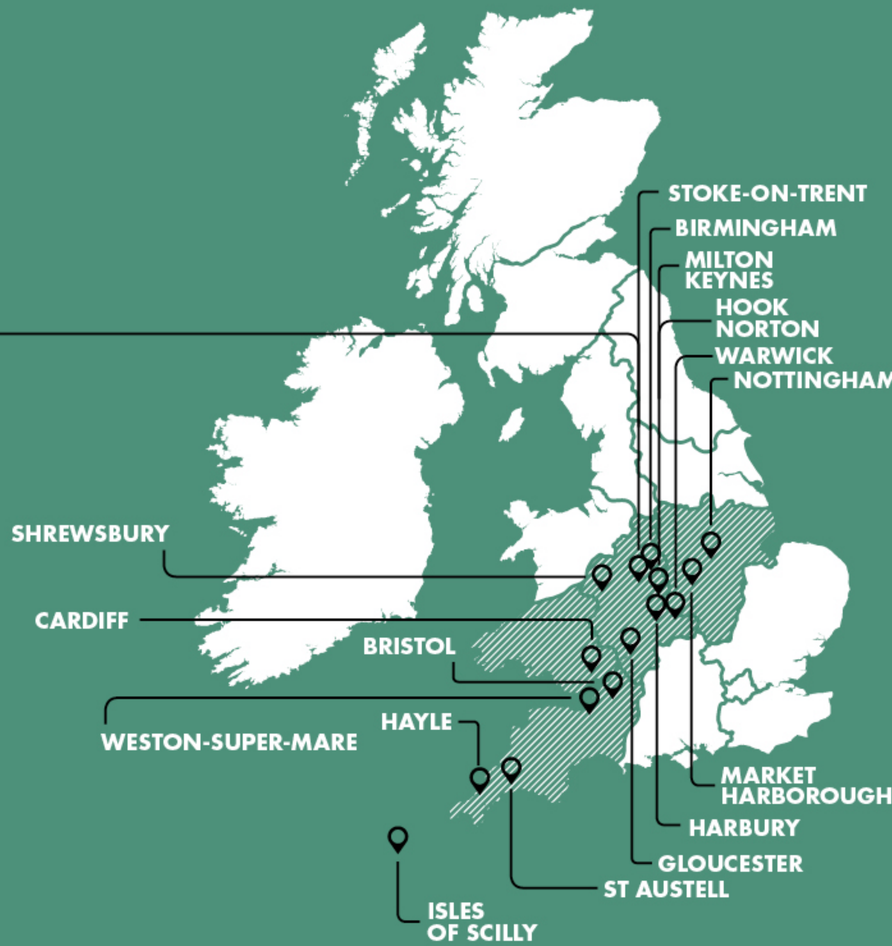
WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS



HV TECHNOLOGIES

LCNF2013 Wednesday 13th November 2013

Jonathan Berry MEng (Hons) MIET

Innovation & Low Carbon Networks Engineer

WESTERN POWER DISTRIBUTION
HV VOLTAGE CONTROL

WESTERN POWER DISTRIBUTION
FLEXDGRID

WESTERN POWER DISTRIBUTION
LOW CARBON HUB

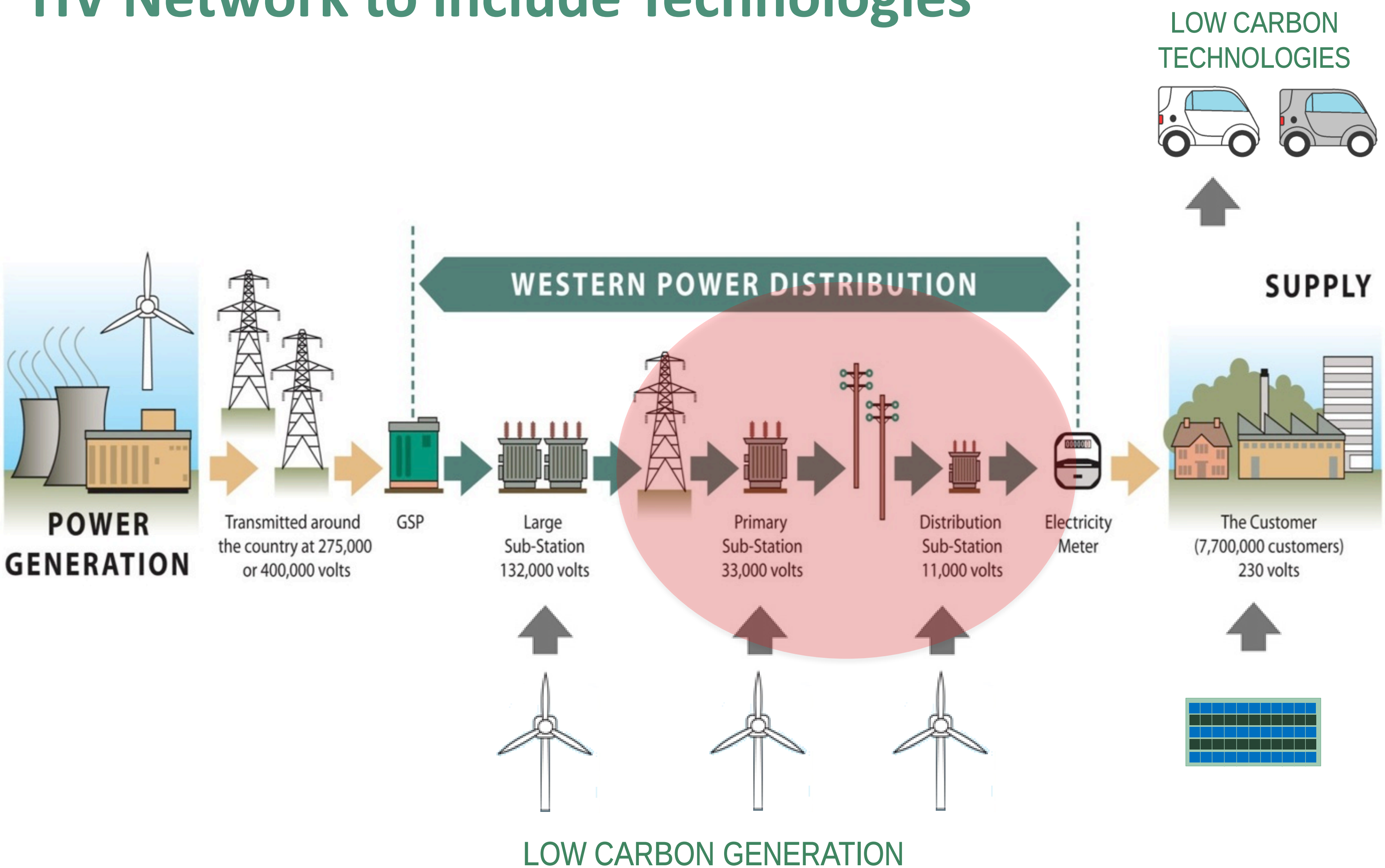
WESTERN POWER DISTRIBUTION
FALCON

WESTERN POWER DISTRIBUTION
ISLES OF SCILLY SMART GRID

Agenda

- HV network issues tackled by HV Technologies
- Project specific examples:
  - FlexDGrid – Fault Level Mitigation Technologies
  - Voltage Control – Hitachi D-SVC
  - LLCH – S&C STATCOM
  - FALCON – Meshed Networks
  - IoS - PMUs

HV Network to include Technologies



Challenges to be overcome

- The inclusion of HV technologies can provide significant network benefit for a number of issues including:
    - Network Security
    - Thermal Capacity
    - Voltage Rise
    - Fault Level
    - Power Factor
    - Power Quality

FlexDGrid

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

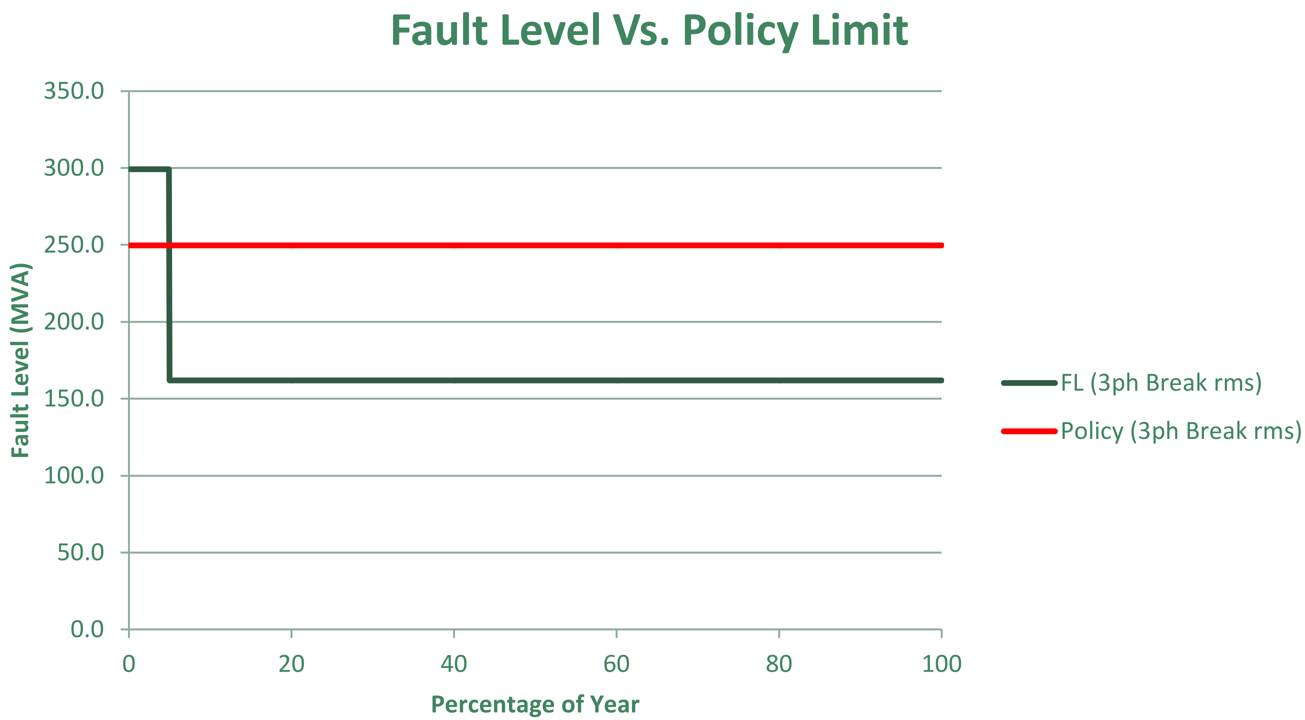
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

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

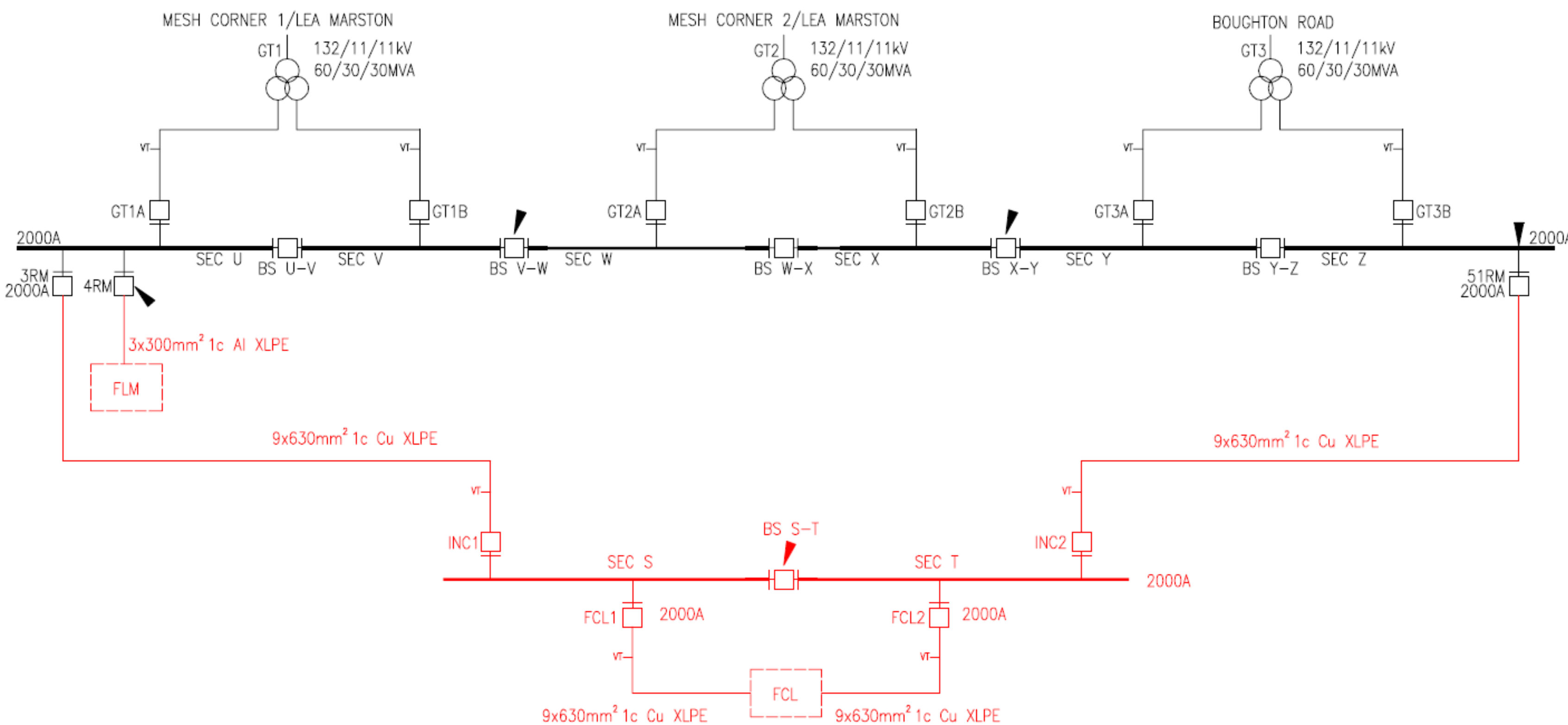
- Three Methods to successfully manage and mitigate the fault level on an 11kV network

FlexDGrid



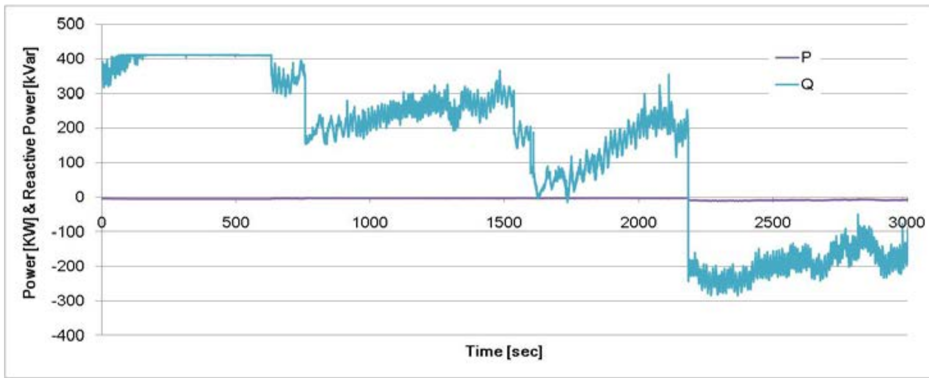
- Fault level of a Primary Substation over a year
  - Significant fault level headroom exists

FlexDGrid – Fault Level Mitigation Technologies

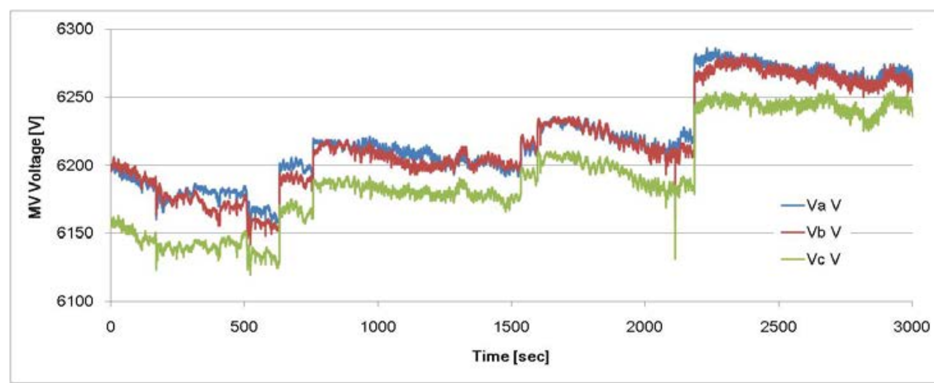


- Integration of Fault Level Mitigation Technologies

Voltage Control Demonstration – D-SVC



- **Performance of D-SVC on 11kV network**
- **Providing system voltage control**



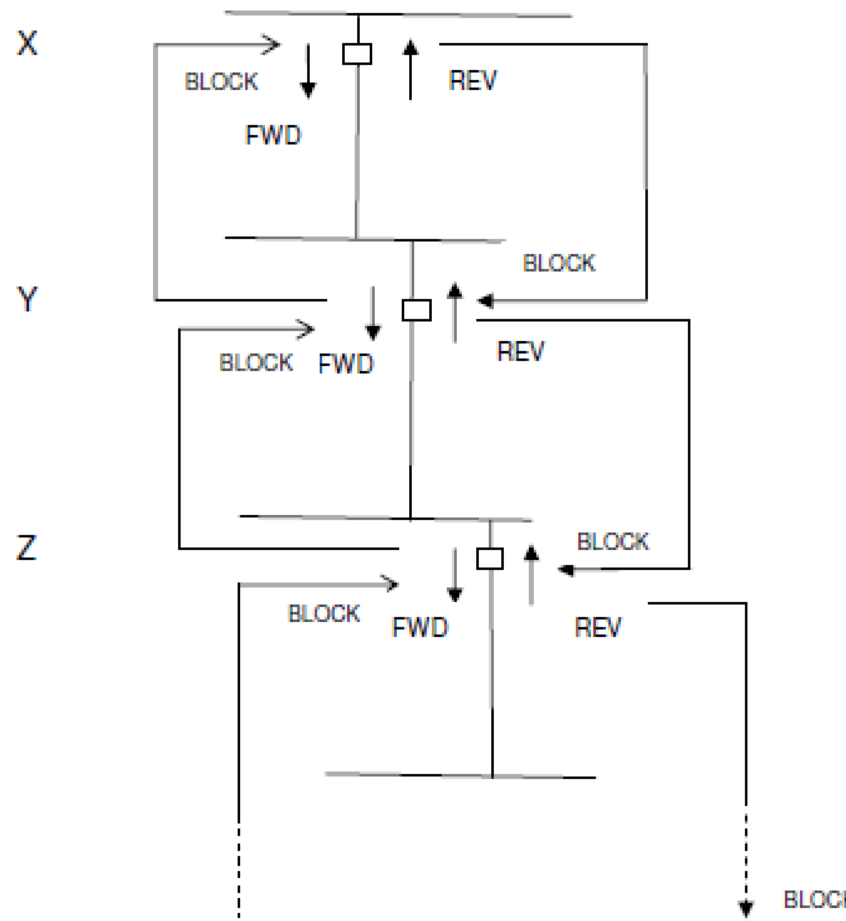
Lincolnshire Low Carbon Hub - STATCOM

- Device to:
  - Control Network Voltage
  - Manage Power Factor
  - Maximise connected DG

- Voltage on a 33kV ring network to be optimised through the use of a STATCOM and an Active Automatic Voltage Control scheme

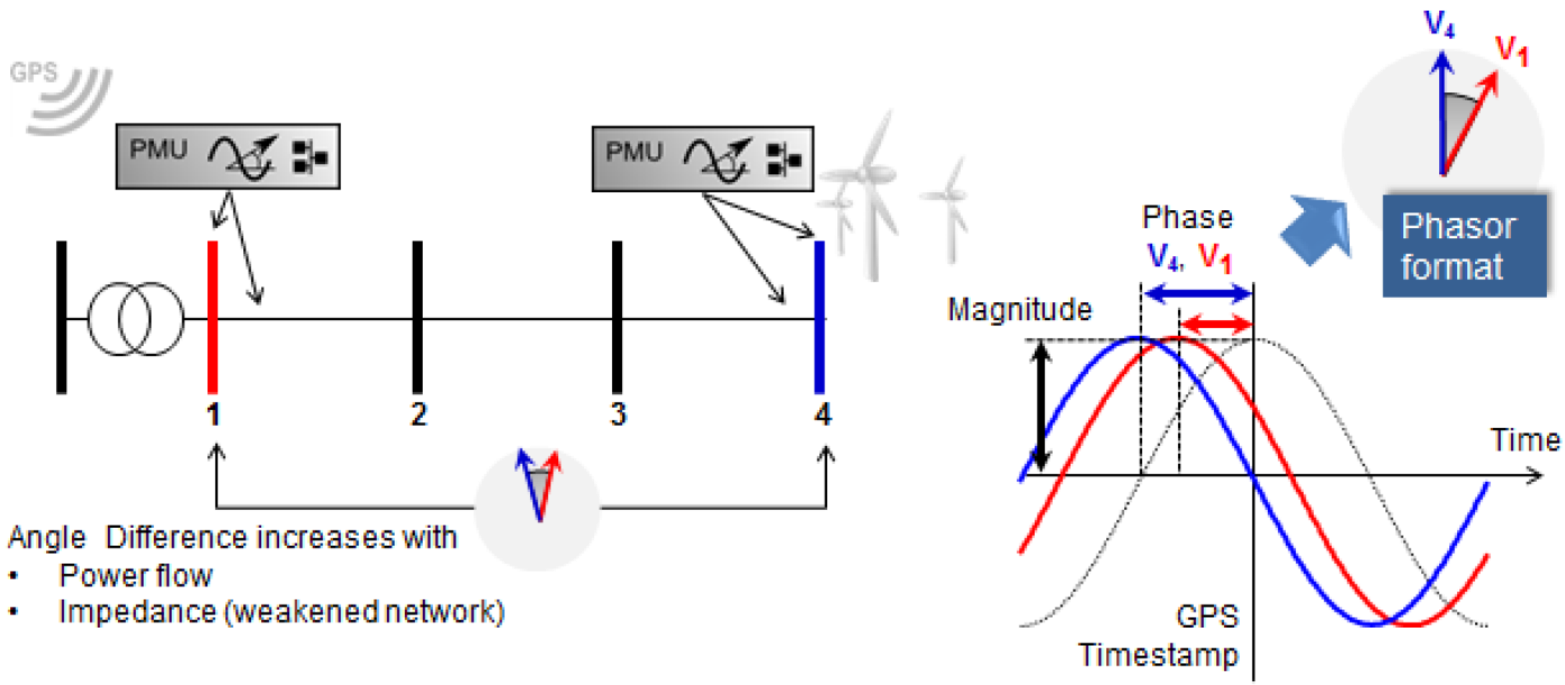
FALCON – Meshed Networks

- Enabling the increase in connectivity of the 11kV network
    - Enhancing network security
    - Reduced customer impact from faults
    - Extension of asset life



Isles of Scilly & FALCON - Phasor Measurement Units

Phasor Measurement Units installed in Milton Keynes and the Isles of Scilly are able to provide time-stamped, high resolution data on current and voltage waveforms.



Thank you

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WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

LCNI 2014 Conference

Innovative DG Connections

Tuesday 21st October 2014

Jonathan Berry – Innovation and Low Carbon Networks Engineer

LCN Fund Low Carbon Networks
THE UNIVERSITY OF WARWICK
PARSONS BRINCKERHOFF

Agenda

- Project Introduction
- Fault Level Modelling
- Fault Level Monitor Installations
- Fault Level Mitigation Technology Installations

FlexDGrid – What and Why

What are we doing?

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

Why are we doing it?

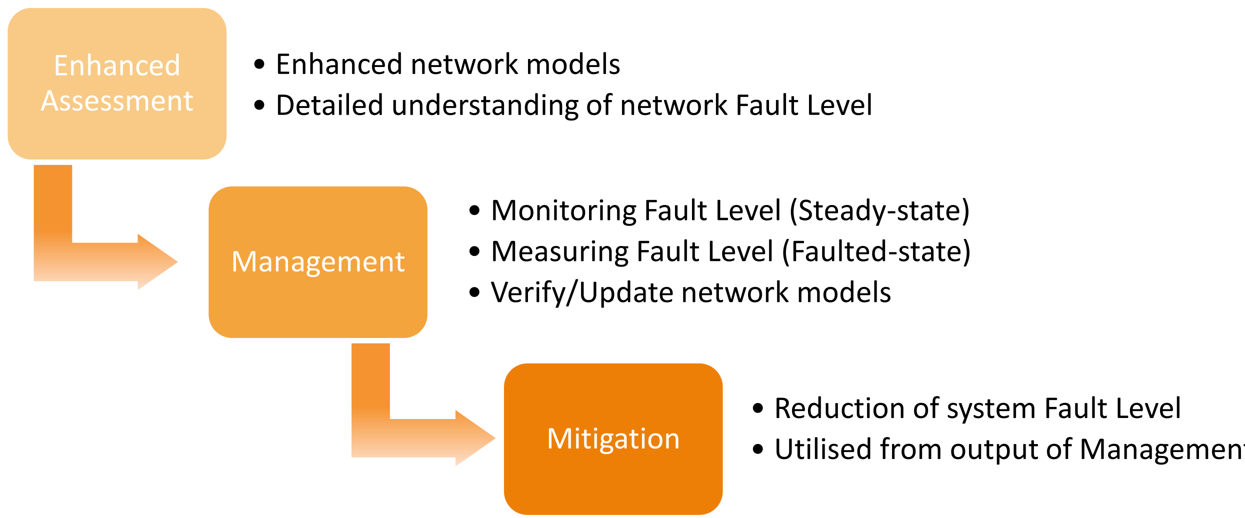
Facilitating the early and cost effective integration of Low Carbon generation

Why are we doing it now?

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

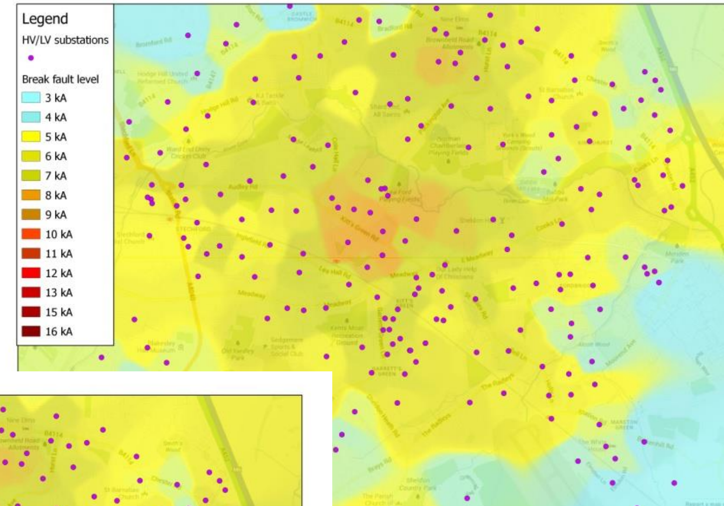
What is FlexDGrid?

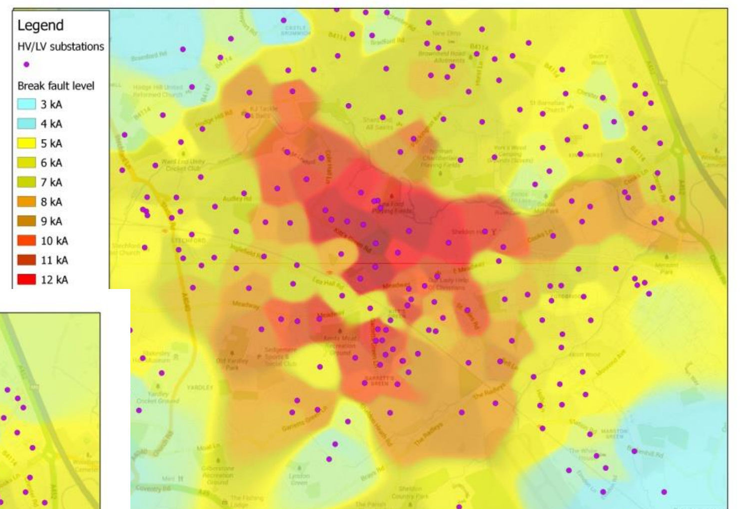
Three integrated Methods leading to quicker and cost effective customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network Fault Level.

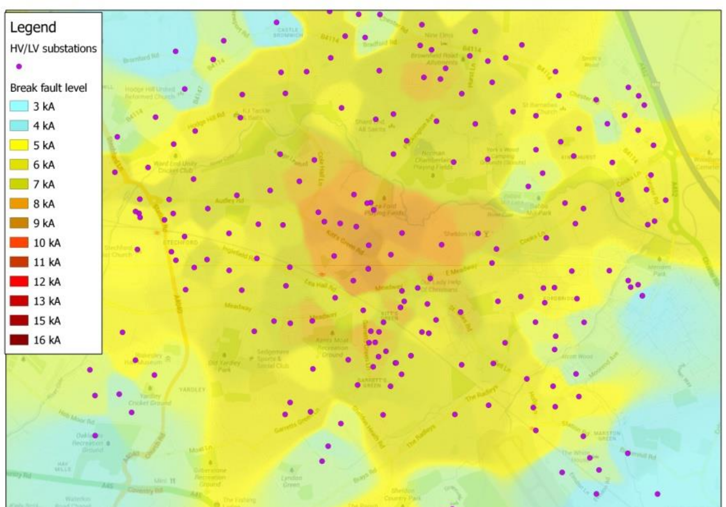


Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional Generation.

Effect on Fault Level

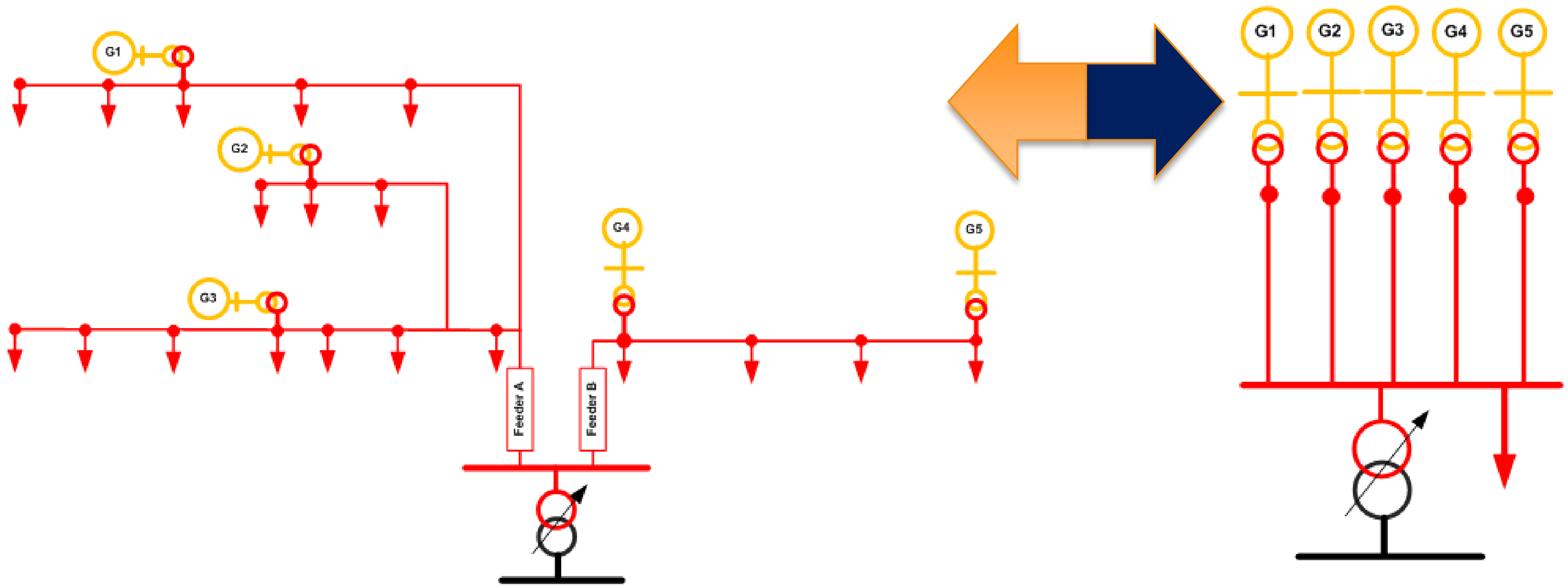






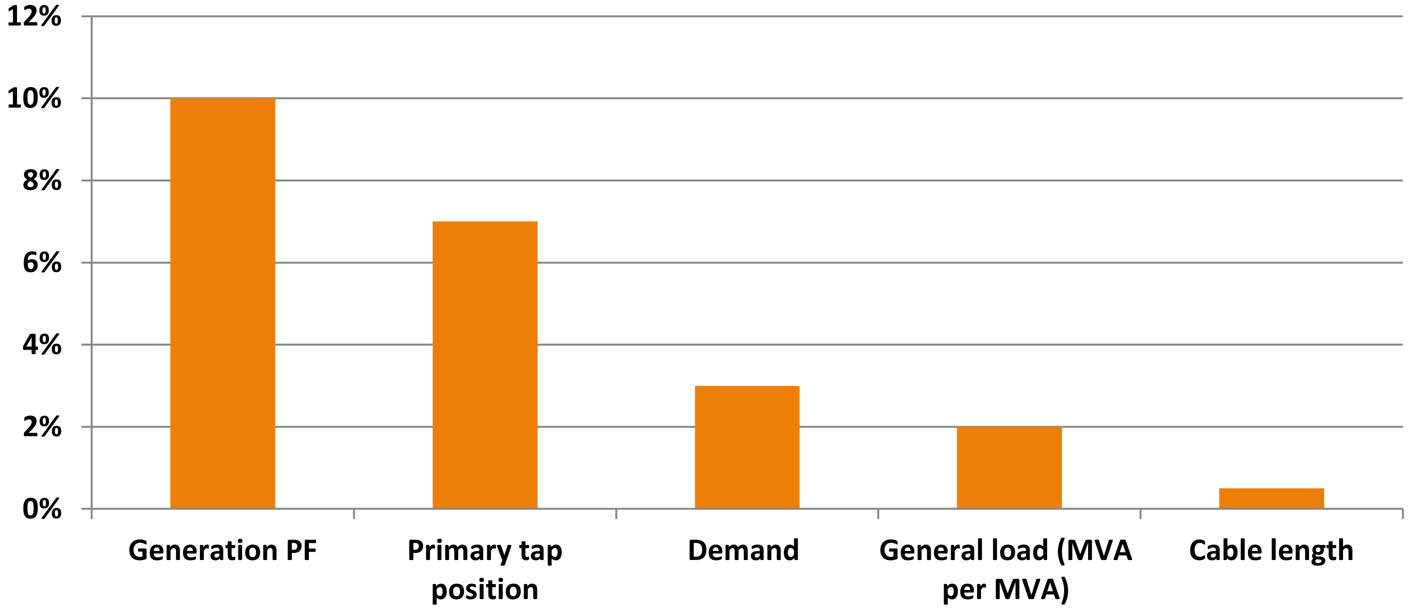
Fault Level Heat Maps

Modelling – Increased Granularity



	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	-	-

Modelling – Sensitivity Analysis



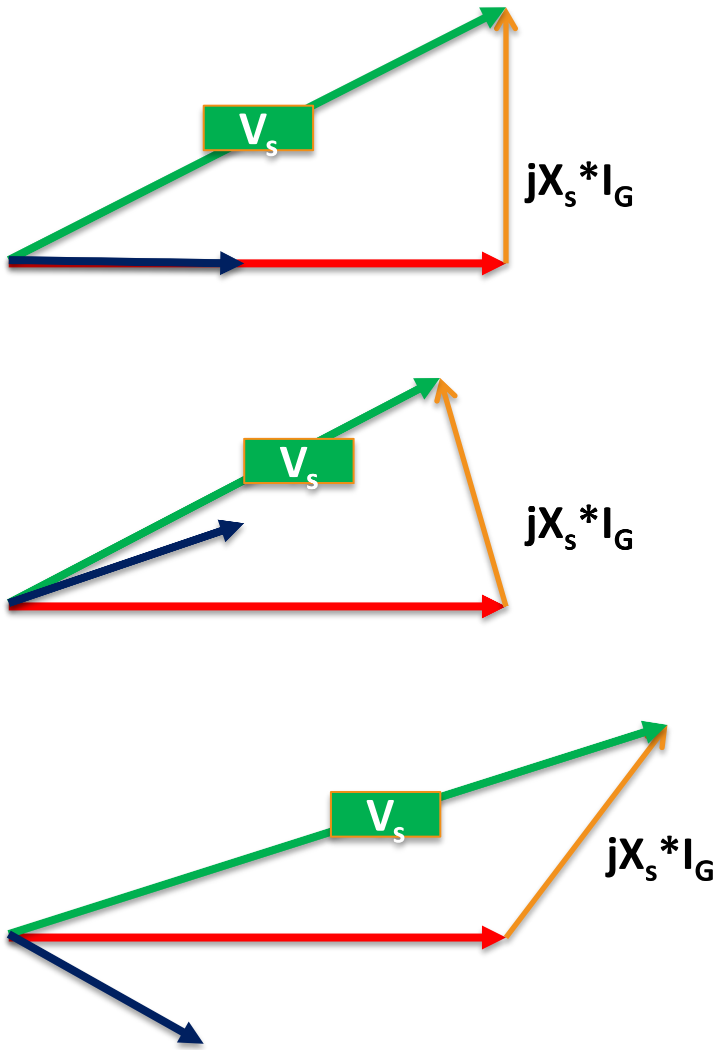
	Variation range	
Cable length	-5%	5%
Demand	-10%	10%
Generation PF	Unity, 0.95 leading, 0.95 lagging, Vset=1	
General load (MVA per MVA)	0	2
Primary tap position (voltage at HV busbars)	0.95 pu to 1.03 p.u	

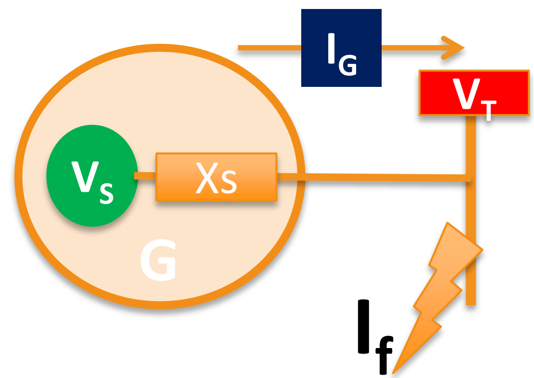
Modelling – Power Factor Effects

Unity PF

Leading PF

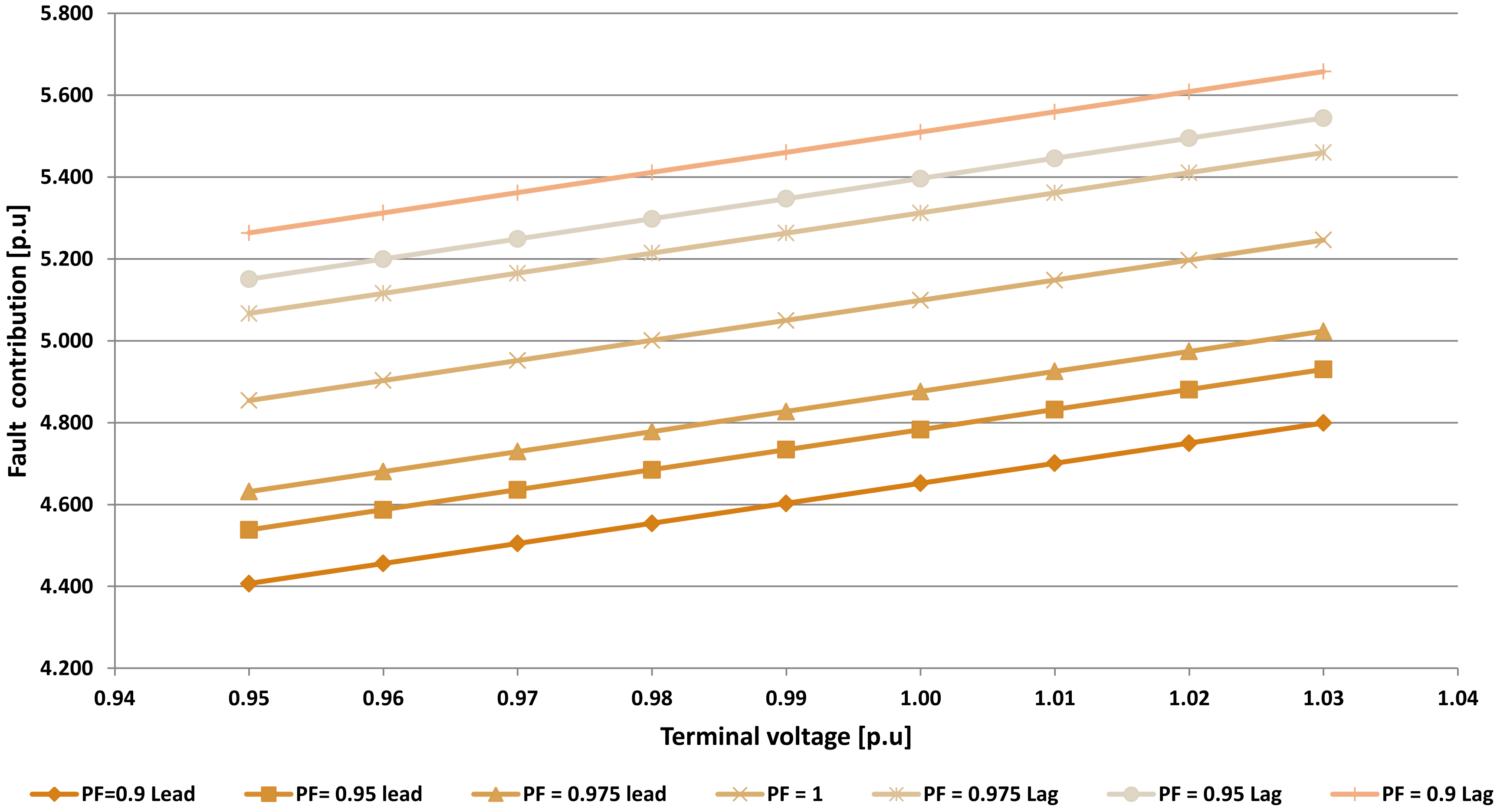
Lagging PF





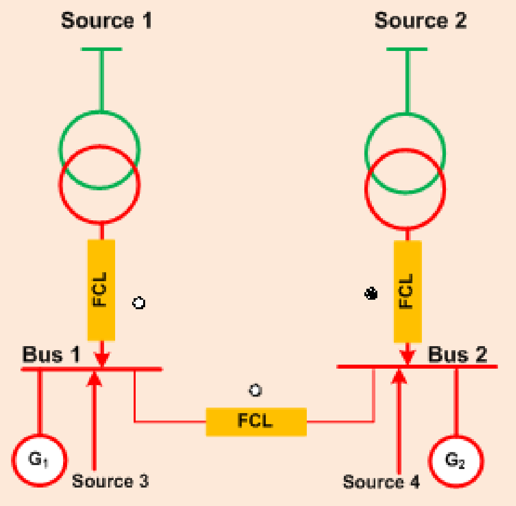
$$I_f = V_s / X_s$$

Modelling – Generation Fault Level



Modelling – Fault Level Mitigation Tech 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

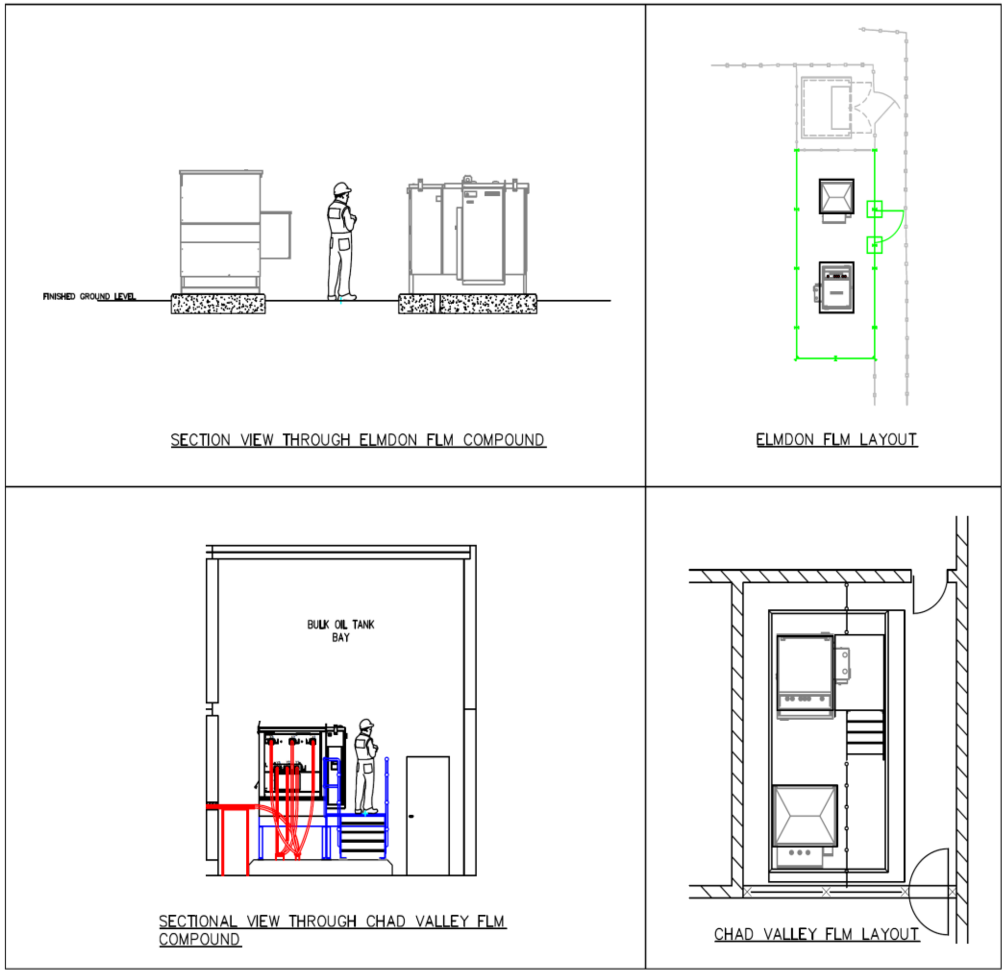
Source 3 - Downstream Fault Contribution			Source 4 - Downstream Fault Contribution		
Breaking fault contribution	2	kA	Breaking fault contribution	1	kA
Making fault contribution	3	kA	Making fault contribution	2	kA

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	-

Excel Based FLMT Model

Fault Level Monitor Installations

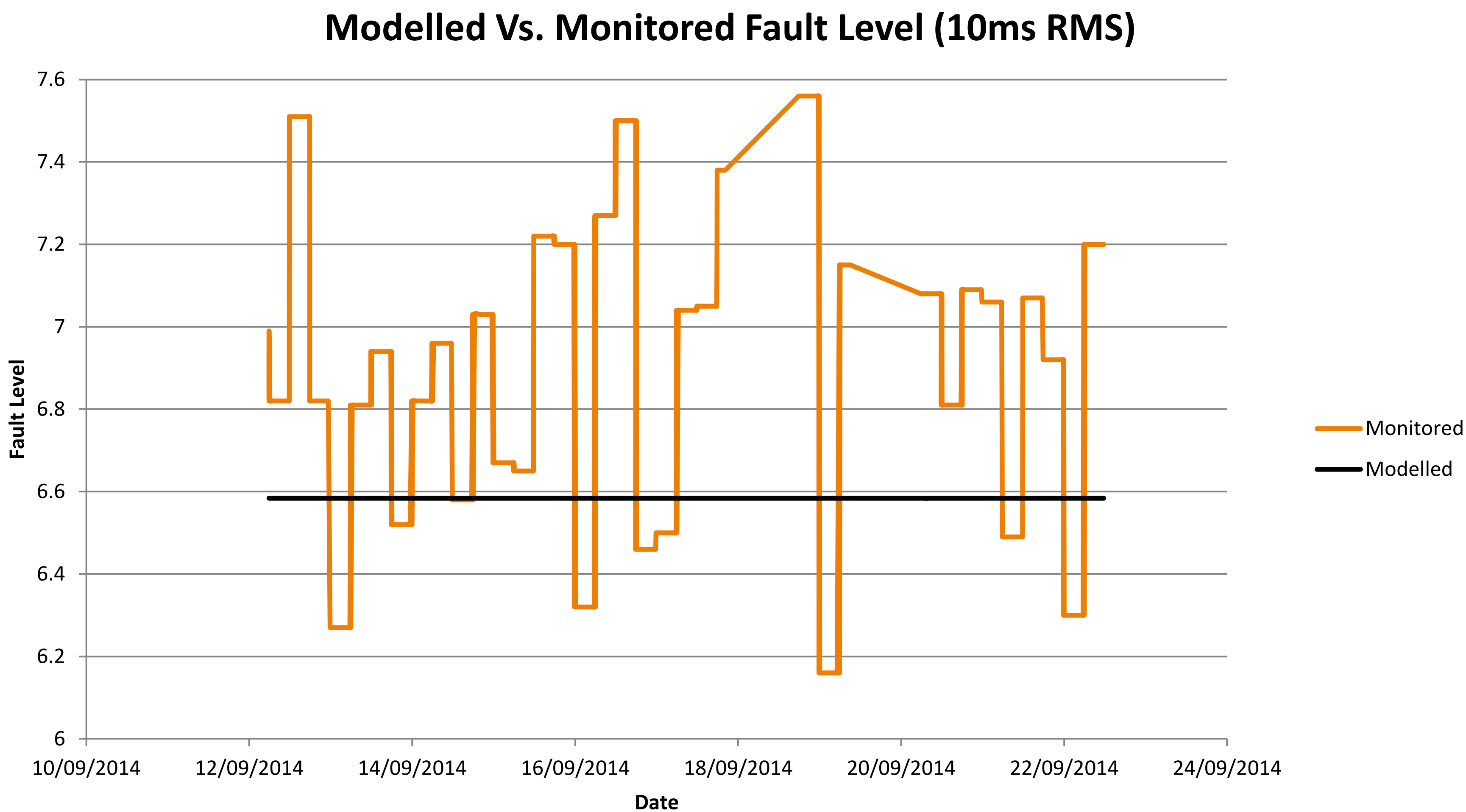


FLM Site Designs

Fault Level Monitor Installations

Ladywood FLM Installation

Fault Level Results from Installation

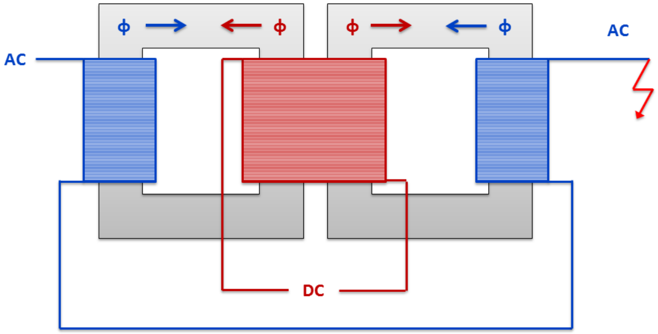


Fault Level Mitigation Technology Installations

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

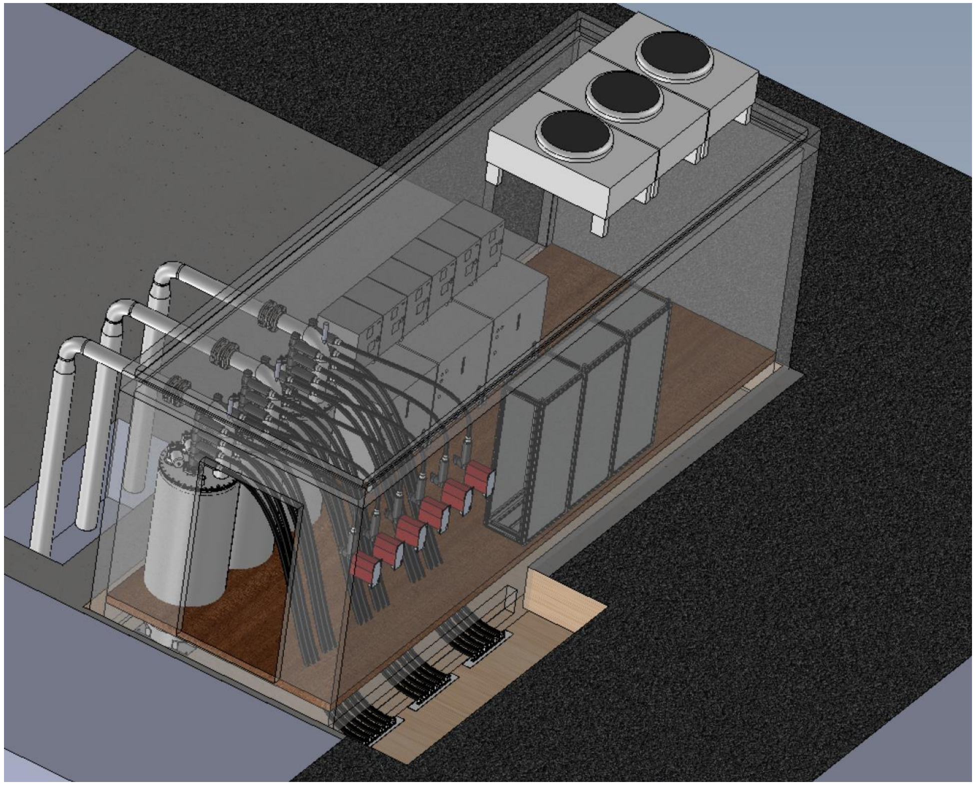
Pre-saturated Core FCL

GridON FCL – During Factory Acceptance Testing

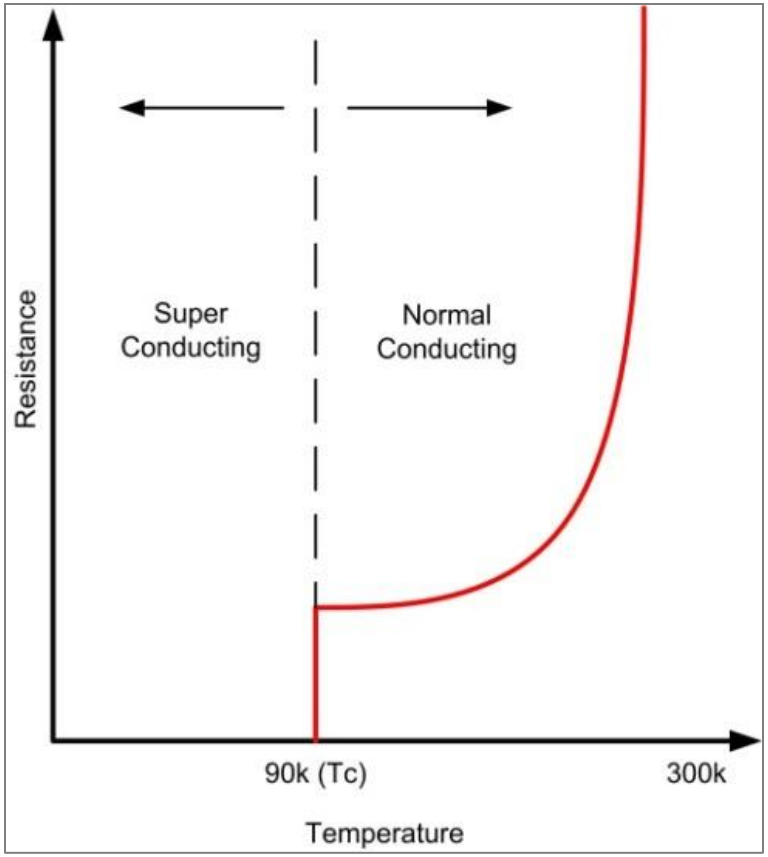


Design

Resistive Superconducting FCL

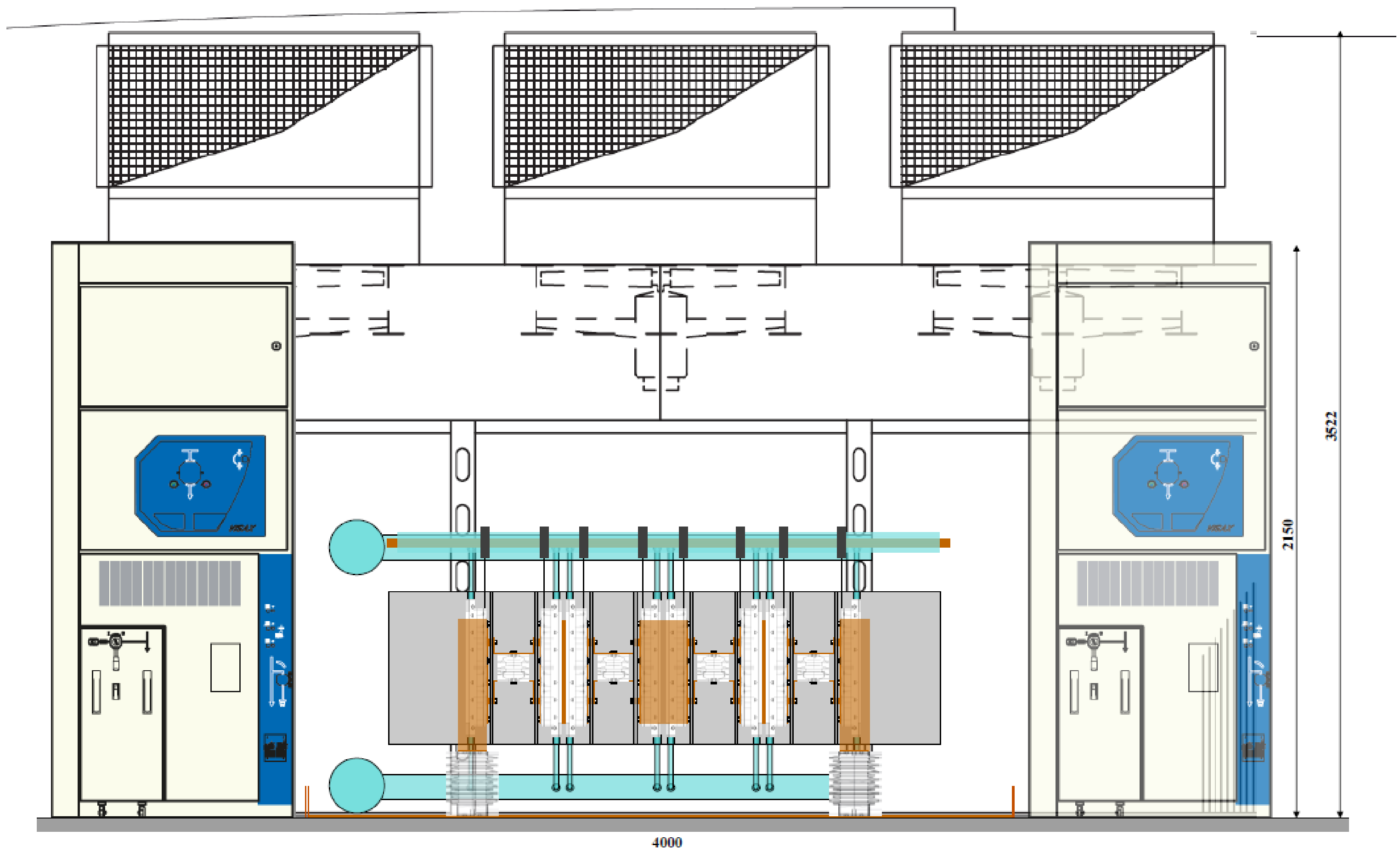


Nexans FCL



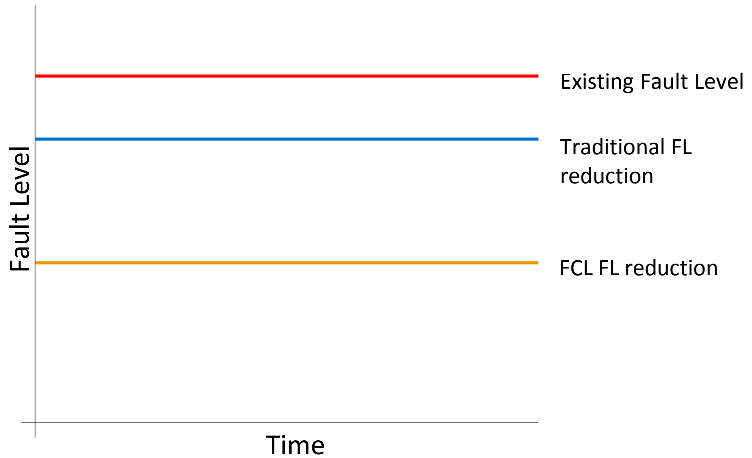
Design

Power Electronic FCL



Alstom Design

FCL Benefits



FlexDGrid Requirements

Following the installation of an FCL be able to:

- Operate the 11kV network in parallel
- Increase the level of generation on the network by 10% of a substation's firm load capacity

Faster Connections

- Installation of an FCL can be carried out quicker than traditional reinforcement

Reduced Costs

- Installation of an FCL can be completed cheaper than traditional reinforcement

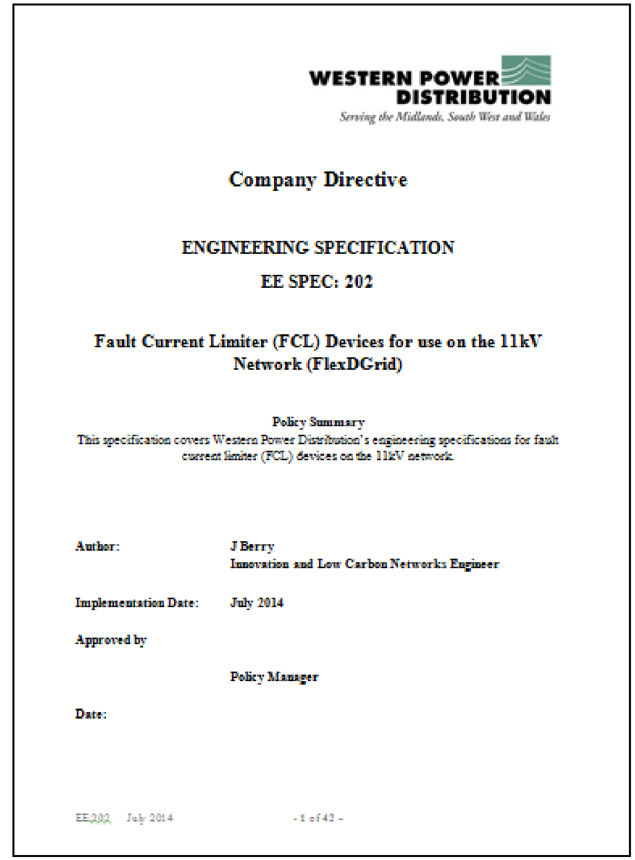
Greater Benefits

- Increased fault level reduction over traditional solutions
- Security of supply improvement through parallel network operation

Policies

Now in Place:

- EE201 – FLM Engineering Specification
- EE202 – FCL Engineering Specification
- ST_SD4R – Application and Connection of 11kV FLMs
- ST_SD4S – Application and Connection of 11kV FCLs



WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Company Directive

ENGINEERING SPECIFICATION

EE SPEC: 202

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

Policy Summary

This specification covers Western Power Distribution's engineering specifications for fault current limiter (FCL) devices on the 11kV network.

Author:	**J Berry** **Innovation and Low Carbon Networks Engineer**
Implementation Date:	**July 2014**
Approved by	
	Policy Manager
Date:	

EE202 July 2014 - 1 of 42 -

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FLEXDGRID

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FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

FlexDGrid

Network Performance

Wednesday 25th November 2015

LCNI Conference

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

Agenda

- Project Overview
- Safety – Increasing network data
- Security – Reliability of supply
- Flexibility – Customer Connections

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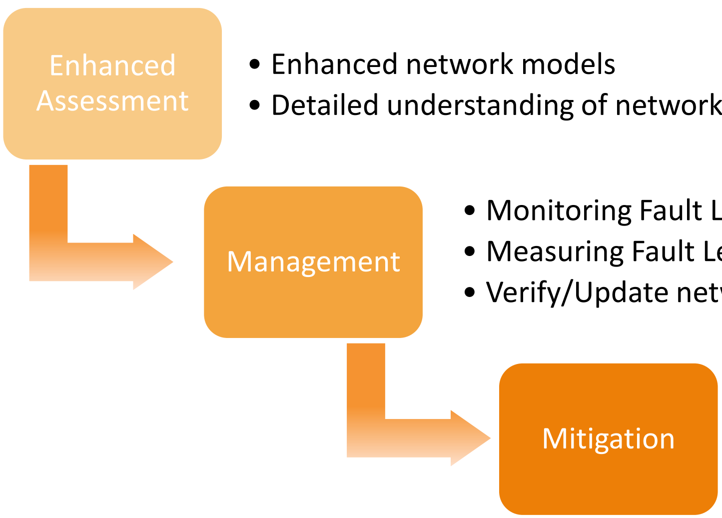

Enhanced Assessment
- Enhanced network models
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- Reduction of system Fault Level
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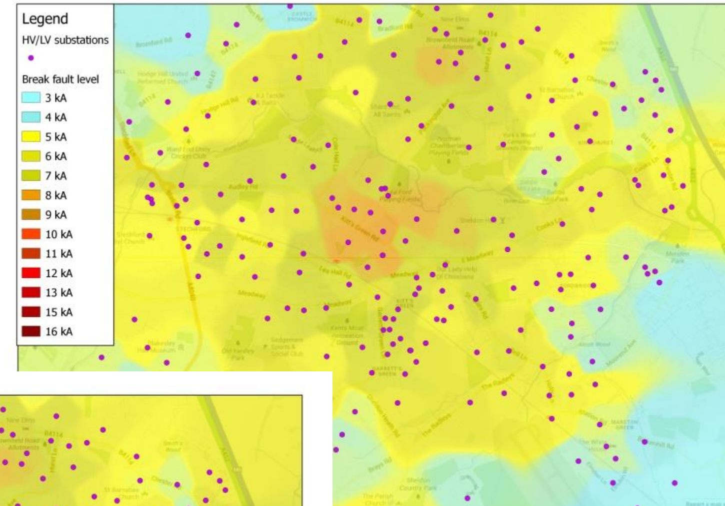
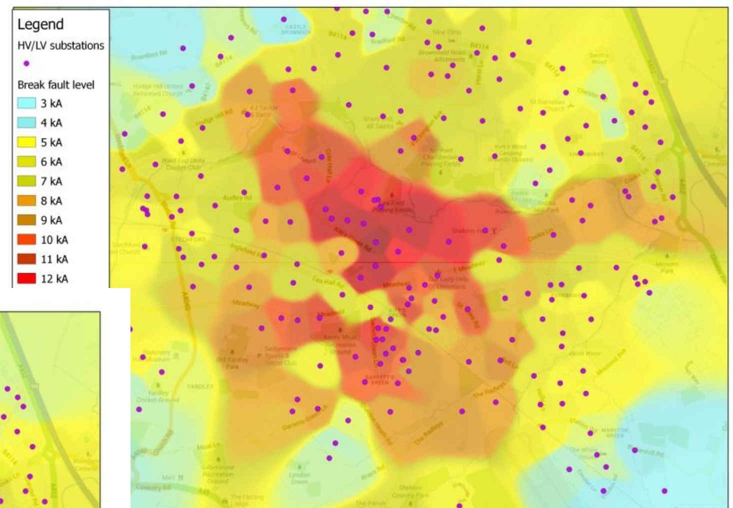
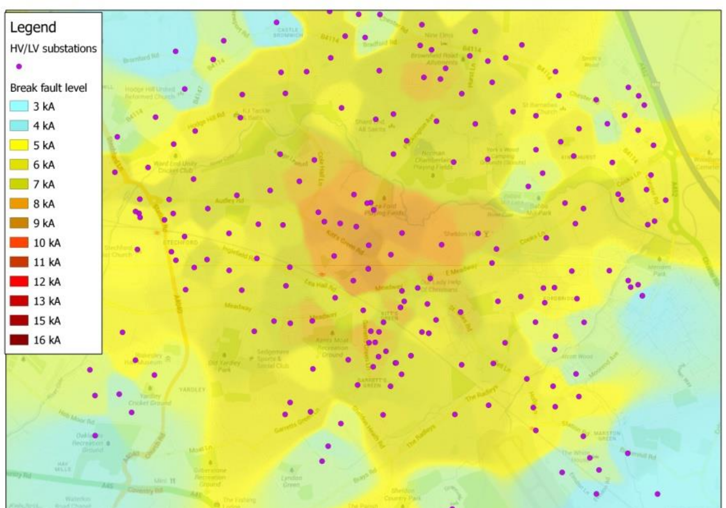
Effect on Fault Level







Fault Level Heat Maps

Safety – Increasing Network Data

- Installation of 10 Fault Level Monitors has enabled significant fault level data to be captured

Safety – Increasing Network Data

- Fault Level data from 11kV networks is now available to enable updated power system analysis models to be created
  - G74 prescribes 1MVA/MVA for LV load on the 11kV network

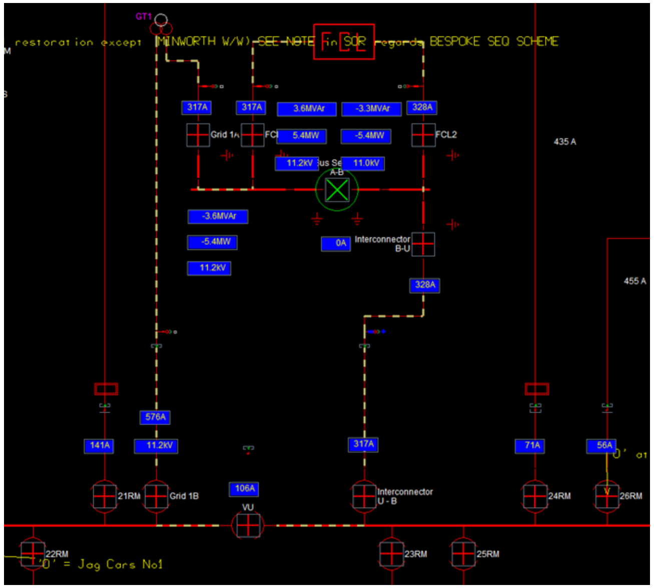
Ladywood					
MVA/MVA per	00:00	06:00	12:00	18:00	Average
1 month	2.1	2.1	1.9	2.2	2.1
weekdays of 1 month	2.3	1.7	1.6	2.5	2.0
weekends of 1 month	2.4	2.1	1.8	2.3	2.2
week 1	2.3	1.7	1.6	2.5	2.0
week 2	2.2	2.7	1.4	1.7	2.0
week 3	2.3	1.7	2.2	2.5	2.2
week 4	1.7	2.5	1.9	2.0	2.0
weekdays of week 1	1.9	1.4	2.0	2.2	1.9
weekdays of week 2	1.6	3.2	1.7	1.6	2.0
weekdays of week 3	2.4	2.2	2.0	2.6	2.3
weekdays of week 4	2.3	2.0	1.6	2.4	2.1
Average	2.1	2.1	1.8	2.2	

Elmdon					
MVA/MVA per	00:00	06:00	12:00	18:00	Average
1 month	2.1	2.2	2.5	2.3	2.3
weekdays of 1 month	2.2	2.3	2.5	2.6	2.4
weekends of 1 month	2.1	1.8	3.0	1.8	2.2
week 1	2.4	2.5	2.8	2.5	2.6
week 2	1.6	2.2	2.4	2.0	2.1
week 3	2.8	2.6	2.7	2.5	2.7
week 4	1.9	2.0	2.3	2.5	2.2
weekdays of week 1	2.6	3.3	2.4	2.0	2.6
weekdays of week 2	1.7	2.0	2.5	2.3	2.1
weekdays of week 3	2.9	2.8	2.8	2.9	2.9
weekdays of week 4	1.6	2.3	2.2	2.8	2.2
Average	2.2	2.4	2.6	2.4	

Substation	domestic (%)	Small I&C (%)	Large I&C (%)
Elmdon	7.18%	7.30%	85.52%
Ladywood	20.42%	28.14%	51.44%

Safety – Increasing Network Data

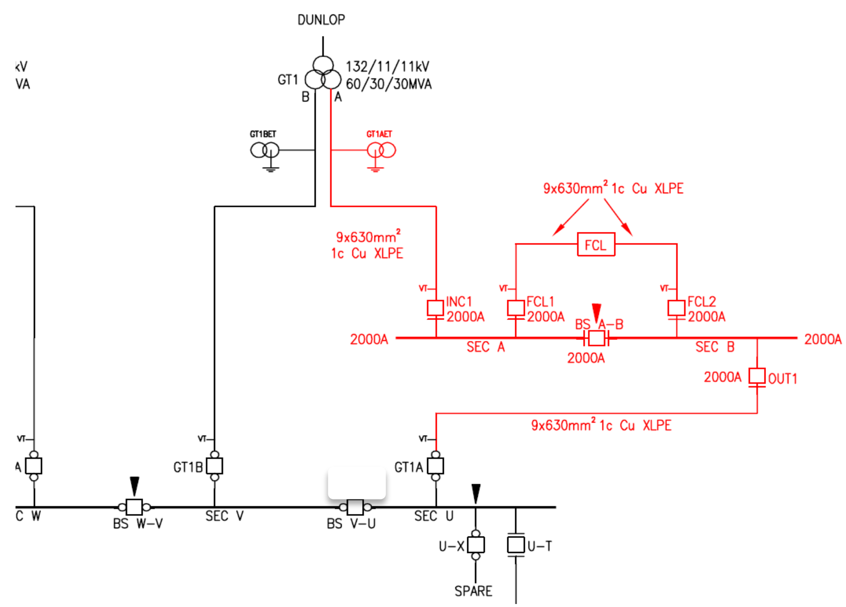
- Real-time fault level data now enables control engineers to have another set of information to allow:
  - Potential to parallel additional elements of network
  - Greater information when planning network changes
  - Visual understanding of the effect a network change has on FL



Security – Reliability of supply

- Through the installation of five FCLs a significant part of the Birmingham 11kV network will be able to be paralleled

- Network paralleling will have a positive effect on:
  - Short Interruptions
  - Customer Interruptions
  - Customer Minutes Lost



Security – Reliability of supply

- Losses benefits are also seen through the paralleling of the network through FCL installations

  - Changes average load through transformer from 70/30 to 50/50 percentage split
  - Saving of 480,000kWh per annum
  - Equivalent to 205,000kg CO_2

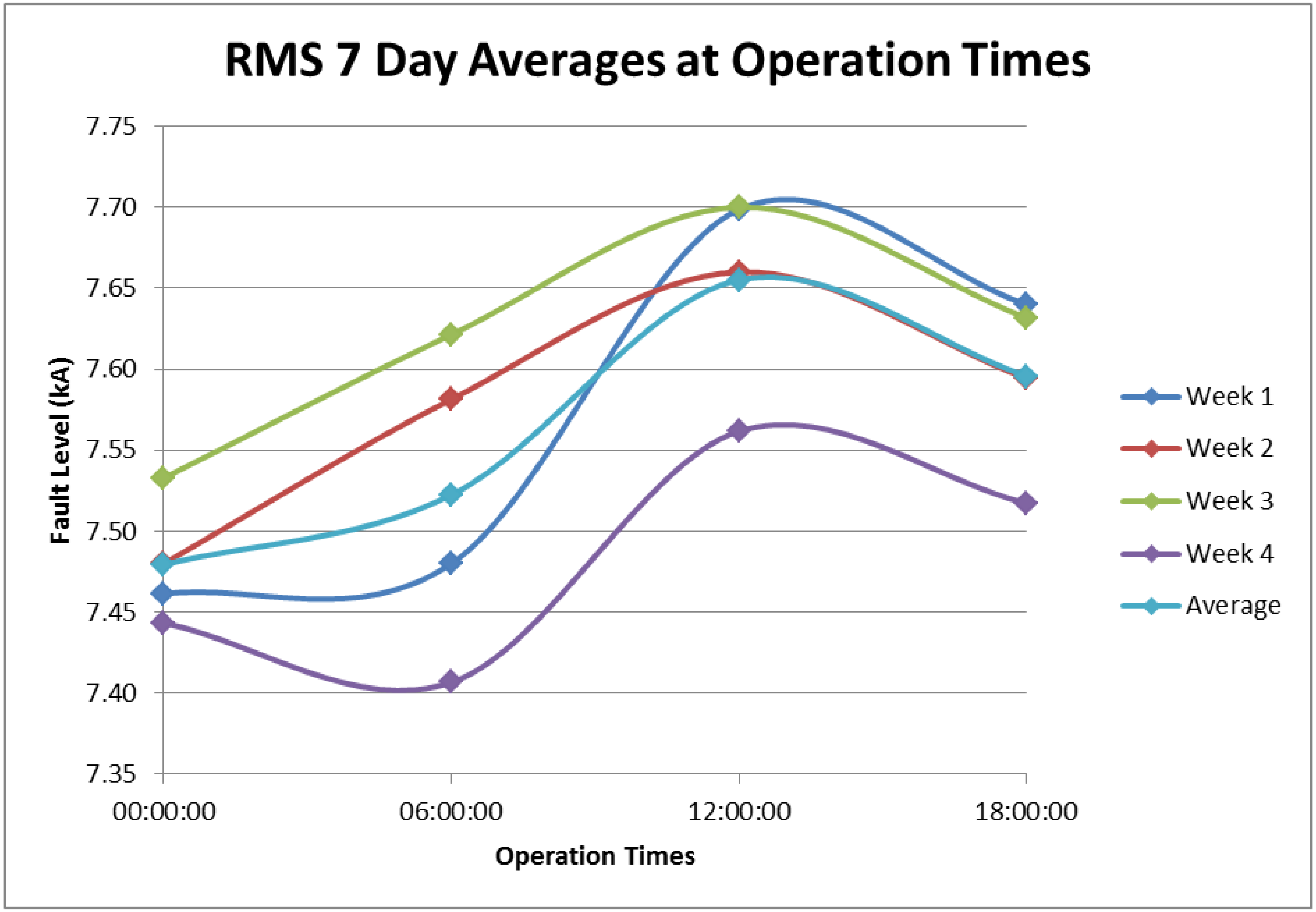
  - If the unbalance was 80/20 then the savings per annum would be:
    - 1,080,000kWh and 462,000kg CO_2

Flexibility – Customer Connections

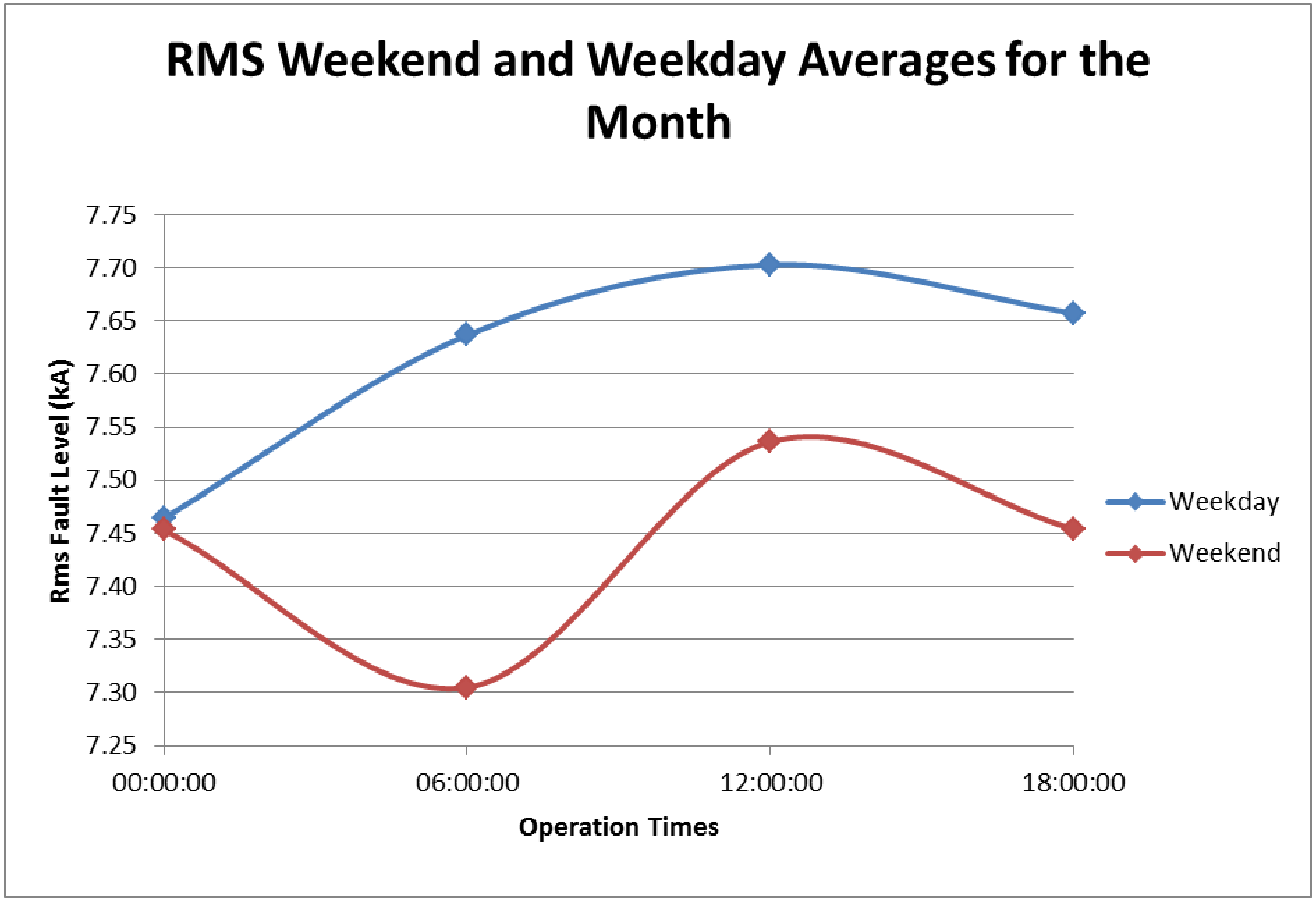
- Through real-time fault level data availability the aim is to be able to provide flexible connections to customers to maximise the use of existing network infrastructure

- Utilising the fluctuating nature of fault levels:
  - Time of day
  - Week day / Weekend
  - Season

Flexibility – Customer Connections



Flexibility – Customer Connections



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WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Fault Current Limiters
Testing, Operation and Learning

Jonathan Berry

12th October 2016

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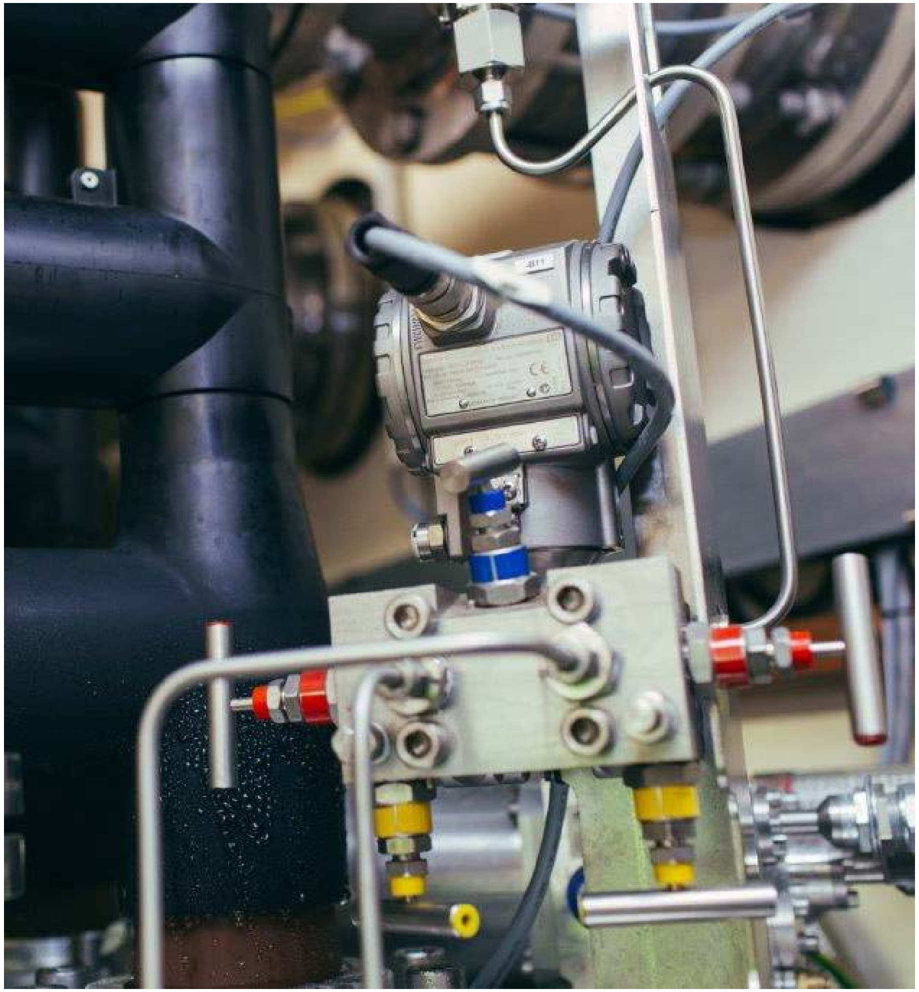
WESTERN POWER DISTRIBUTION
FLEXDGRID

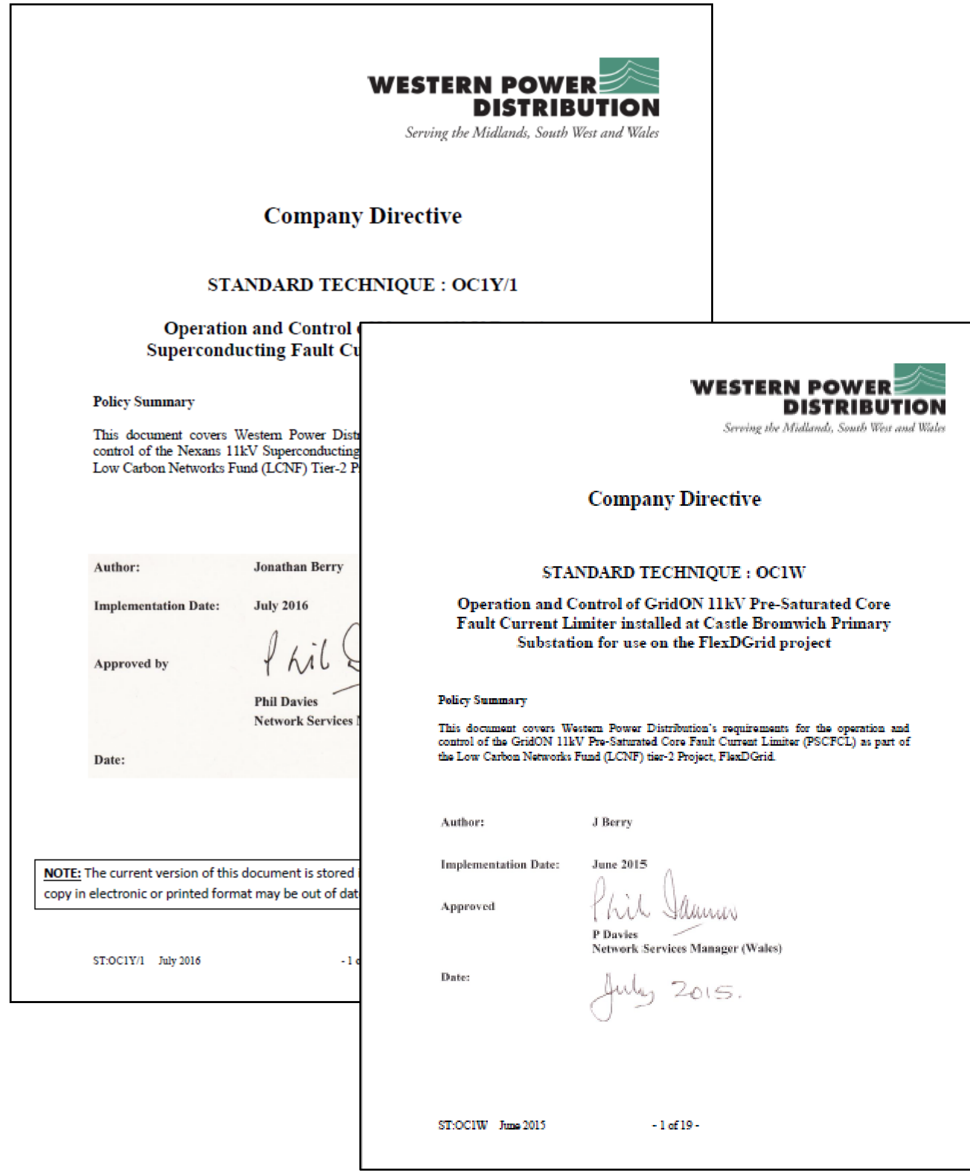
Introduction

- Policy documentation
- PSCFCL and RSFCL
  - Overview
  - Testing
  - Technology operation
  - Learning points



Policy Documents

- Two documents specifically 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:

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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.

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Implementation Date: June 2015

Approved: P Davies
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Date: July 2015.

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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.

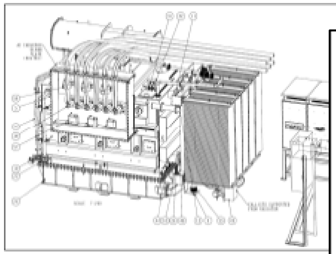


Figure 3-2: General Arrangement of FCL

3.3.2 There are two cubicles associated with the FCL. The AC cubicle is the sı 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 (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:

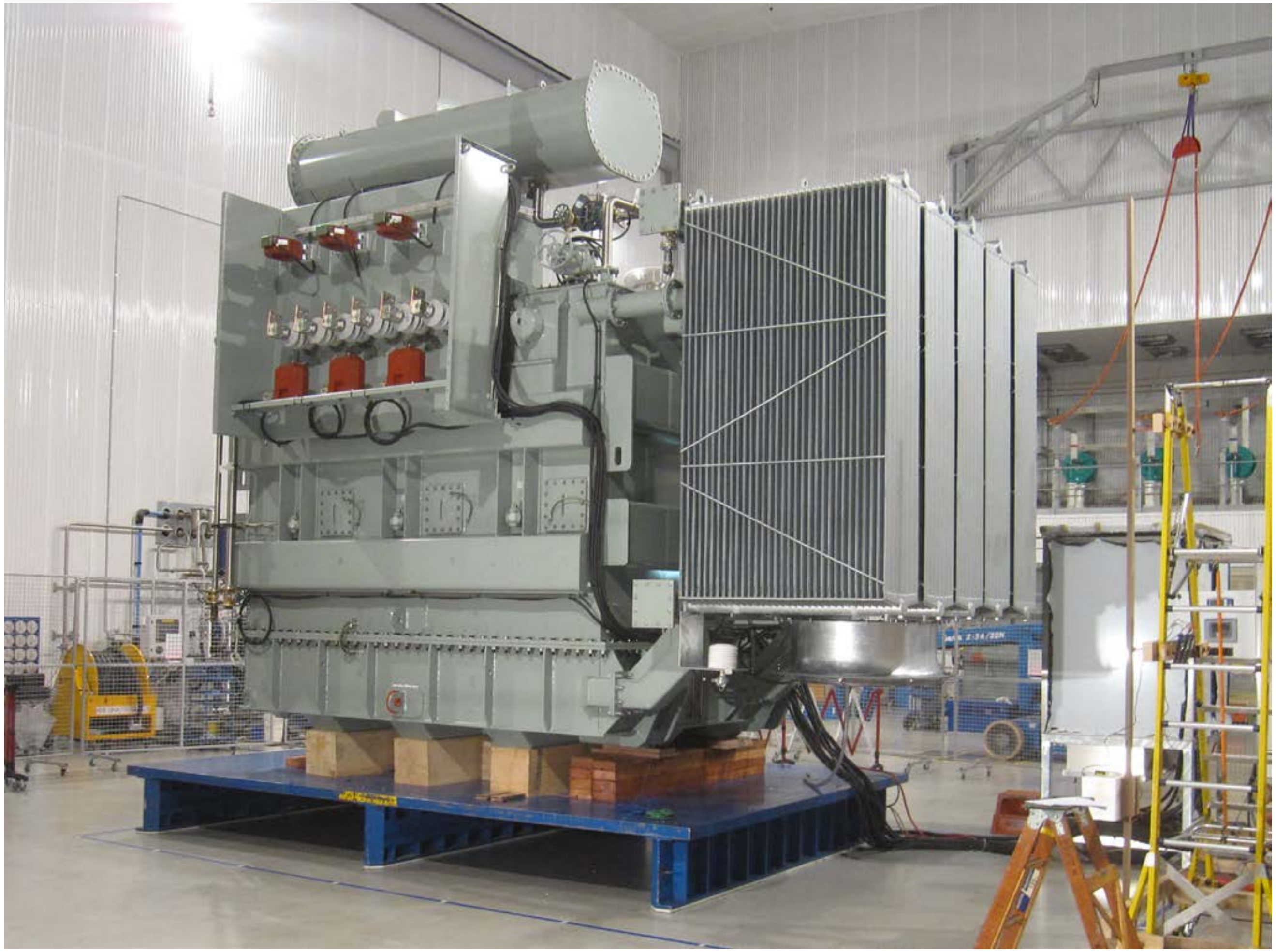
- Close Bus-Section A-B – this will allow any load current to by-pass the FCL. Note that this will result in a short-term solid parallel of windings GT1A and GT1B
- Open Bus-Section U-V – this will break the parallel of GT1A and GT1B windings
- Open FCL circuit breakers – this will remove the FCL AC 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

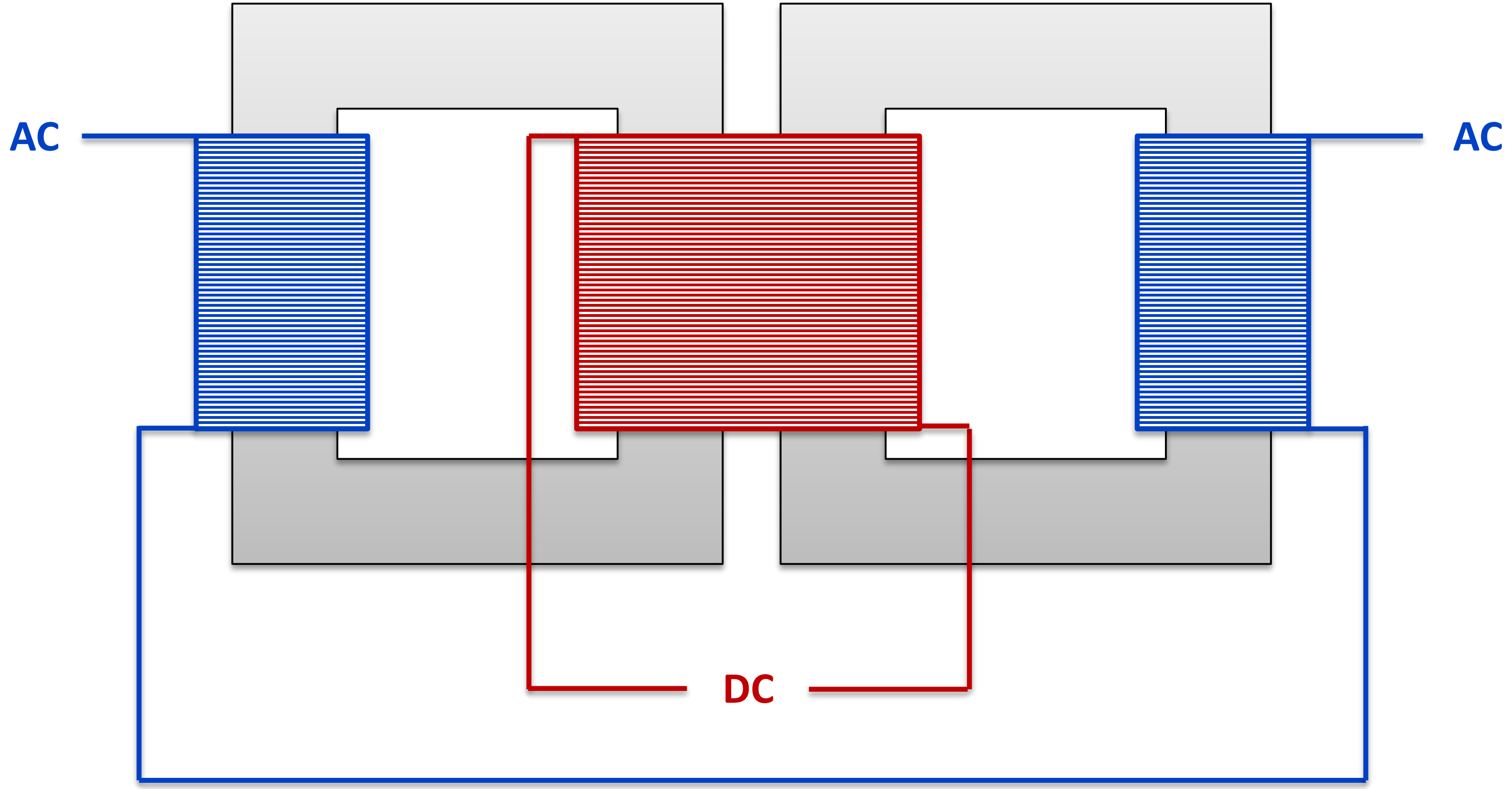
Pre-Saturated Core Fault Current Limiter



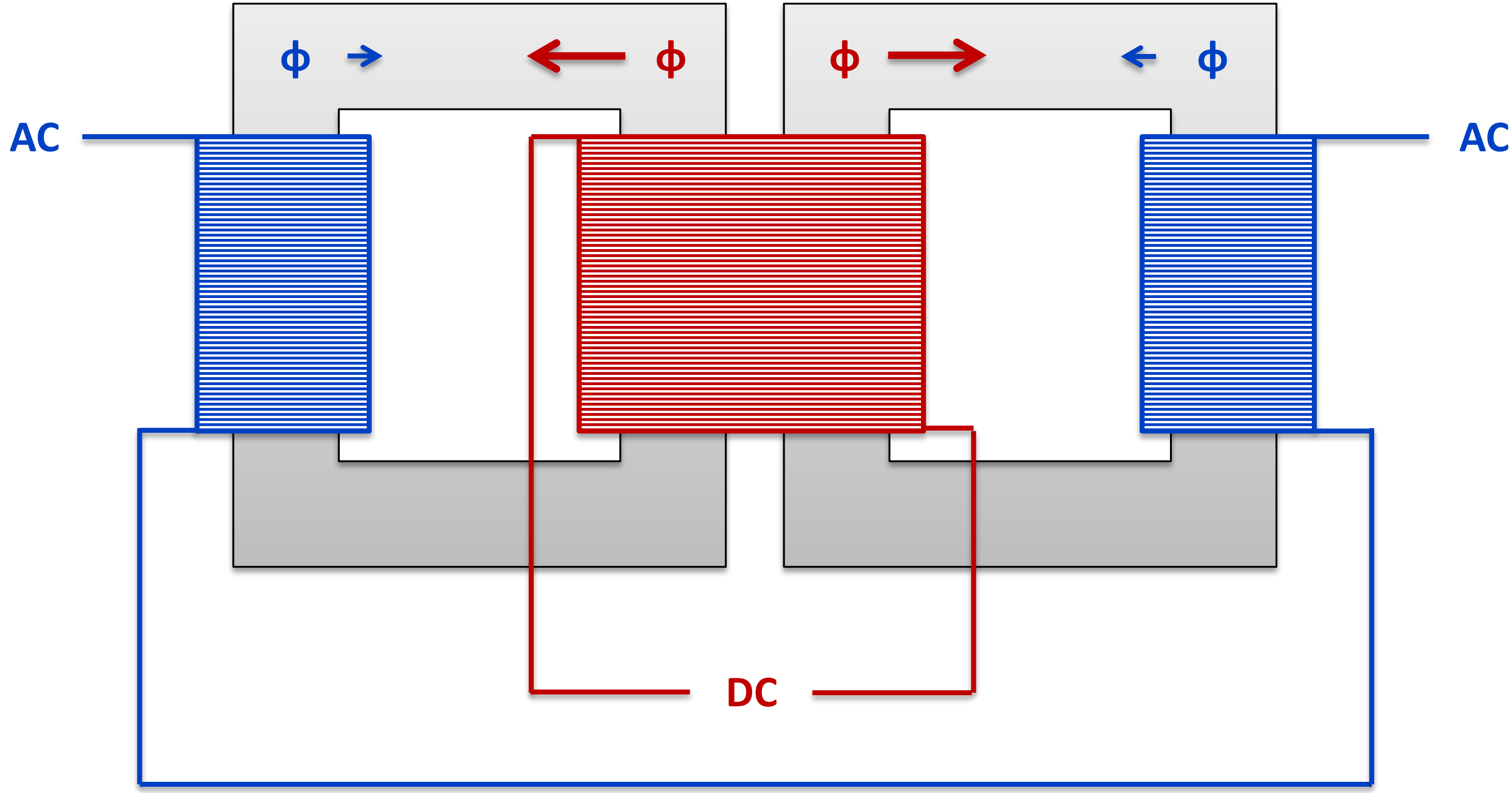
Pre-Saturated Core Fault Current Limiter

- 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)

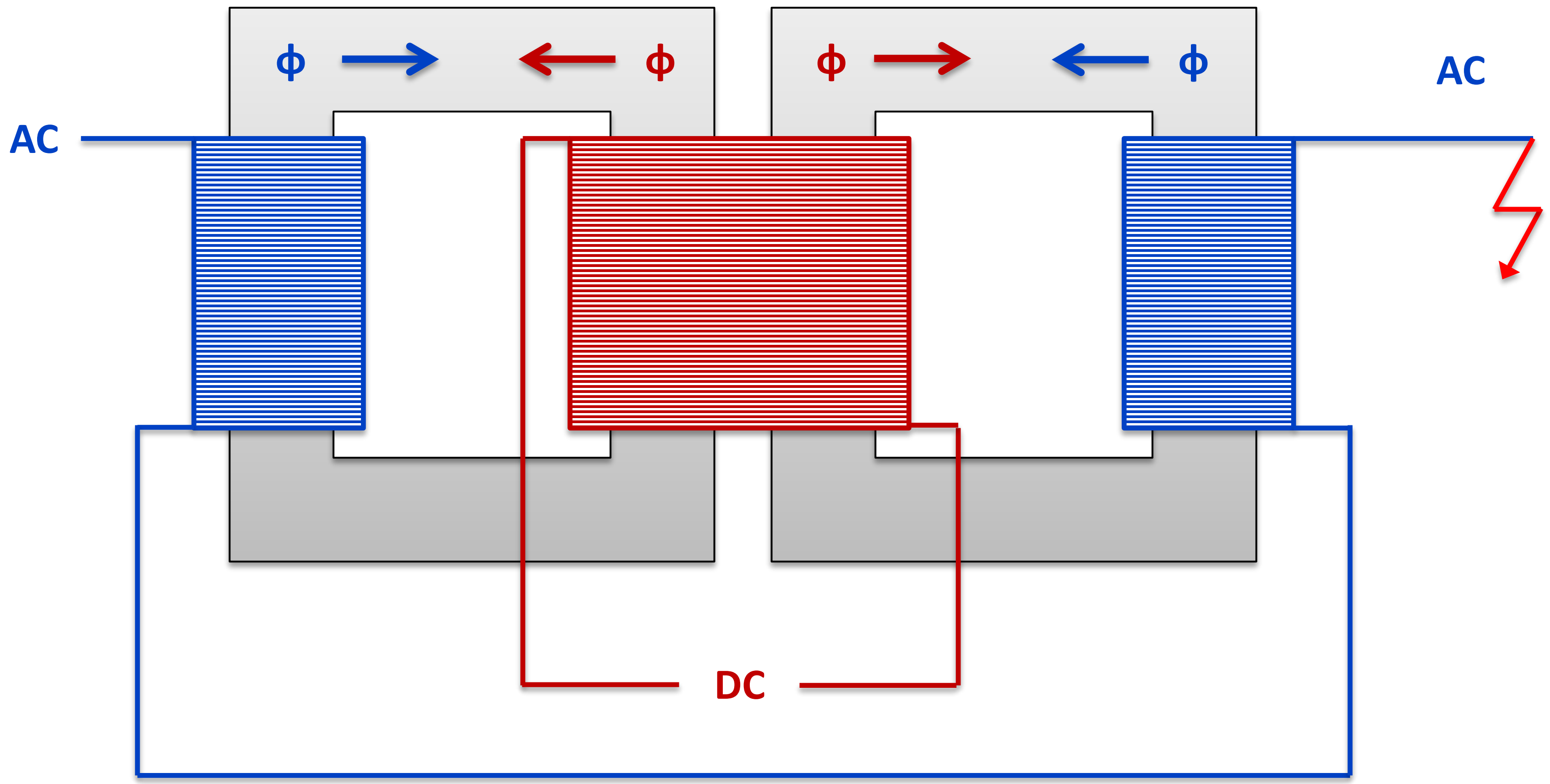
Diagram of PSCFCL



Normal Operation of PSCFCL



Operation of PSCFCL during a fault



Details for GridON PSCFCL Installation

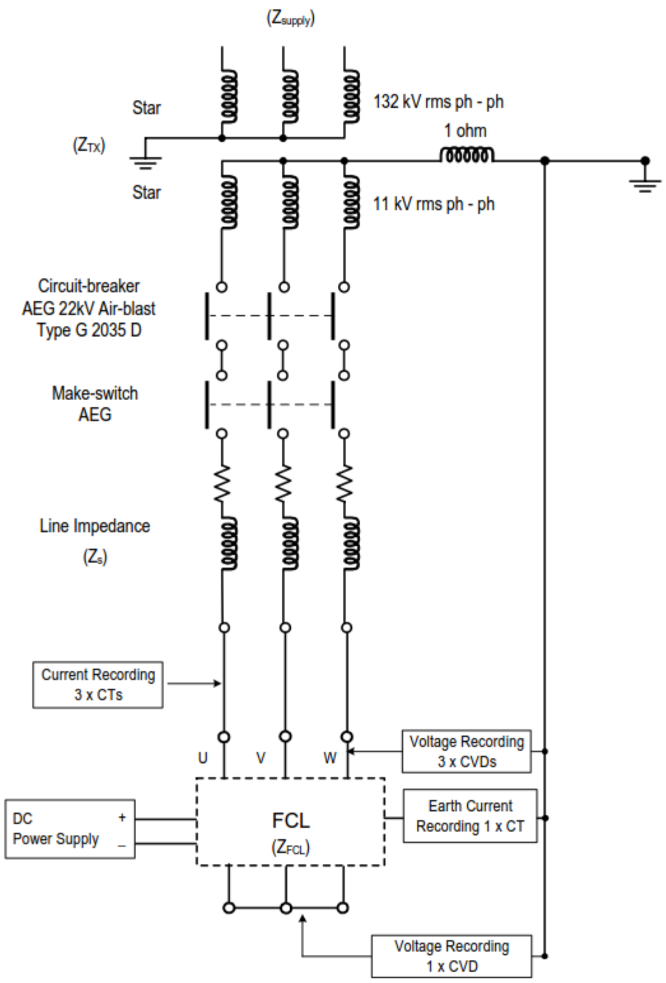
- Rating: 30MVA ONAN, 38MVA ONAF
- Break fault level reduction required: 44%
- Peak fault level reduction required: 53%
- Mass: 168 Tonnes
- Dimensions (LxWxH): 6.4 x 4.5 x 5.3 m

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

Testing – 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

Testing – GridON FCL



Testing – 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

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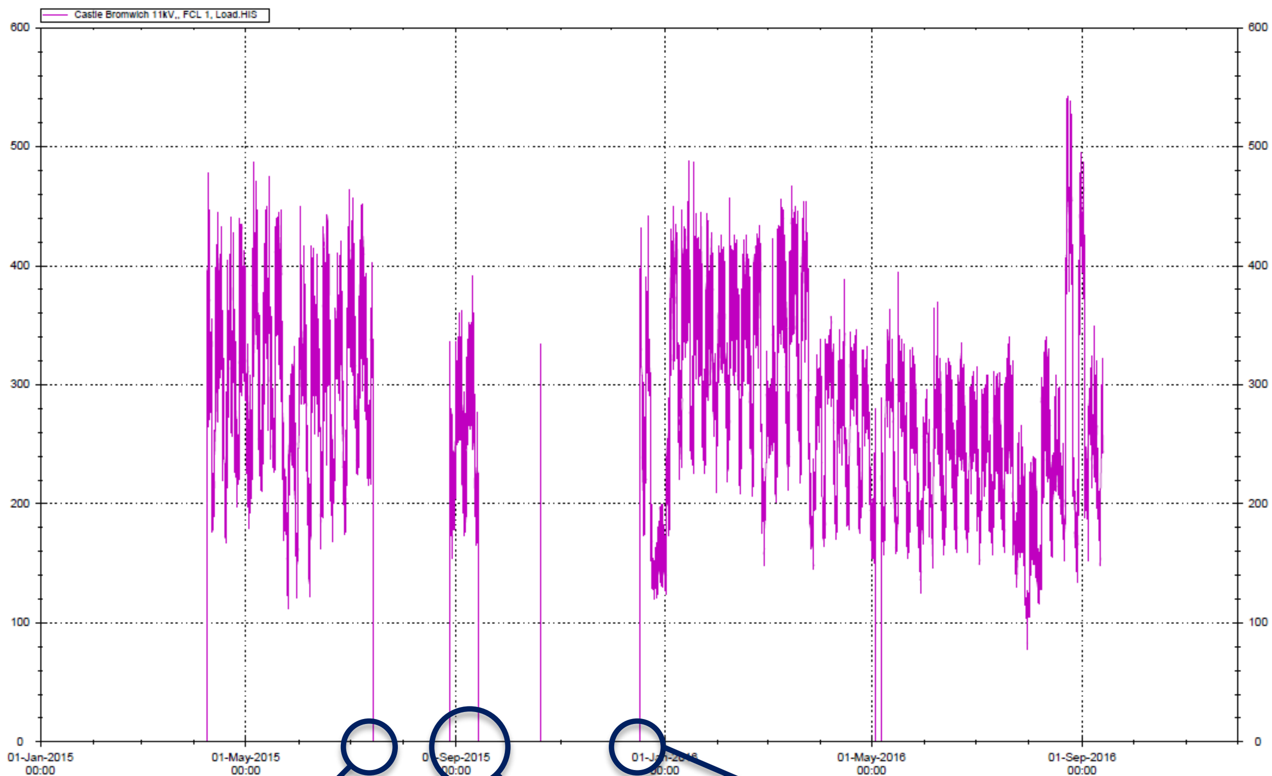
Operation – GridON FCL



Investigation of DC Alarm (14 July)

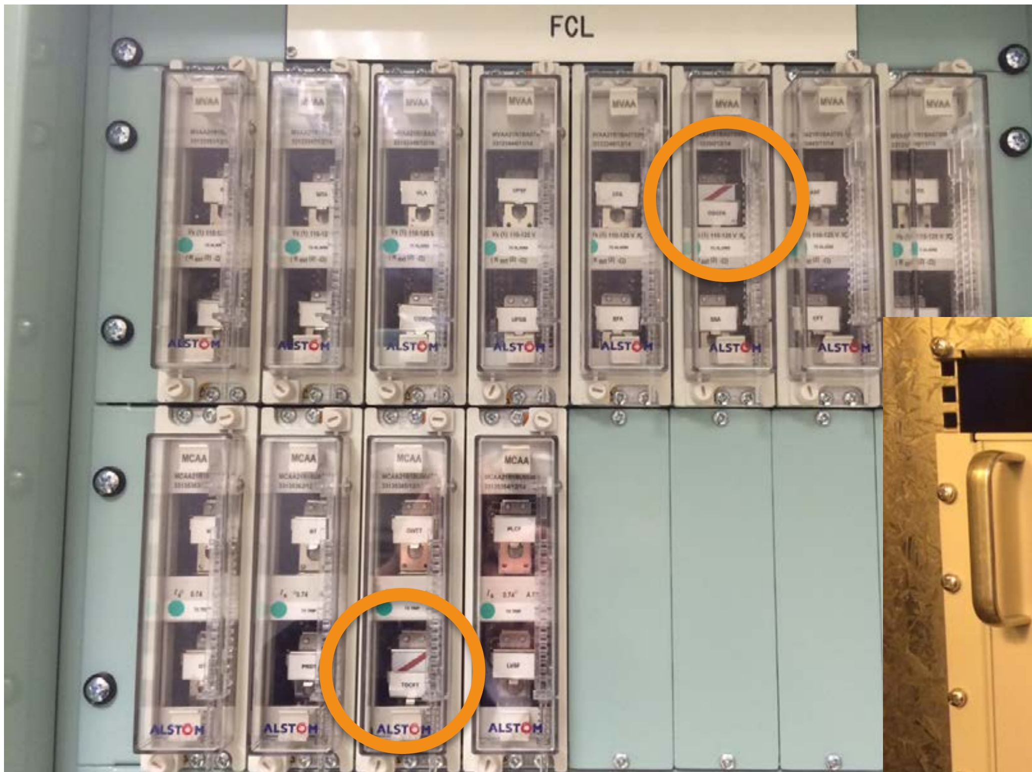
Energisation (28 Aug) after investigation and subsequent trip (14 Sept)

Device re-energised (17 Dec)

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

Operation – GridON FCL



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

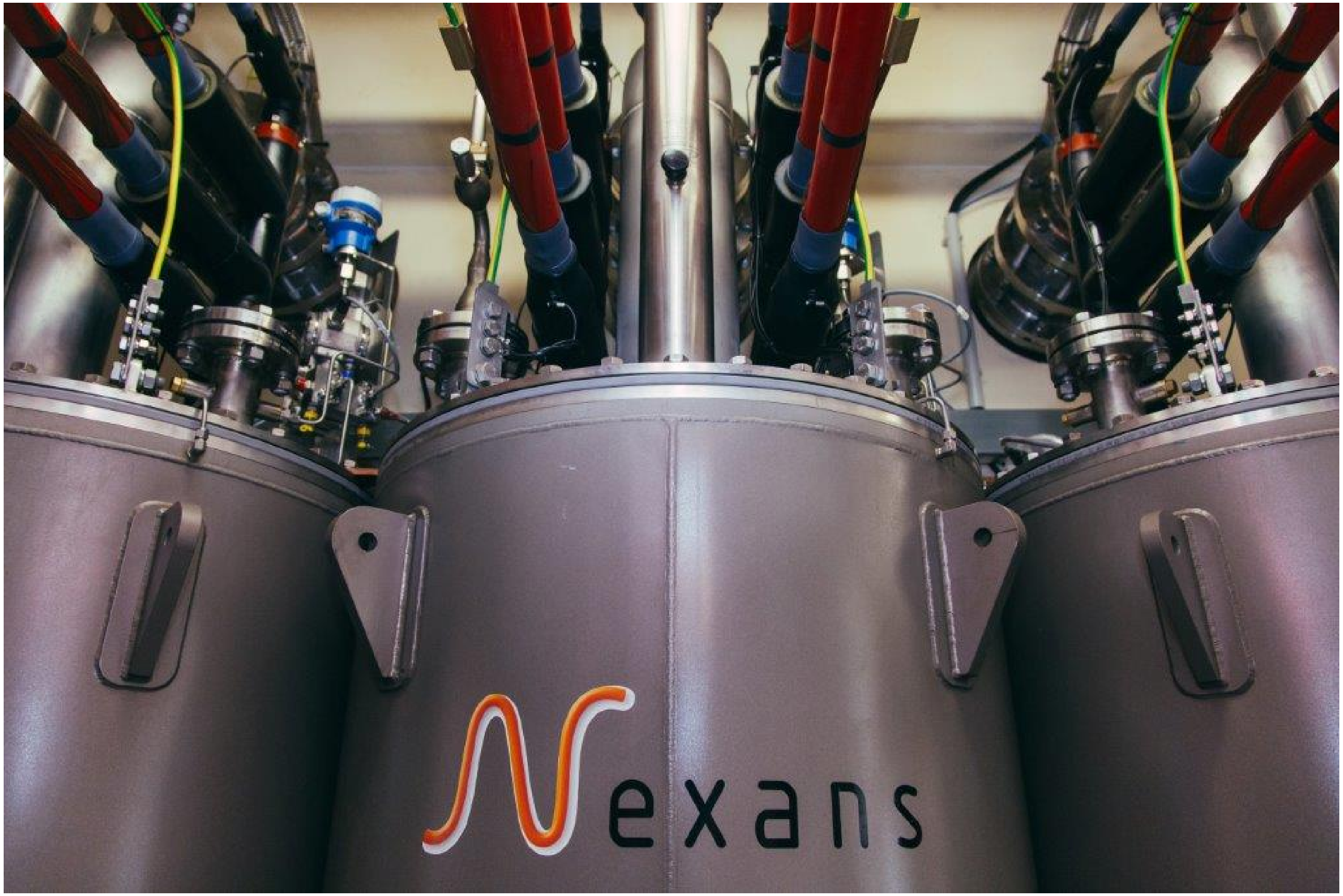
Short circuit testing

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

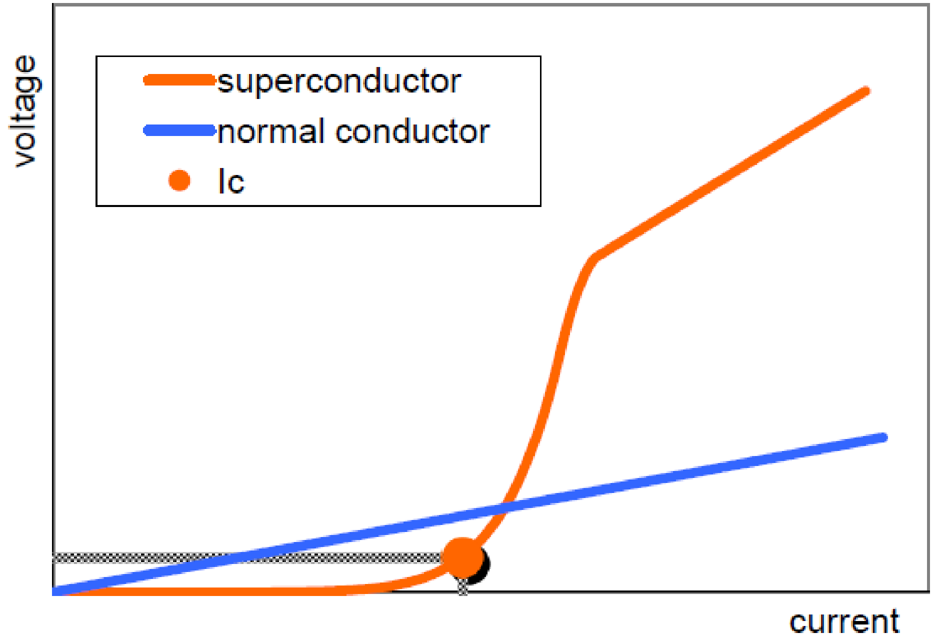
These issues were rectified before final testing so that the performance onsite was not affected

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)



Details for Nexans RSFCL Installations

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:

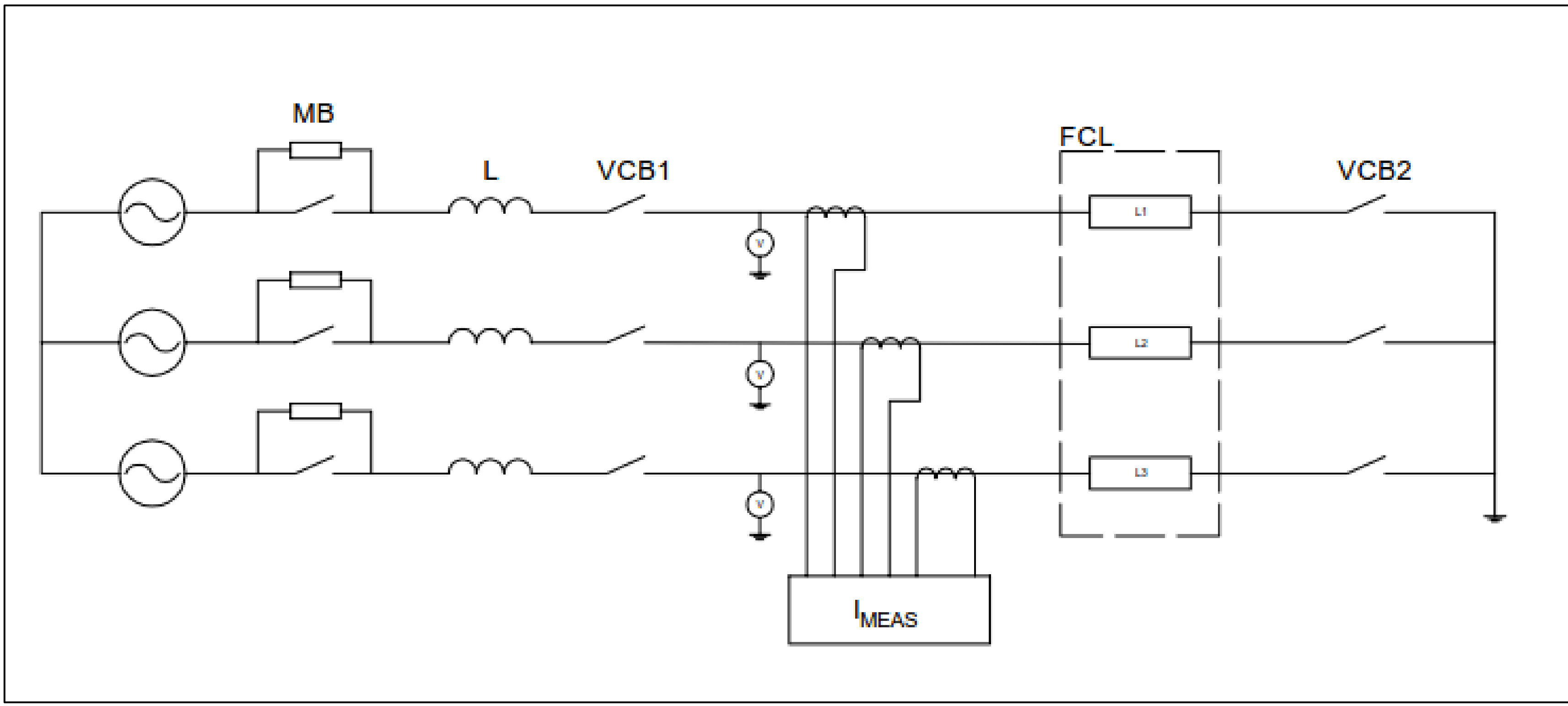
- 1050A rated
- Peak fault reduction (@10ms) 21.97kA to 7.70kA or below
- Peak fault reduction (@90ms) 7.66kA to 3.05kA or below
- 33.4kA short circuit current withstand capability

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

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



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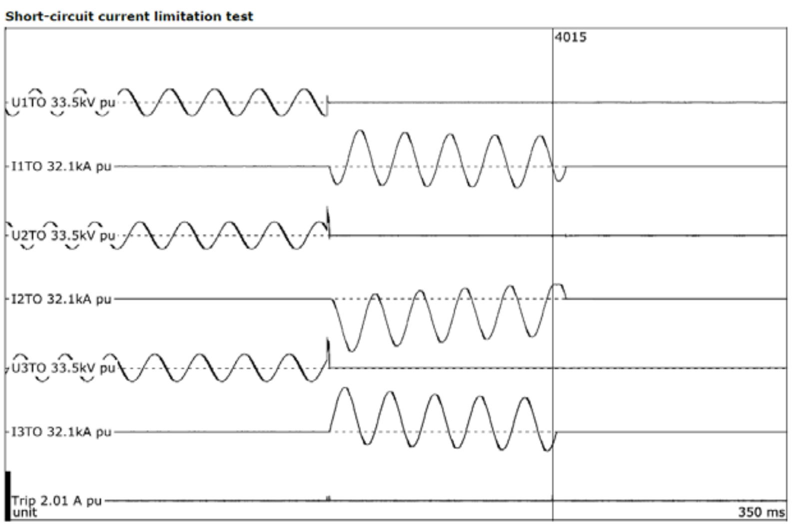
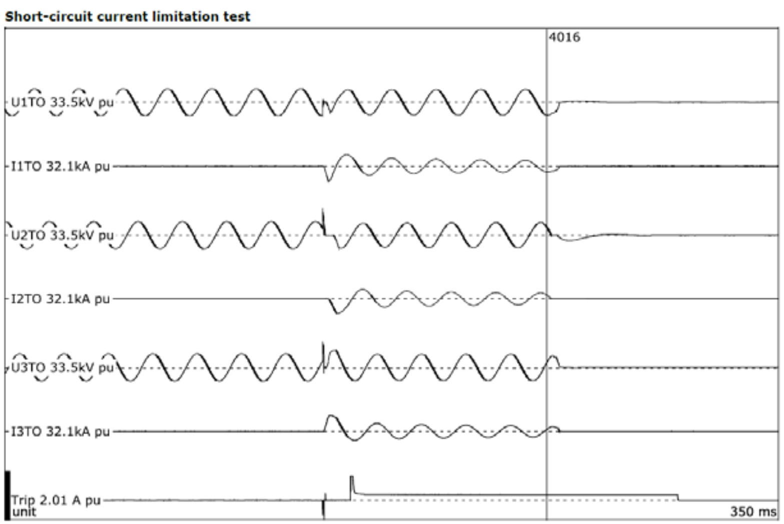
Testing – Nexans RSFCL





Testing - Nexans

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

<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

Works required at Chester Street to fix the cooling system issues:

- 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

Works required at Bournville to fix the cooling system issues:

- 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

THANKS FOR LISTENING

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