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FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Fault Current Limiters Testing, Operation and Learning

3.1 Innovative Fault Level Management

LCNI 2016, Wednesday 12th October

Jonathan Berry

Innovation & Low Carbon Networks Engineer

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

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Future Networks Programme

PROTEUS NEW | FLEXDGRID | PLUGS AND SOCKETS | SOLA BRISTOL | LOW CARBON HUB | OPEN LV NEW

NETWORK EQUILIBRIUM | SMART ENERGY ISLES | NETWORK TEMPLATES | FALCON

Assets

- Telemetry
- Decision support
- Improved assets
- New assets
- Flexibility
- Automation
- Incident response

Customers

- New connections
- Upgrades
- Information
- Self Serve
- Products/Service
- Tariffs
- Communities

Operations

- Reliability
- Forecasting
- DSO
- DSR
- GBSO Interface
- Efficiency
- SHE and Security

Network and Customer Data

- Airborne Inspections
- AIRSTART[1]
- Telecoms Analysis
- Superconducting Cable
- SF6 Alternatives
- MVDC Test Lab
- Smart Energy Laboratory
- Statistical Ratings
- Primary Network Power Quality Analysis

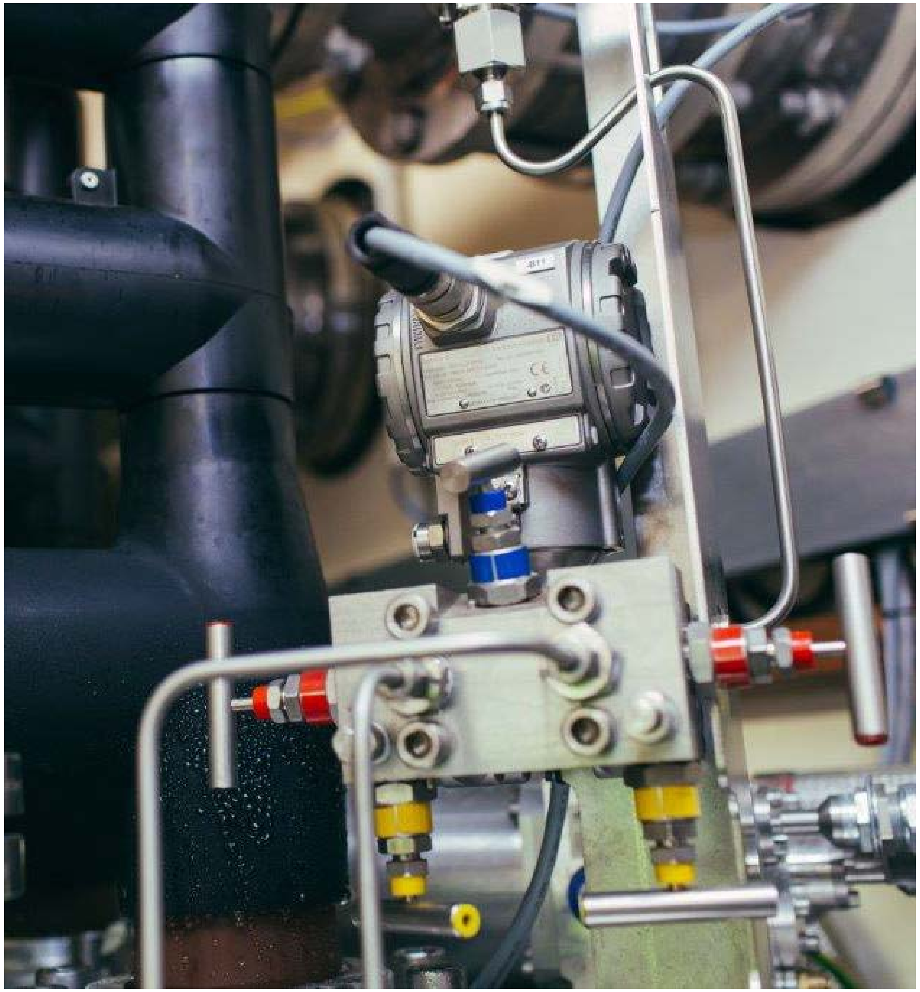
- Hybrid Heat Pump Demonstration
- Hydrogen Heat & Fleet
- Carbon Tracing
- HV Voltage Control
- Solar Storage
- LV Connect and Manage
- Sunshine Tariff
- CarConnect
- Industrial & Commercial Storage

- DSO/SO Shared Services
- Project SYNC
- Project ENTIRE
- Smart Meter data for Network Operations
- Distribution Operability Framework
- Times Series Data Quality
- Voltage Reduction Analysis
- LV Connectivity
- Smart Systems and Heat[2]

Note: 1 – Funded by Aerospace Technology Institution; Note 2 – Funded by the Energy Systems Catapult

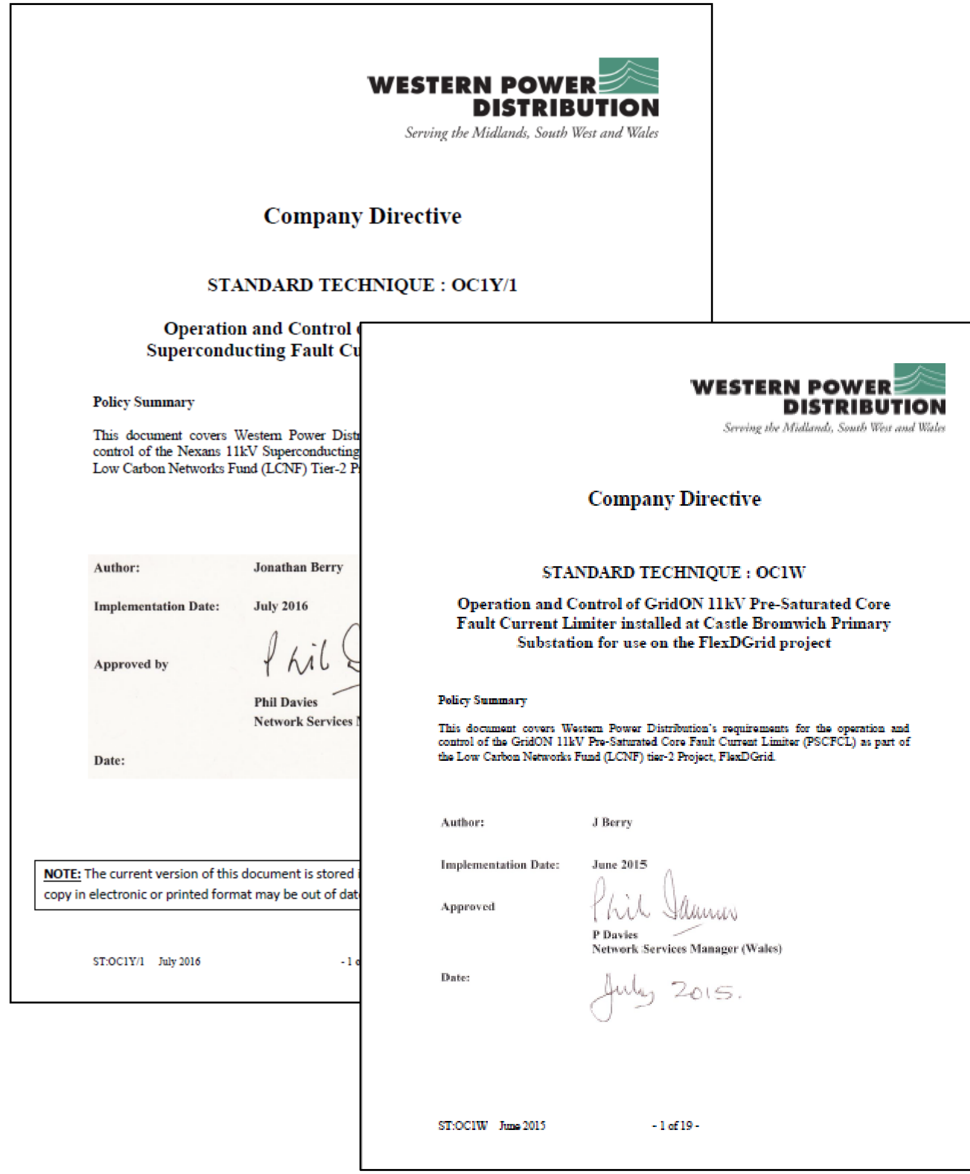
Introduction

- 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



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Company Directive

STANDARD TECHNIQUE : OC1Y/1

Operation and Control (
Superconducting Fault Cu

Policy Summary

This document covers Western Power Distr
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 M
Date:	

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

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WESTERN POWER DISTRIBUTION
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Company Directive

STANDARD TECHNIQUE : OC1W

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

Policy Summary

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

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

ST:OC1W June 2015 - 1 of 19 -

Policy Documents

Operation and Control:

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

Inspection and Maintenance:

- Inspection procedure
- Maintenance guidance
- Maintenance Intervals

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

3.3 General Arrangement

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

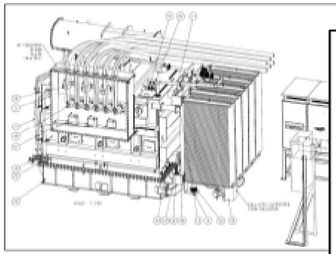

Figure 3-2: General Arrangement of FCL

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

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

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

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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.

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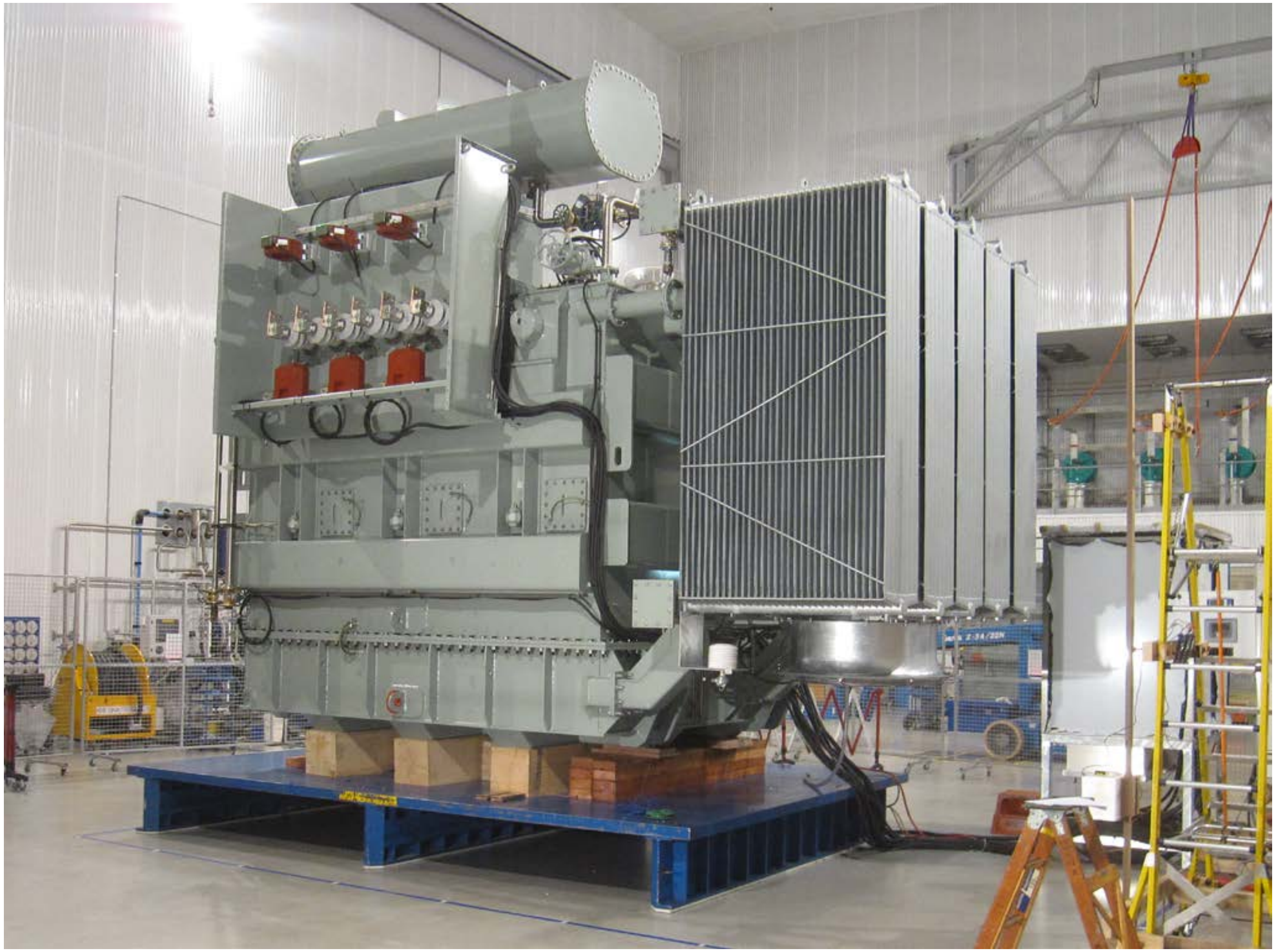
Fault Level Reduction

- 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)

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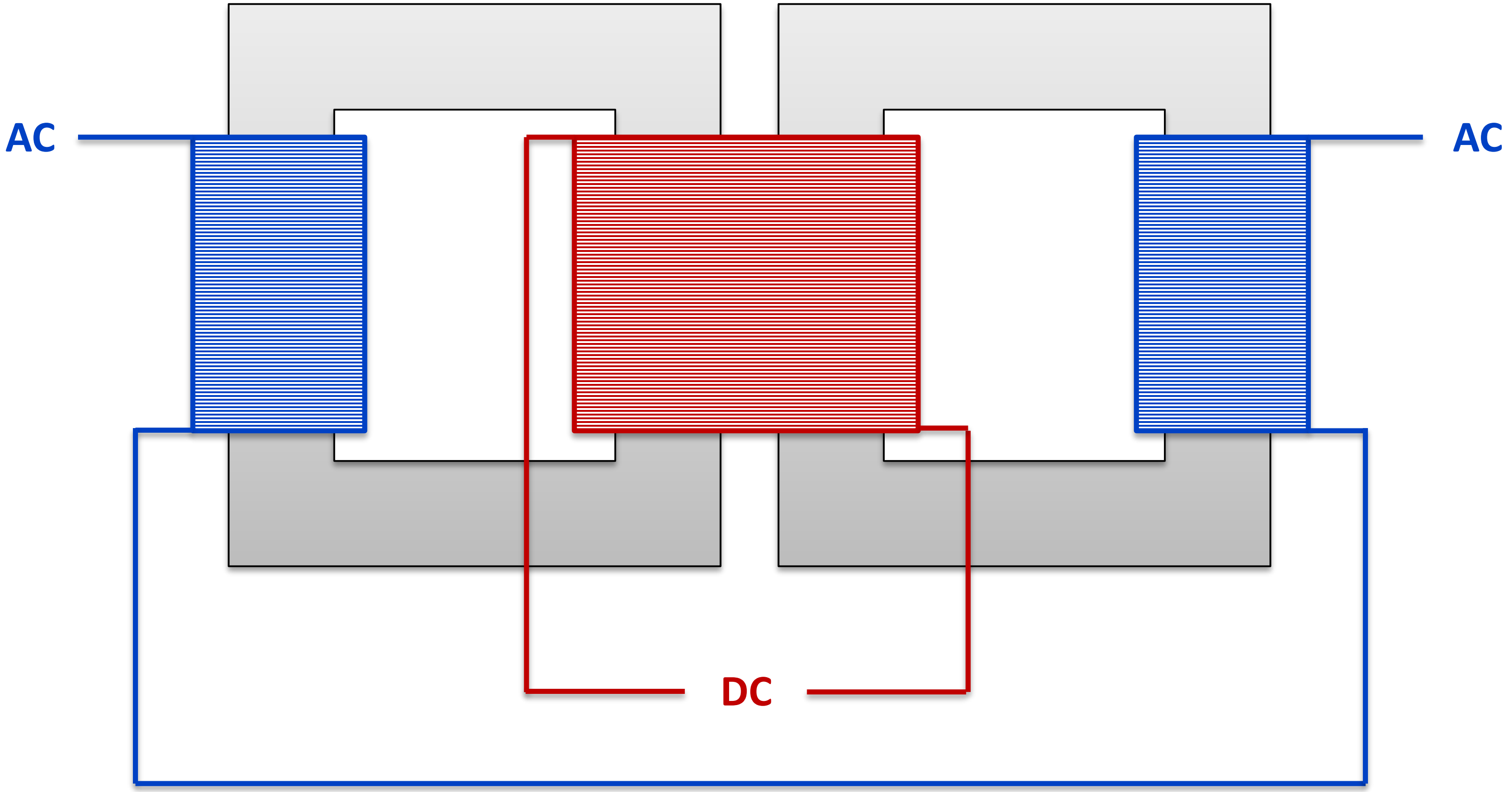
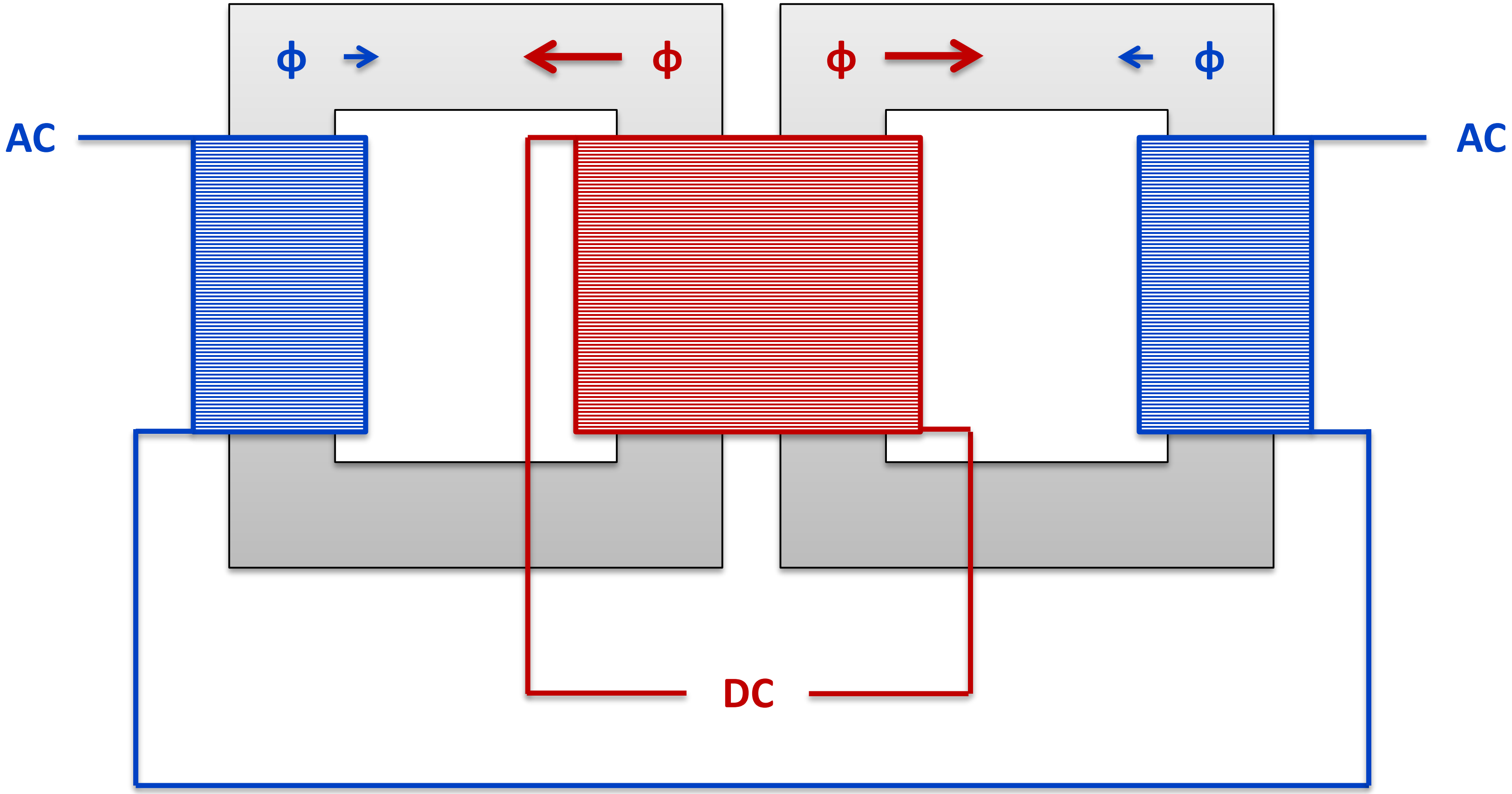
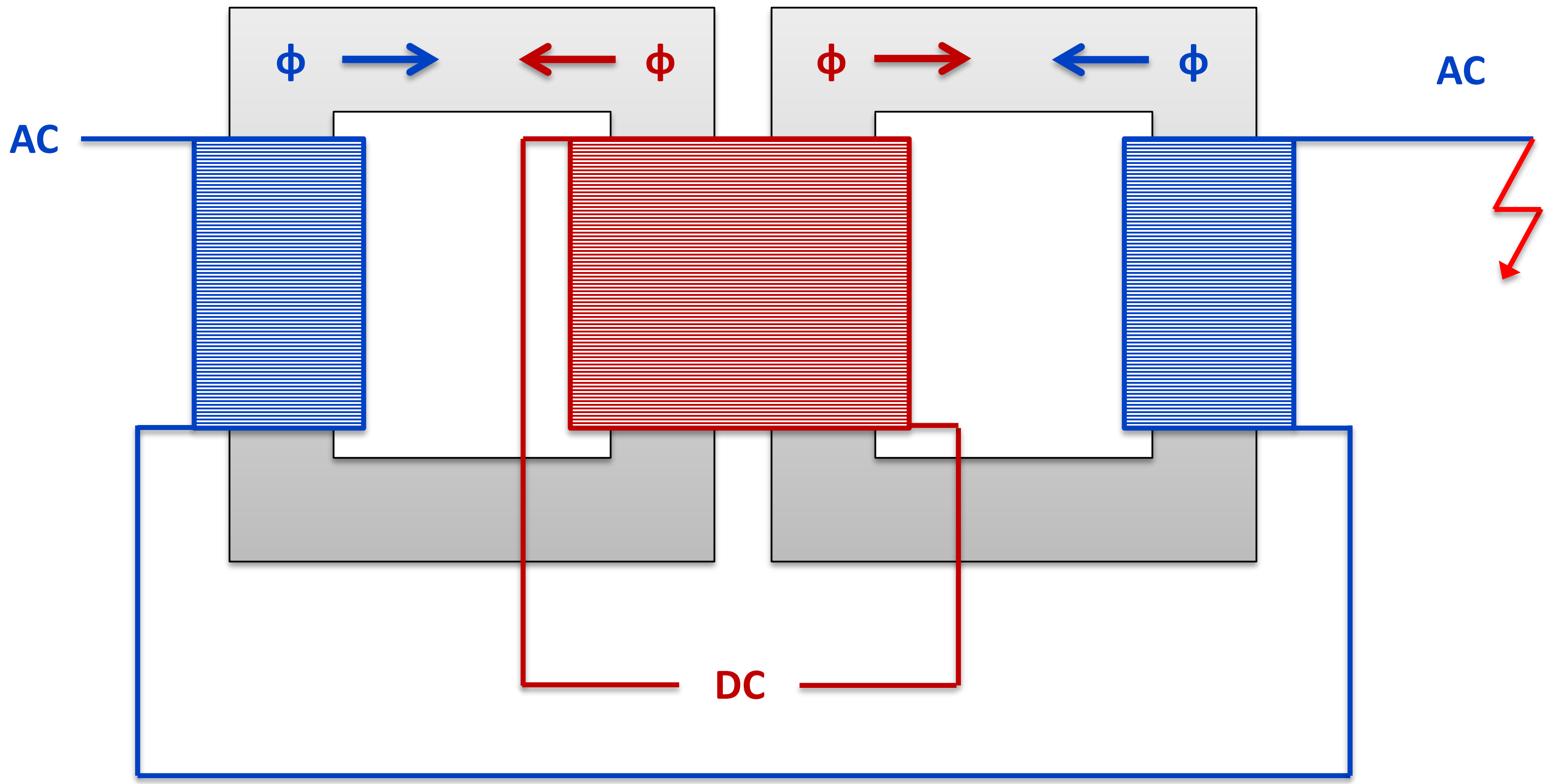
Diagram of PSCFCL



Normal Operation of PSCFCL



Operation of PSCFCL during a fault



Details for GridON PSCFCL Installation

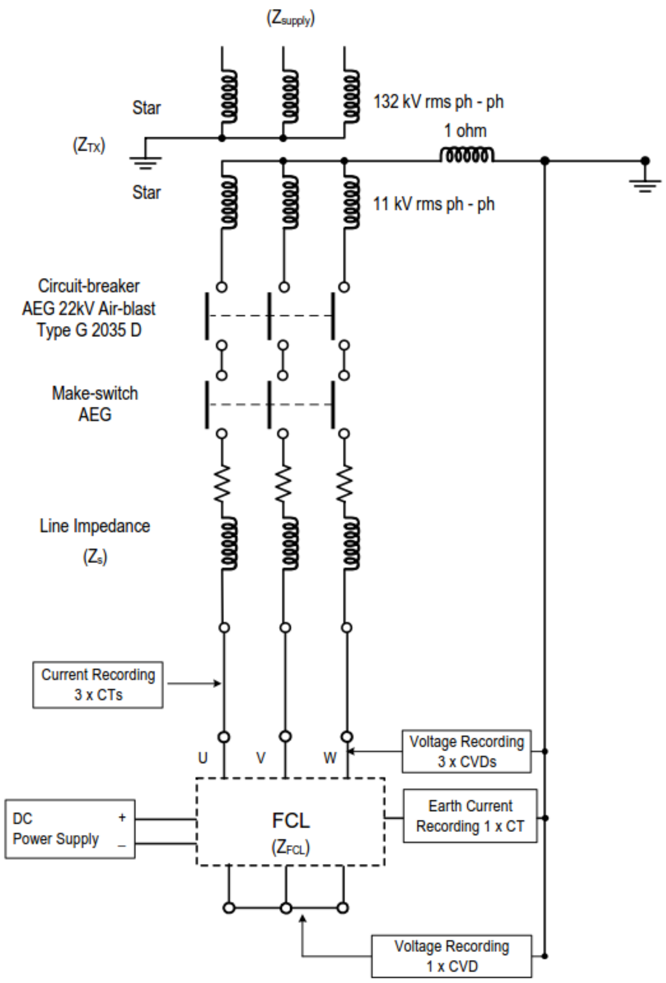
- Rating: 30MVA ONAN, 38MVA ONAF
- Break fault level reduction required: 44%
- Peak fault level reduction required: 53%
- Mass: 168 Tonnes
- Dimensions (LxWxH): 6.4 x 4.5 x 5.3 m

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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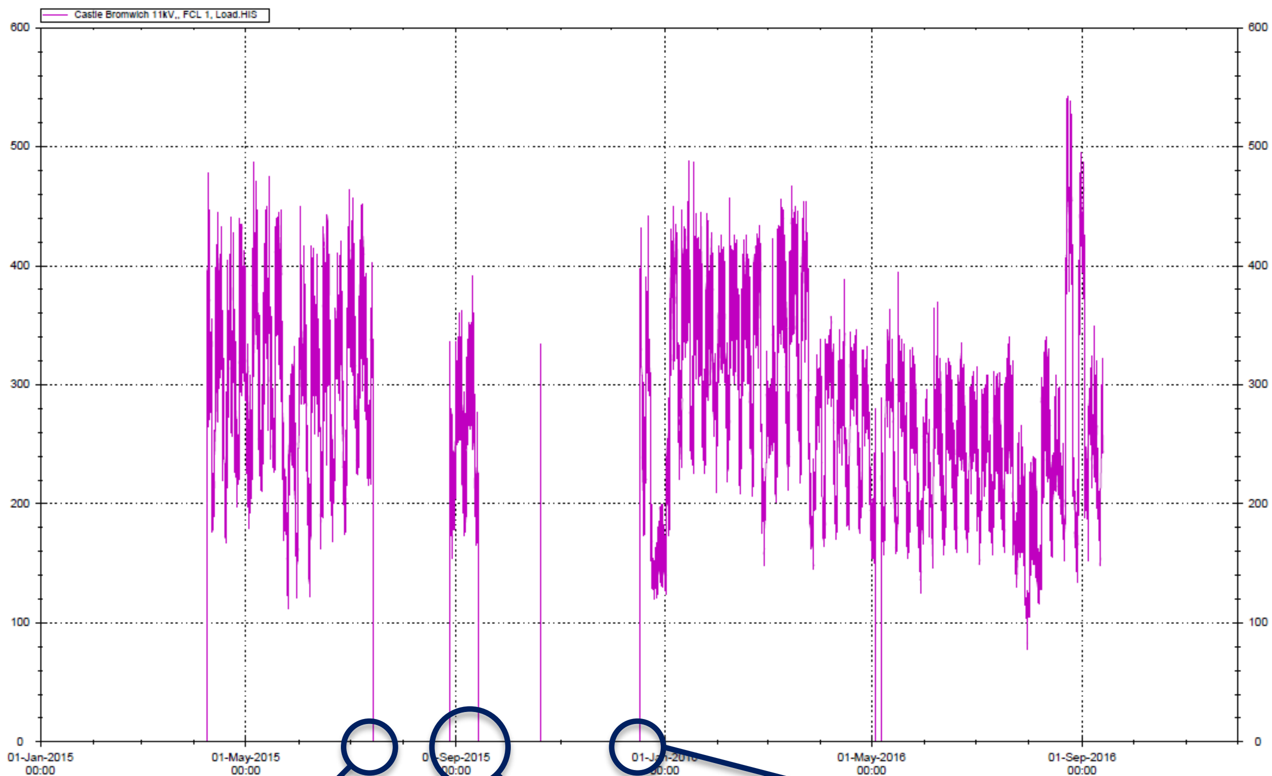
Operation – GridON FCL



Investigation of DC Alarm (14 July)

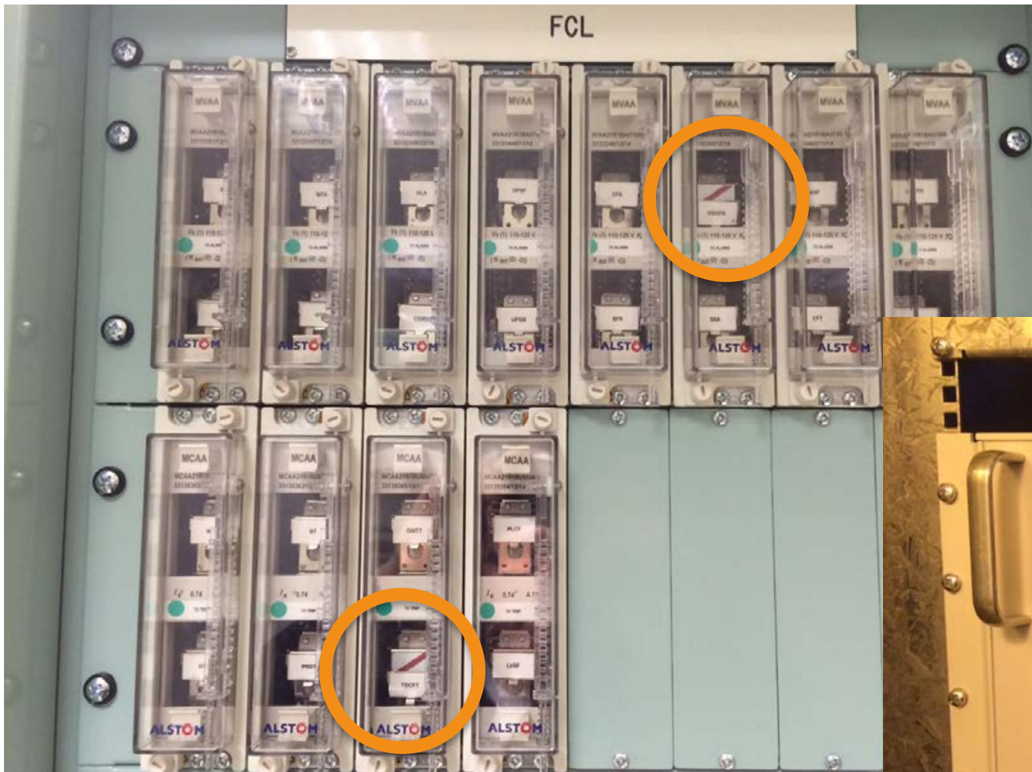
Energisation (28 Aug) after investigation and subsequent trip (14 Sept)

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

<u>Changes in Design</u>

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

<u>An extra 20% allowance had been made during WPD design</u>

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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

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Learning – GridON FCL

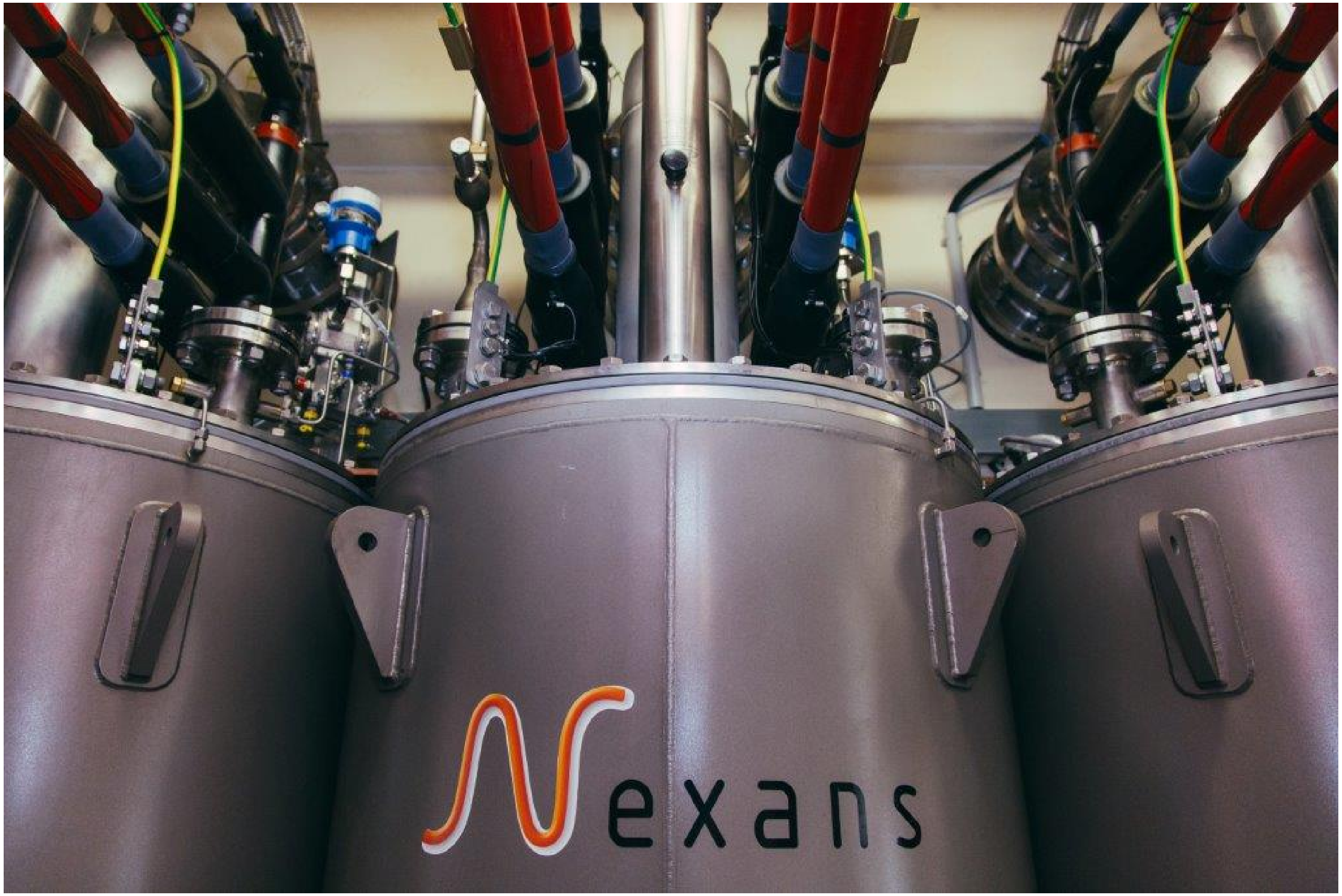
Short circuit testing

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

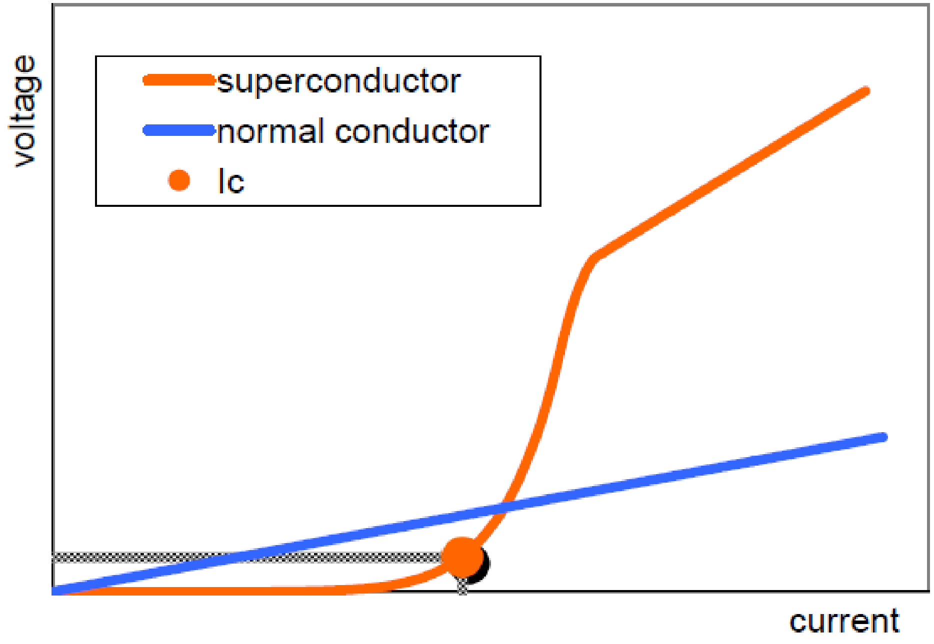
These issues were rectified before final testing so that the performance onsite was not affected

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)



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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:

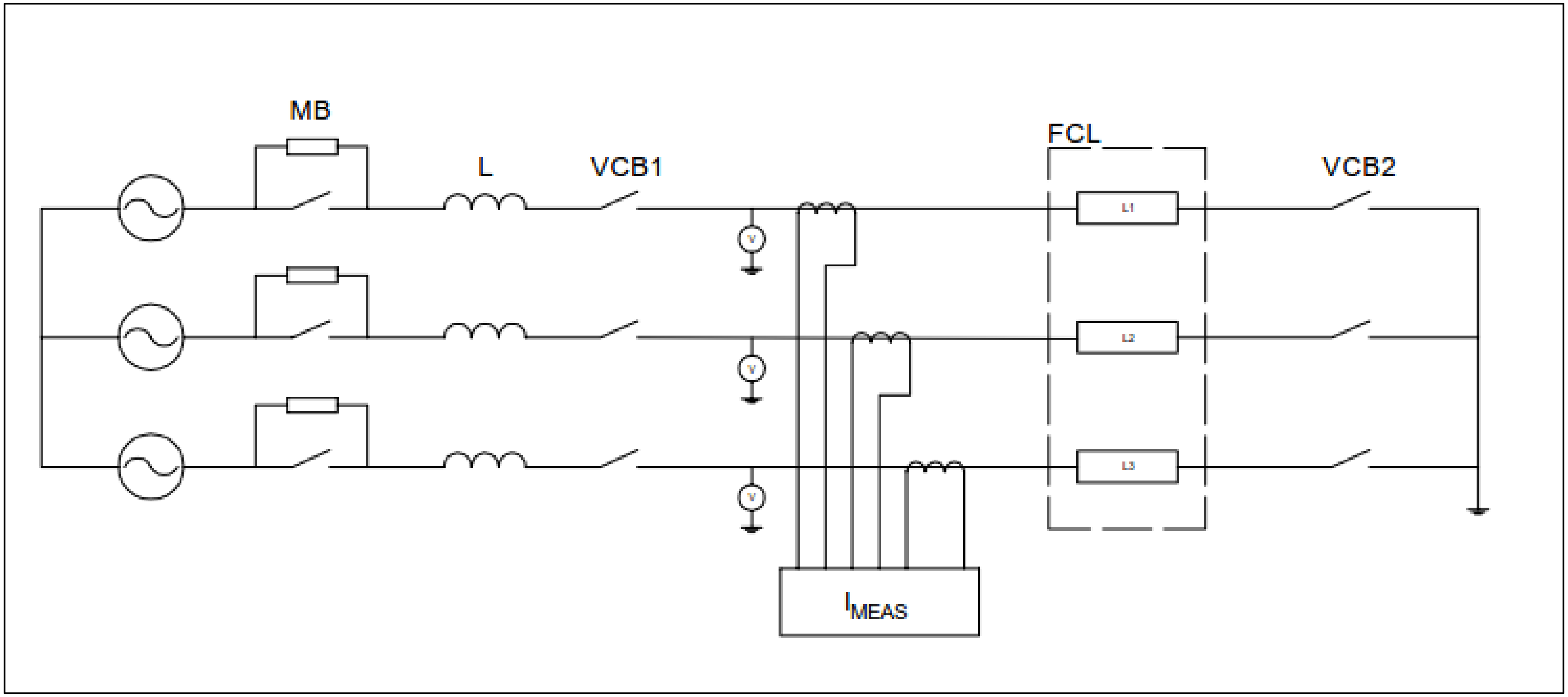
- 1050A rated
- Peak fault reduction (@10ms) 21.97kA to 7.70kA or below
- Peak fault reduction (@90ms) 7.66kA to 3.05kA or below
- 33.4kA short circuit current withstand capability

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

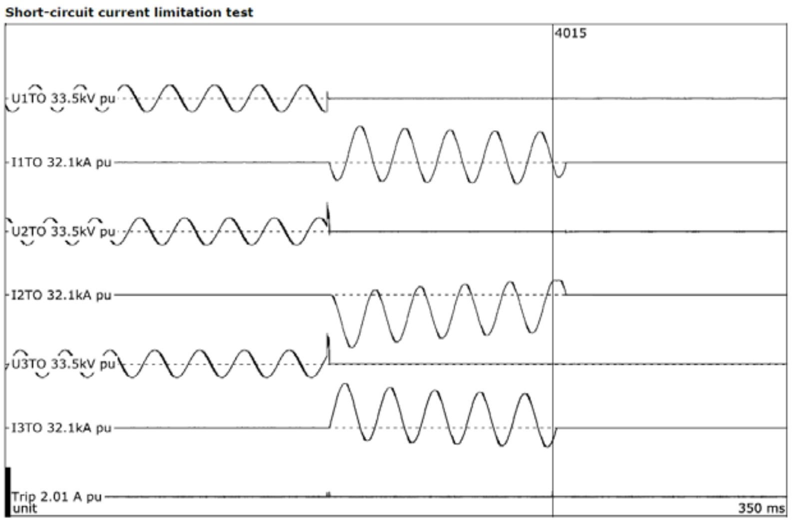
Testing – Nexans RSFCL

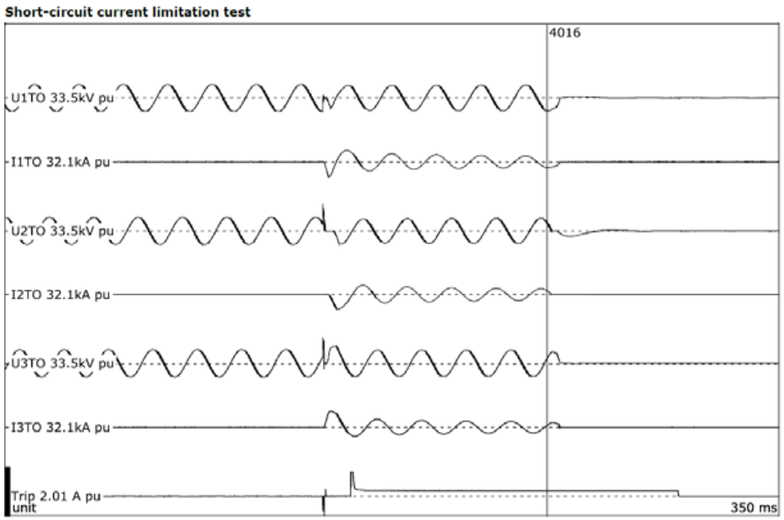
- Tested at KEMA's Testing Lab in Arnhem, Netherlands
- FCL underwent several short circuit tests to determine the performance
- Testing was successful with the FCL meeting the requirements of the contract

Testing – Nexans RSFCL



Testing – Nexans RSFCL





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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

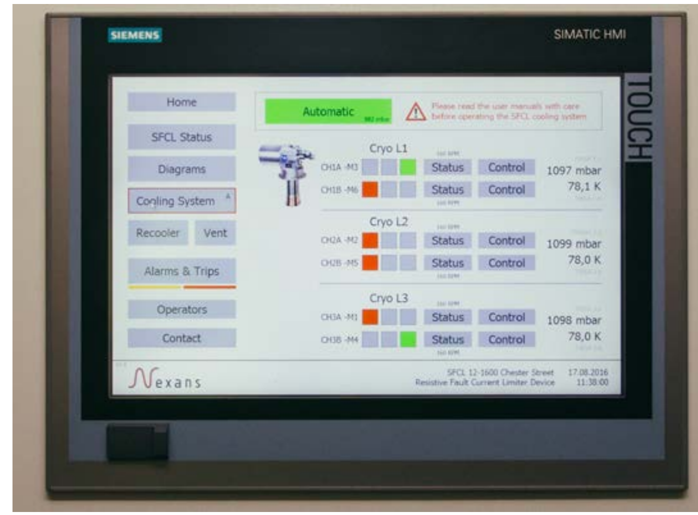
Learning – Issues with Cooling System

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

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

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

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



Learning – Enclosure

Advantages:

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

Disadvantages:

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

Conclusion:

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

THANKS FOR LISTENING

WESTERN POWER DISTRIBUTION

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