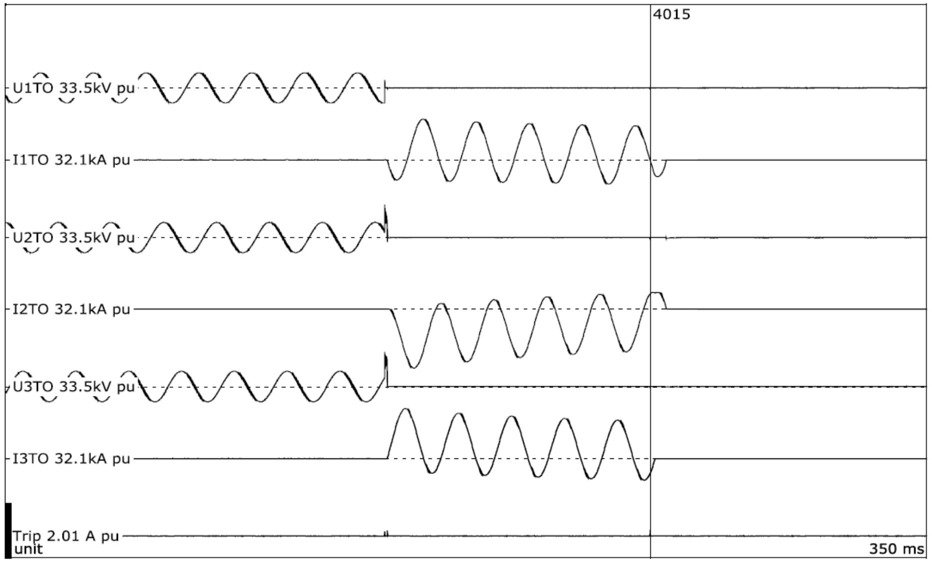
- Peak prospective current set to above >33.4kA.
- Applied to Phase L2.
- Peak prospective current limited to 9.59kA.

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			

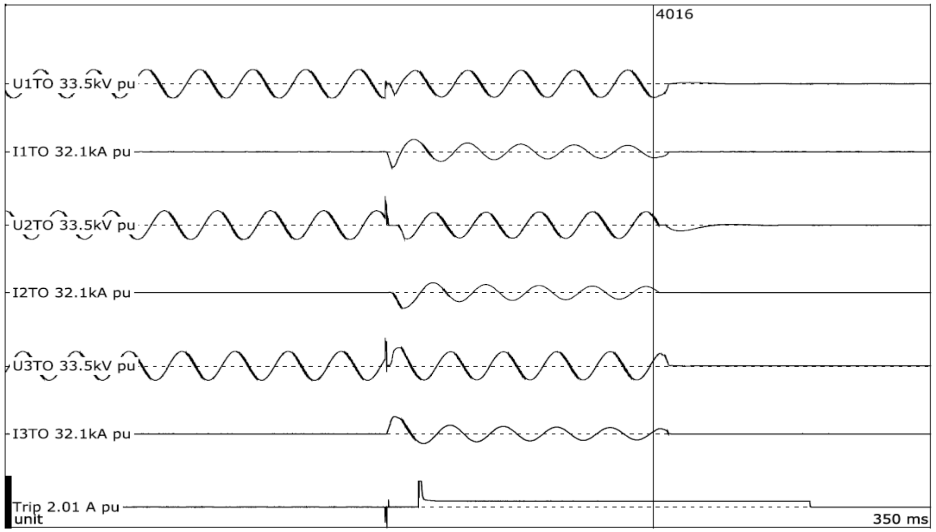
Remarks	
151005-4014	Checking of the prospective current.
151005-4015	Checking of the prospective current.
151005-4016	The SFCL was set to blow off nitrogen after limitation. Maximum prospective peak current was applied in phase L2. Moderate emission of nitrogen gas after the test.

FCLs: Operation and Benefits

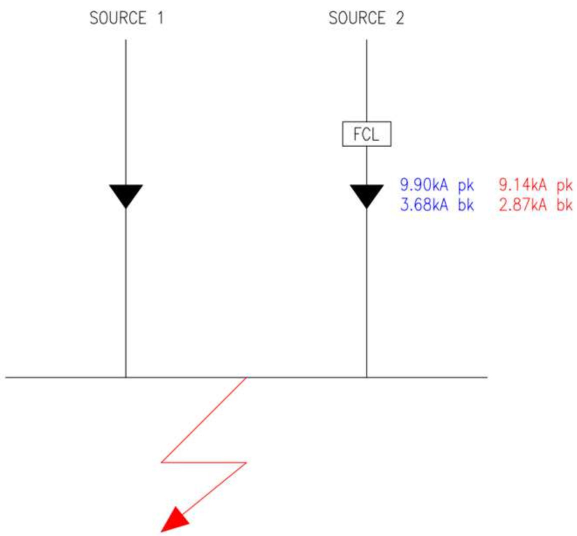
Short-circuit current limitation test



Short-circuit current limitation test



Fault Level Reduction – Chester Street

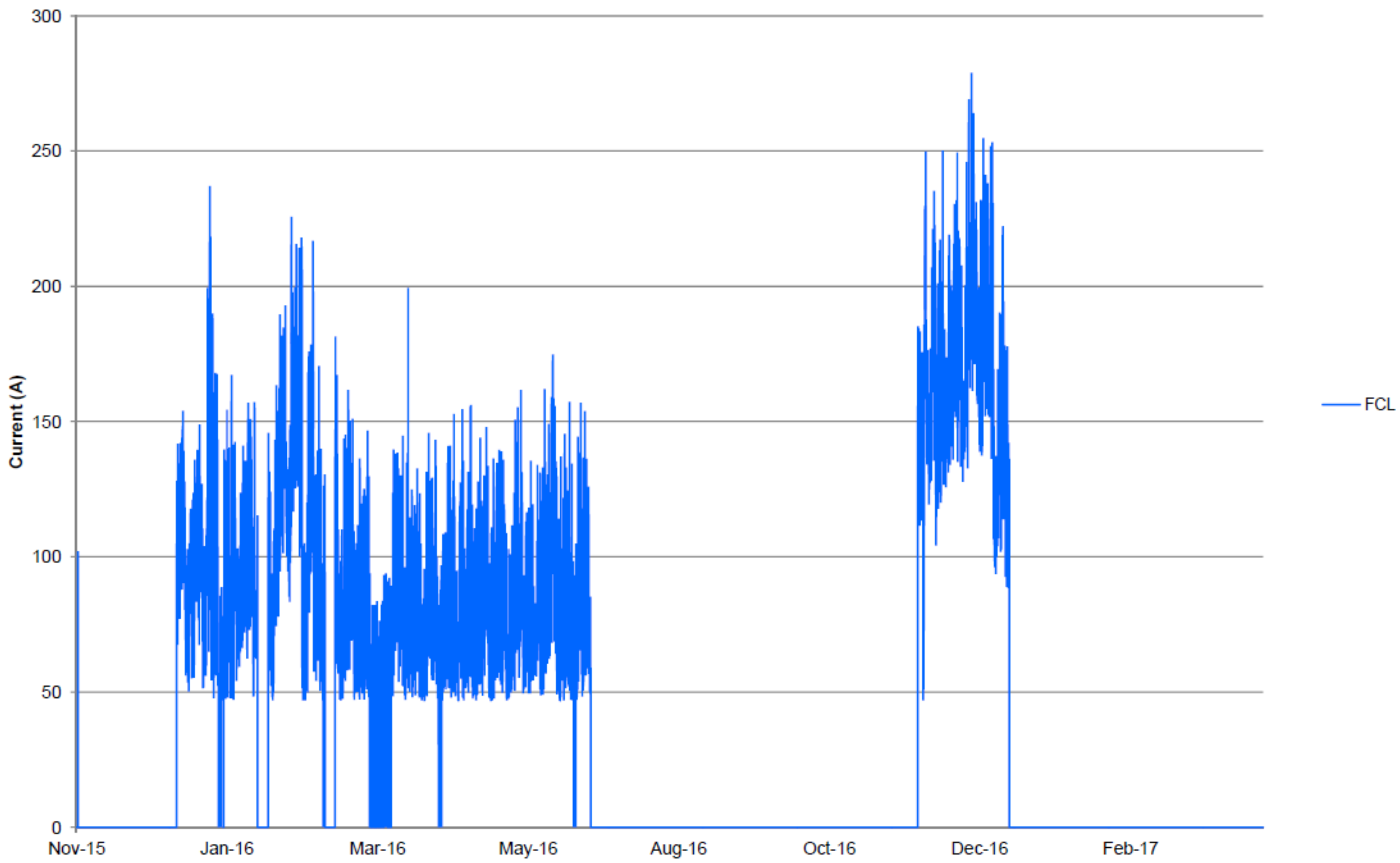


Scenario	Prospective Current	Required Limitation	Actual Limitation	Margin
Peak Make	19.76kA	9.90kA	9.14kA	+7.7%
RMS Break	7.03kA	3.68kA	2.87kA	+22.0%

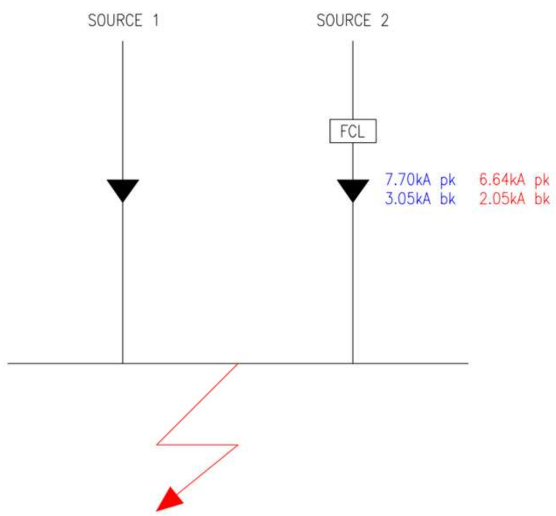
Technology Operation – Chester Street

Milestone	Date
Device build complete	21st August 2015
Factory Tests Complete	23rd September 2015
KEMA Tests Complete	5th October 2015
Device Energised	25th November 2015

Technology Operation – Chester Street



Fault Level Reduction – Bournville

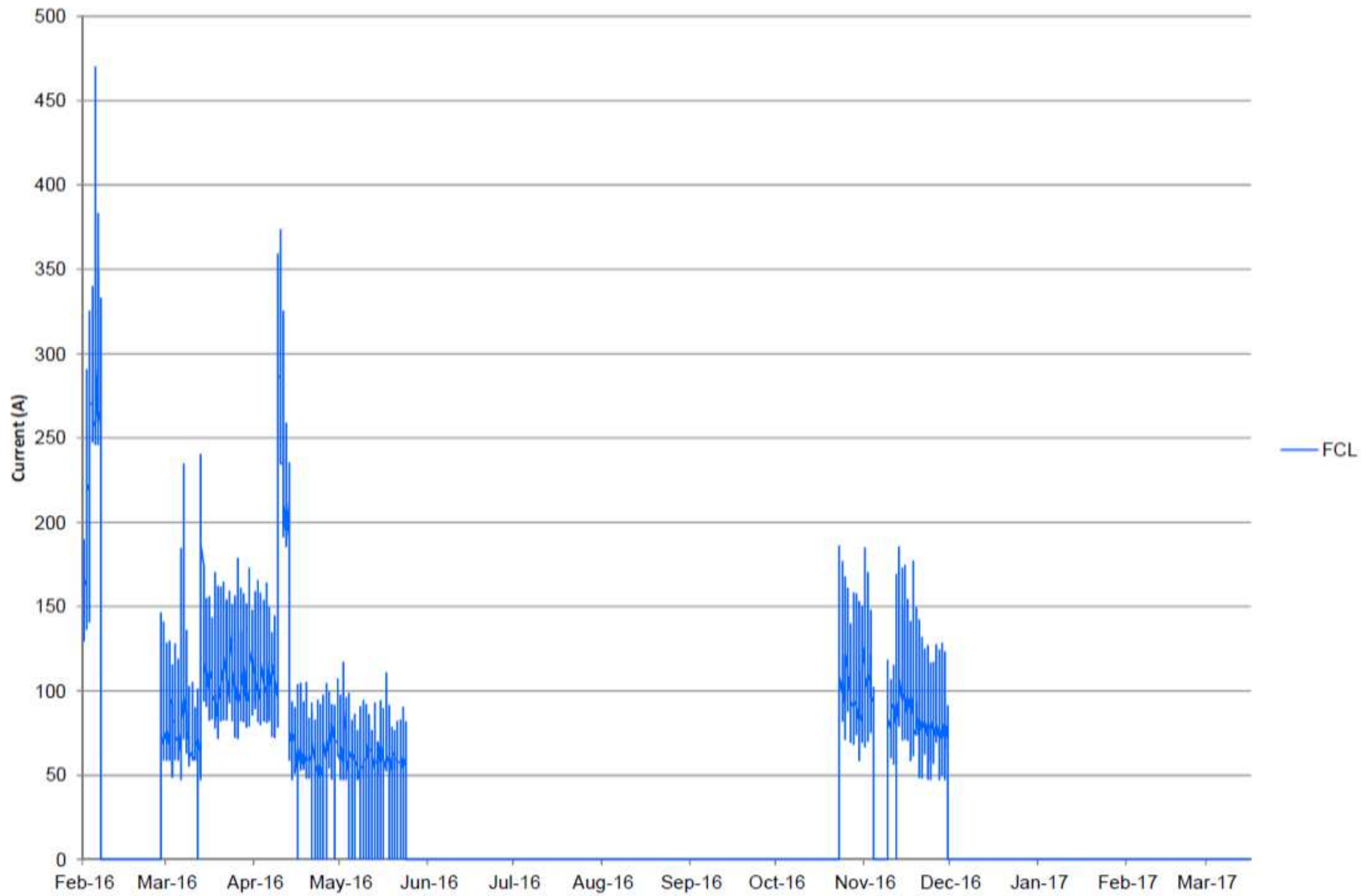


Scenario	Prospective Current	Required Limitation	Actual Limitation	Margin
Peak Make	21.97kA	7.7kA	6.64kA	+13.8%
RMS Break	7.66kA	3.05kA	2.05kA	+32.8%

Technology Operation - Bournville

Milestone	Date
Device build complete	21st August 2015
Factory Tests Complete	30th November 2015
KEMA Tests Complete	7th December 2015
Device Energised	17th February 2016

Technology Operation - Bournville



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.

<u>Detailed cooling system calculations required in future with adequate margin applied.</u>

Learning – Issues with Cooling System

- First time with cooling system in sustained operation

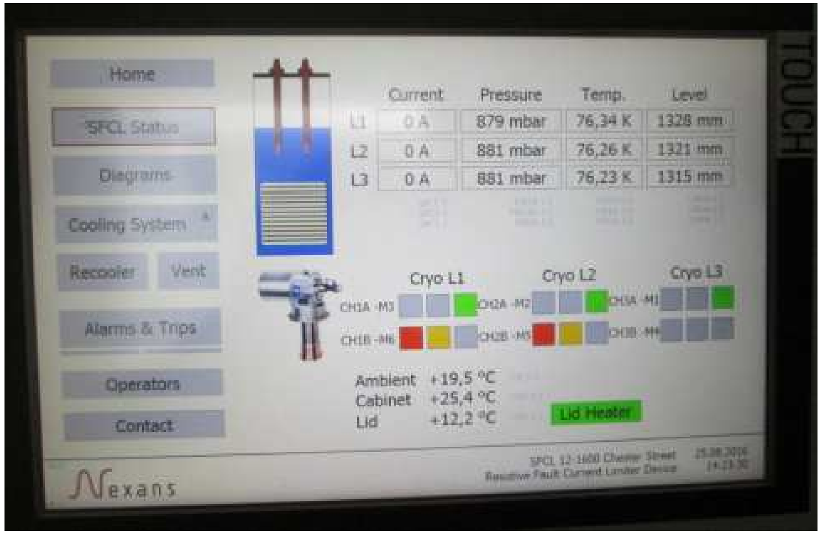
A number of recooler faults at both Chester Street and Bournville:

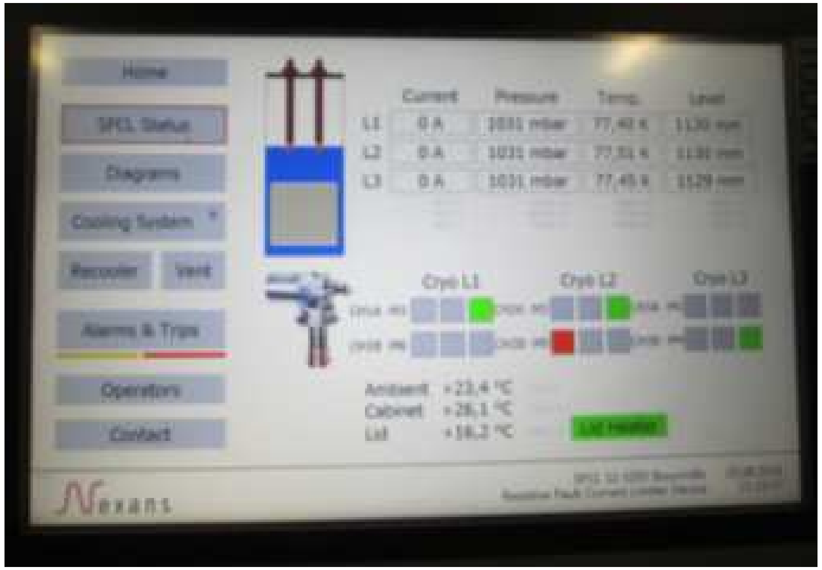
- Damaged pipework during commissioning
- Water level dropping below the trip level
- Air intake becoming clogged with debris leading to inadequate air flow

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>

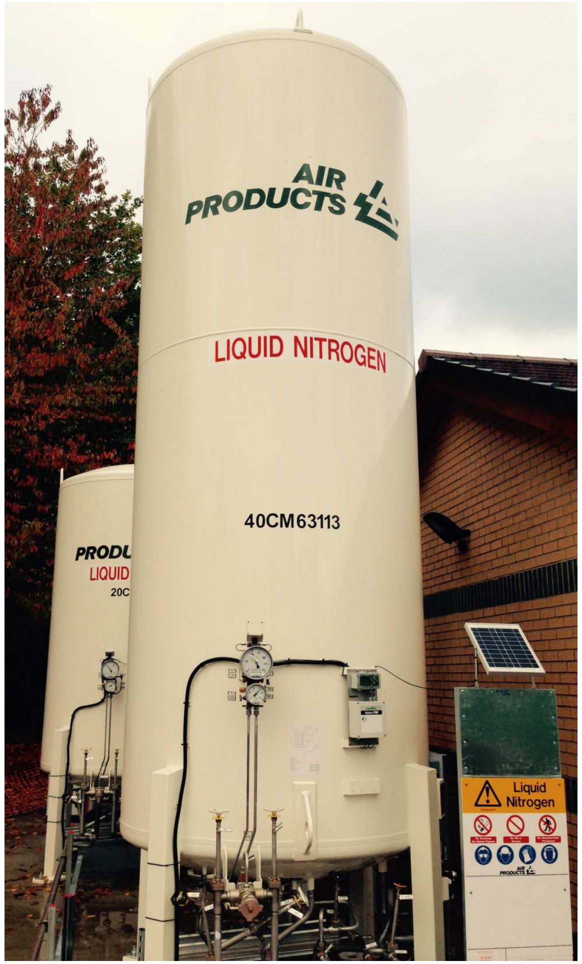
- Recooler M9 has an undiagnosed fault (overheating and low cooling water level). The manufacturer is organising an investigation by a specialist company
- With M9 switched off the cooling capability of the device is limited. Decision taken to keep the FCL disconnected
- The first scheduled maintenance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

- An open loop cooling system could overcome the issues with the problems encountered on the Nexans RSFCL.
- The following points need to be considered
  - Large reduction in moving parts
  - Space for storage tank
  - Tank provision and filling costs vs. maintenance and cooling system losses



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

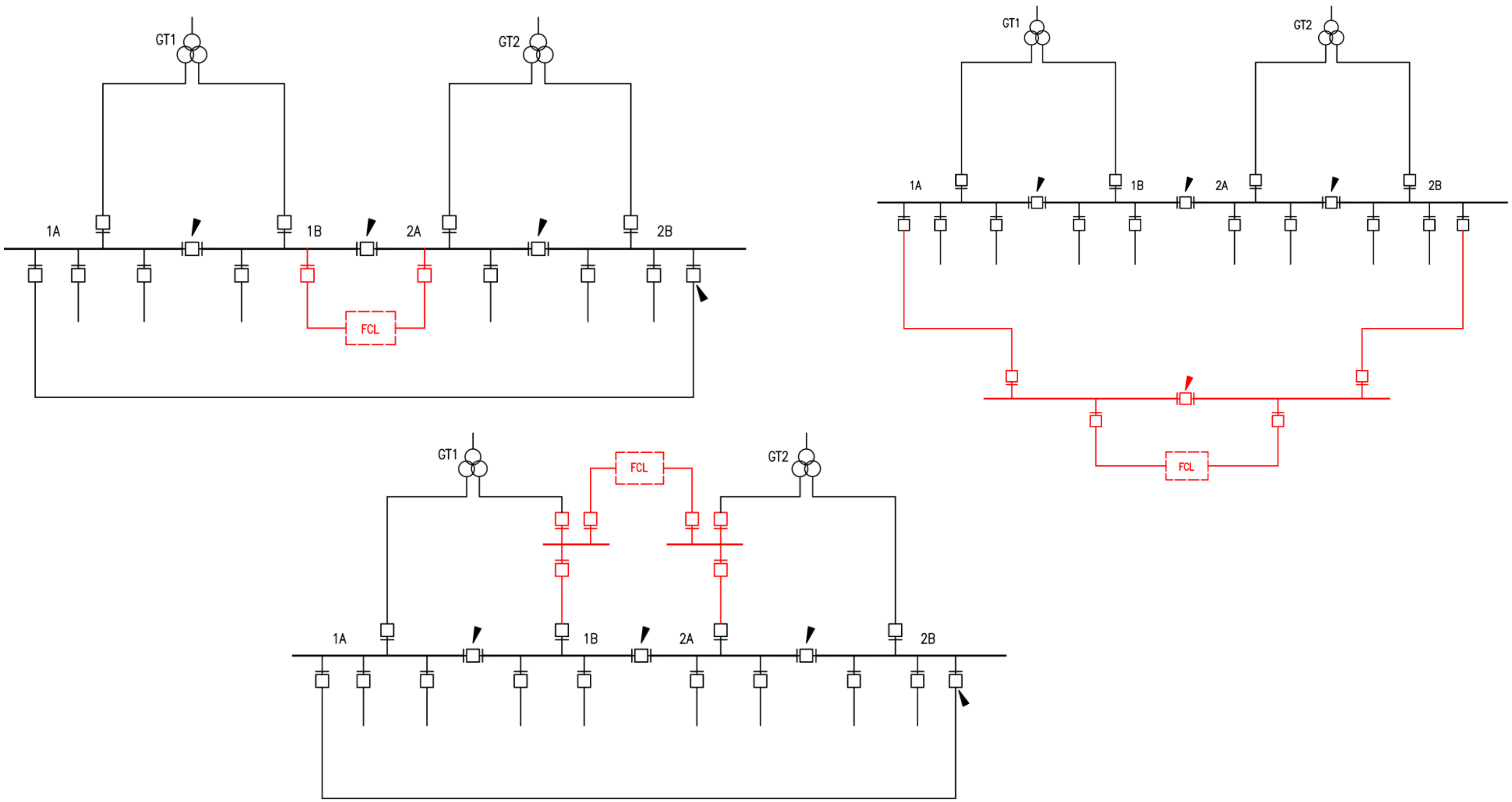
Benefits

- The design and installation of three FCLs on the 11kV network has produced the following benefits:
  - Released FL capacity
  - Increase network security
  - Developed existing technologies
  - Learning and outcomes shared with DNOs

Benefits – FL Capacity

Substation	Capacity Released
Castle Bromwich	13MVA
Chester Street	19MVA
Bournville	20MVA
TOTAL	**52MVA**

Benefits – Increased Network Security



Benefits – Development of Existing Technologies

- Detailed design of technologies has helped to develop the technologies for use on DNO network:
  - Large current applications possible!
  - Solution to control magnetic fields
  - Auxiliary systems to UK standards
  - Policies created for specifying FCLs

Benefits – Learning

- The learning points and information gained throughout the project have been captured in:
  - SDRCs (particularly 2, 3, 6, 8 and 9)
  - Policies and Standards
  - Workshops
  - Presentations

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Thank you for your time

Questions?

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Next Steps and Close

- Future work to transition technologies in to BaU
- Closedown Report
- Final Dissemination Event – 12th July 2017