WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Closedown Dissemination Event
12th July 2017

Welcome and Introduction

Roger Hey

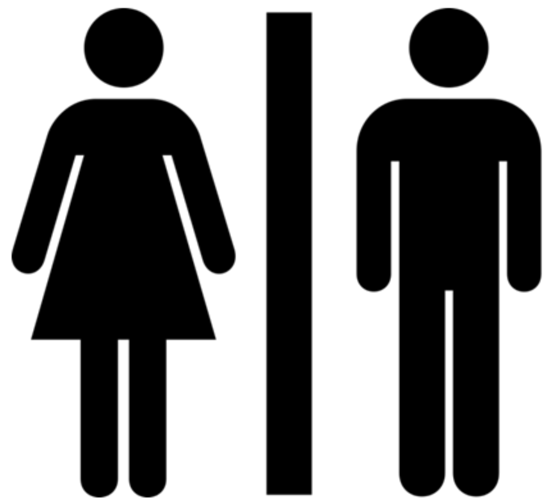
Future Networks Manager

LCN Fund Low Carbon Networks

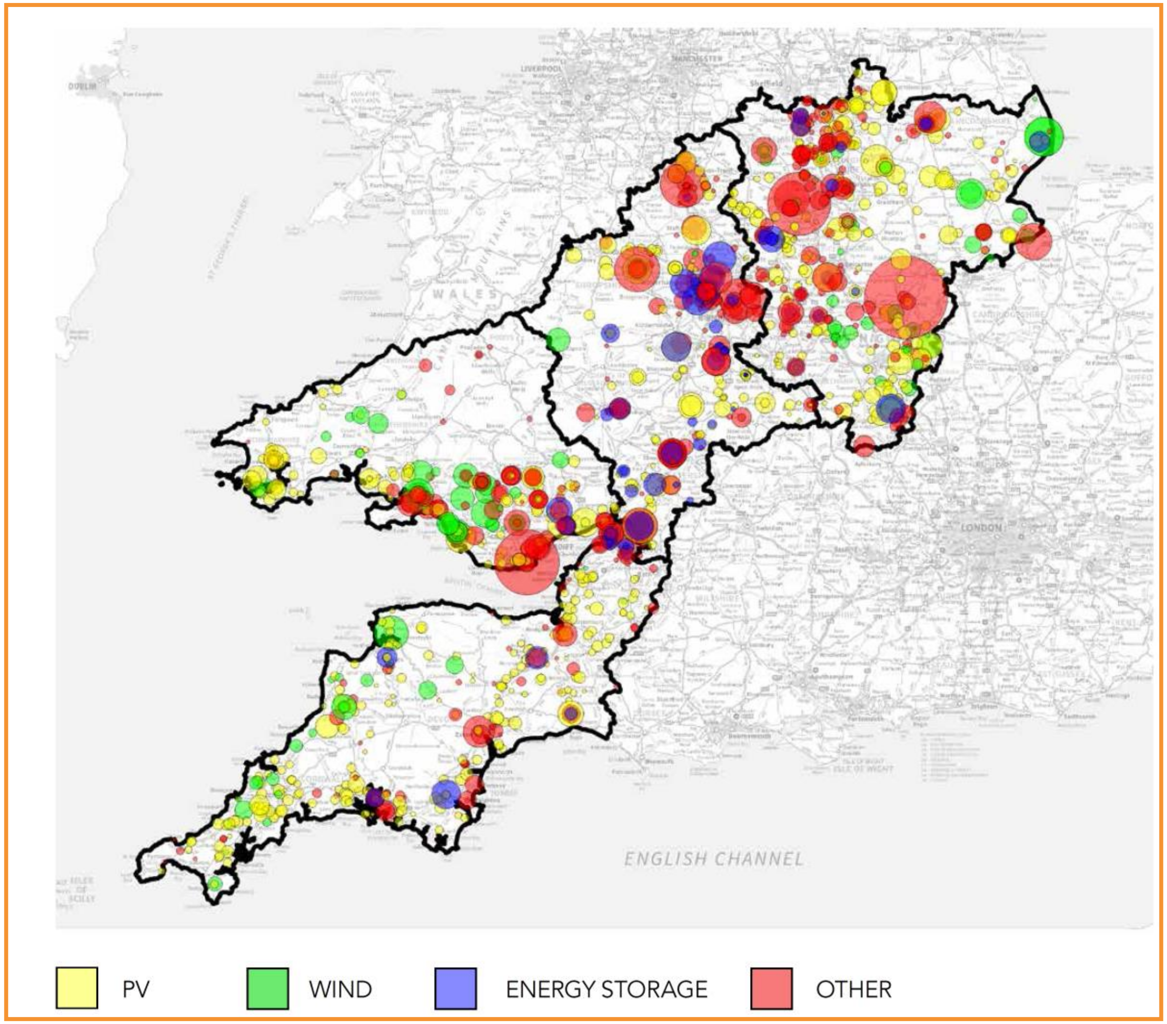
THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Housekeeping



Generation Across WPD's Network



Future Networks Programme

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

Innovation Programme

DSO Transition Programme

Innovation - Objectives

The objectives of WPD's innovation programme are to:

- Develop new *smart* techniques that will accommodate increased load, storage and generation (Distributed Energy Resources – DER) at lower costs than conventional reinforcement;
- Facilitate energy and capacity markets; including local flexibility services
- Improve performance against one or more of our core goals of safety, customer service, reliability, the environment or cost effectiveness;
- Ensure solutions are compatible with the existing network;
- Deliver solutions so that they become business as usual; and
- Provide long term, whole system outcomes and value for money for consumers.

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Future Networks Programme - July 2017

NEW

- WESTERN POWER DISTRIBUTION HARP
- WESTERN POWER DISTRIBUTION FLEXDGRID
- WESTERN POWER DISTRIBUTION PLUGS AND SOCKETS
- WESTERN POWER DISTRIBUTION SOLA BRISTOL
- WESTERN POWER DISTRIBUTION LOW CARBON HUB
- WESTERN POWER DISTRIBUTION OPEN LV
- WESTERN POWER DISTRIBUTION EFFS
- WESTERN POWER DISTRIBUTION NETWORK EQUILIBRIUM
- WESTERN POWER DISTRIBUTION SMART ENERGY ISLES
- WESTERN POWER DISTRIBUTION NETWORK TEMPLATES
- WESTERN POWER DISTRIBUTION FALCON

Future Networks Programme

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Network and Customer Data

- Airborne Inspections
- AIRSTART1
- 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 Heat2

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

DSO Transition Programme

Assets

Investment in technology to ensure networks operate at high performance levels

Roll out of Active Network Management across entire network by 2021, with expanded connections options available for customers allowing them to get quicker and cheaper access to the network.

Telecommunications readiness and strategic investment in fibre networks will deliver more visibility and controllability

Customers

Propositions for DSR services will be developed for specific customer group, prioritised in regions and customer segments as the need arises

Creation of a localised visibility platform that will demonstrate where there is congestion or capacity on the network, informing localised tariffs and supporting the development of a Local Energy Market

Alternative connection products will be extended to all WPD areas and extended to include demand and storage connections

Network operations

Invest in technology to give us unprecedented visibility and monitoring of the network
Use complex data analytic tools to forecast requirements and ensure the network is proactively managed

Upgrade business areas to facilitate flexibility services such as demand side response

Continue work to develop and update regional energy scenarios that will establish future network needs and inform strategic investment in the network

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Agenda	
09.30 – 10.00	Arrival and Refreshments
10.00 – 10.15	Welcome and Introduction
10.15 – 10.45	Project Overview and Original Aims
10.45 – 11.15	Enhanced Fault Level Assessment
11.15 – 11.30	*Refreshments*
11.30 – 12.15	Fault Level Monitors – Design and Implementation
12.15 – 13.15	*Lunch*
13.15 – 14.00	Fault Current Limiters – Design and Implementation
14.00 – 14.30	Customer Benefits – Connections and Security
14.30 – 14.45	*Refreshments*
14.45 – 15.15	Alternative Connections
15.15 – 15.30	Next Steps and Close

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Project Introduction, Aims and Objectives

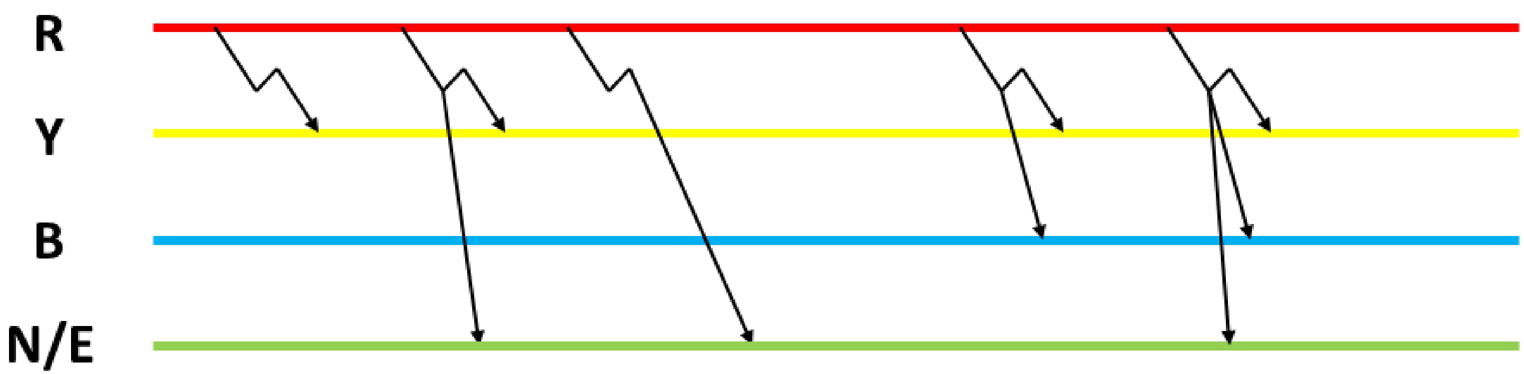
Jonathan Berry

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

What is Fault Level?

Technical Definition

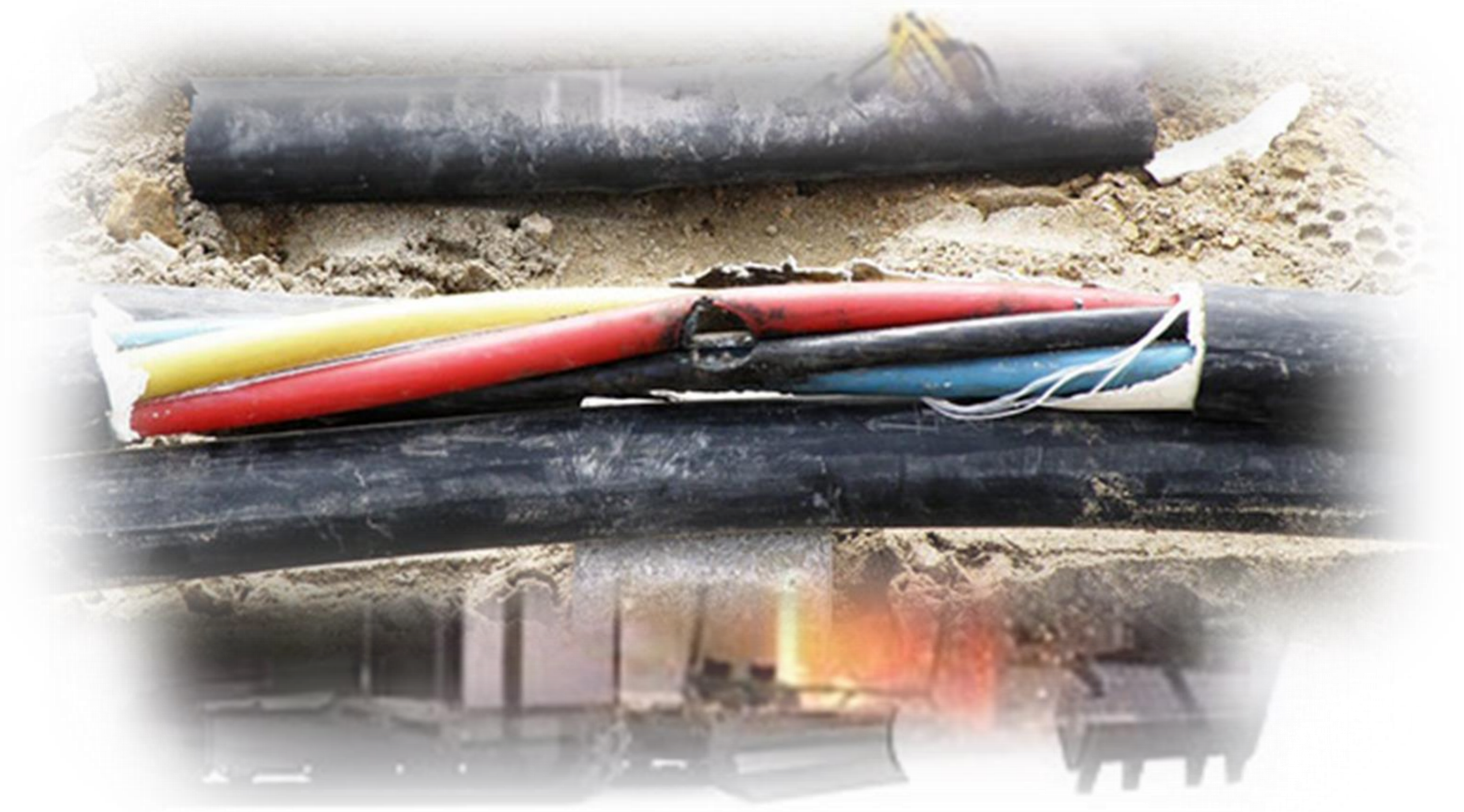
A short circuit (fault level) is an electrical circuit that allows a current to travel along an unintended path with no or very low electrical impedance.



Examples of unintentional conducting paths in a 3-phase system (faults)

What is Fault Level?

What actually causes faults on the system?



What is Fault Level?

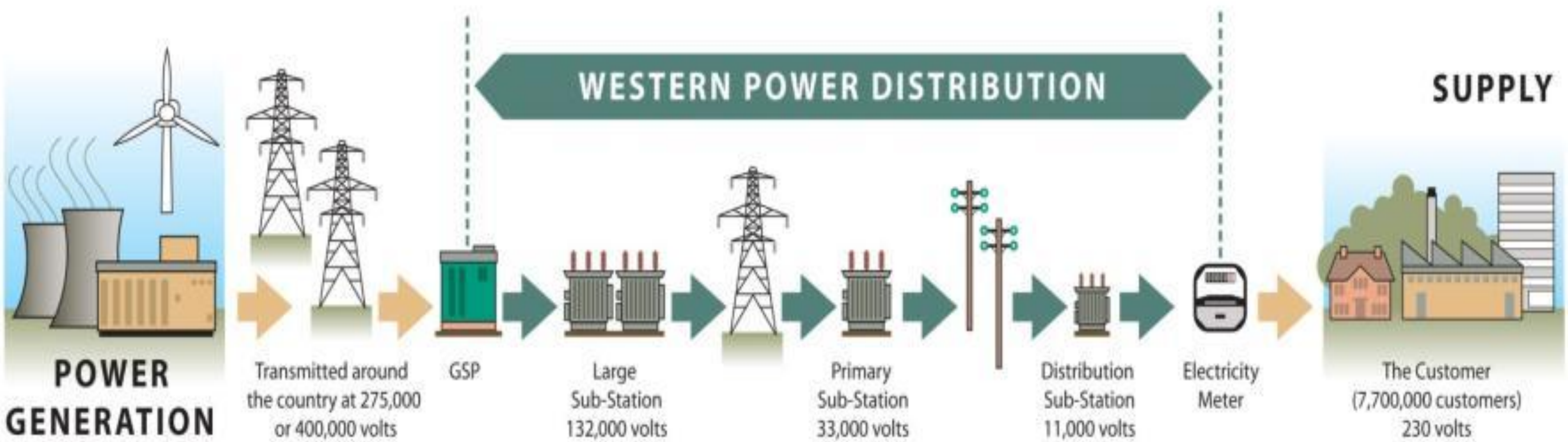
What actually causes faults on the system?

What is Fault Level?

What actually causes faults on the system?

What is Fault Level?

What effects it and how does it change?



What is Fault Level?

What dominates the distribution fault level?

What is Fault Level?

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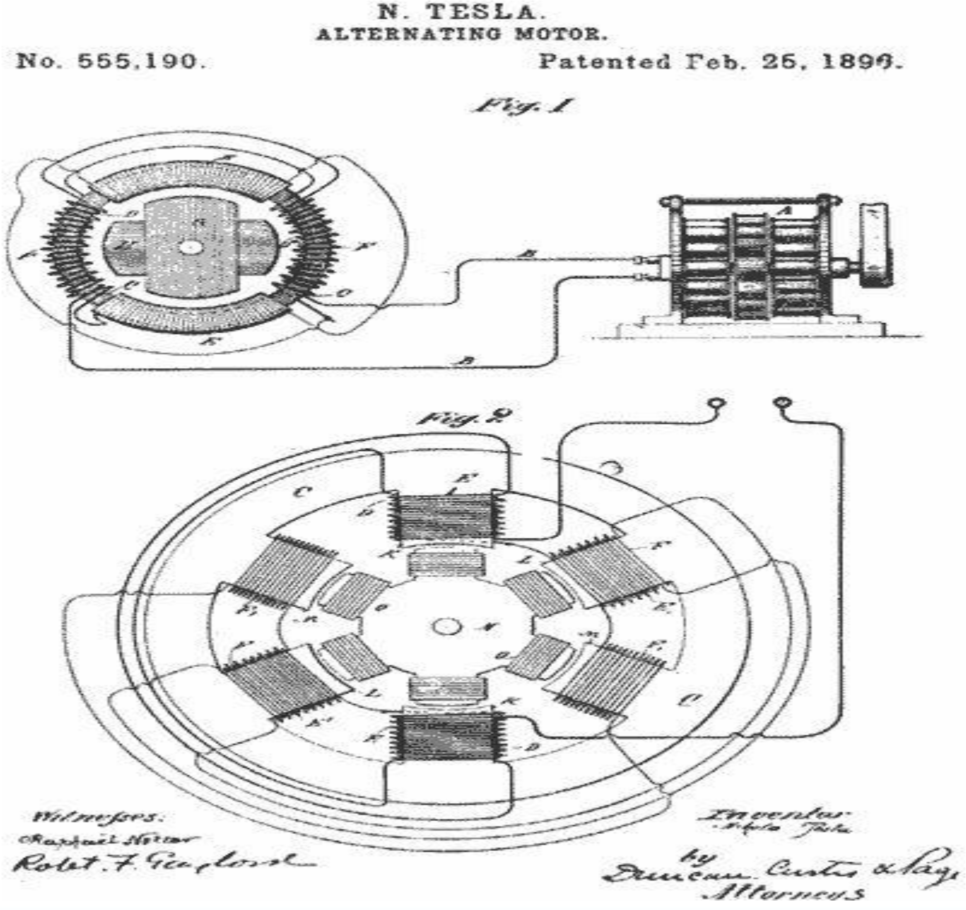
What dominates the distribution fault level?



What is Fault Level?

How is it generated and changed?

$$V = IR$$

What is Fault Level?

How is it generated and changed?

$$V = IZ$$

$$Z = R + X$$

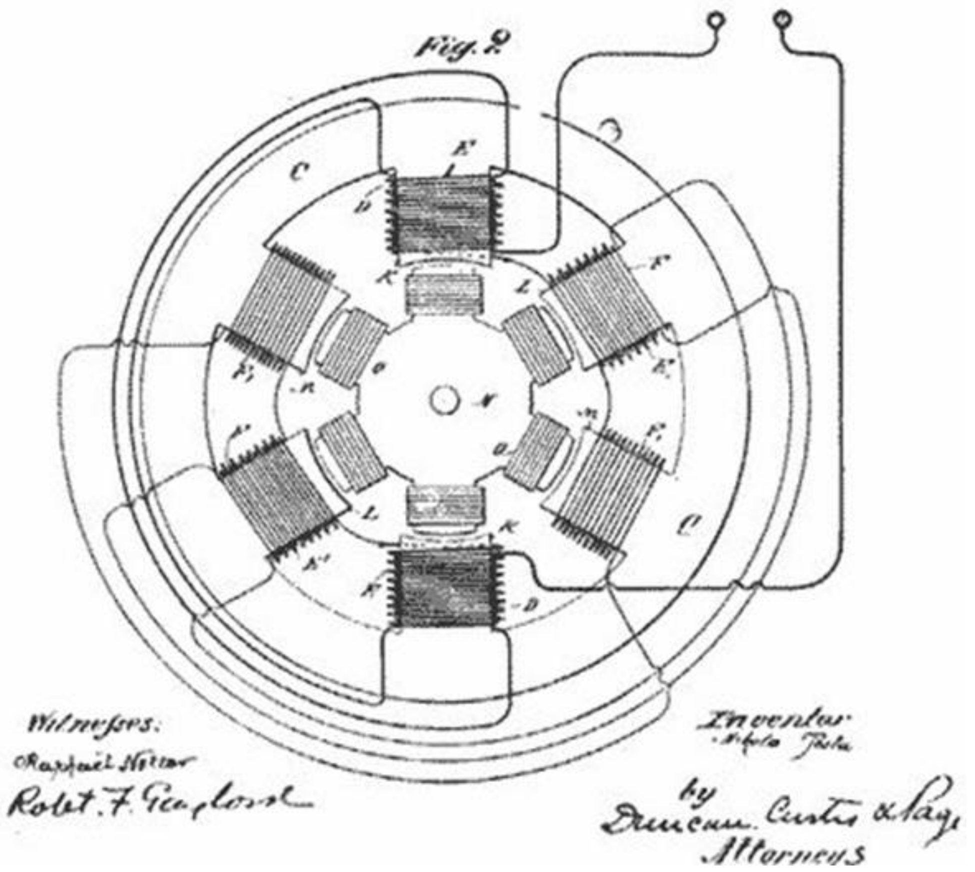
What is Fault Level?

How is it generated and changed?

$$I = \frac{V}{Z}$$

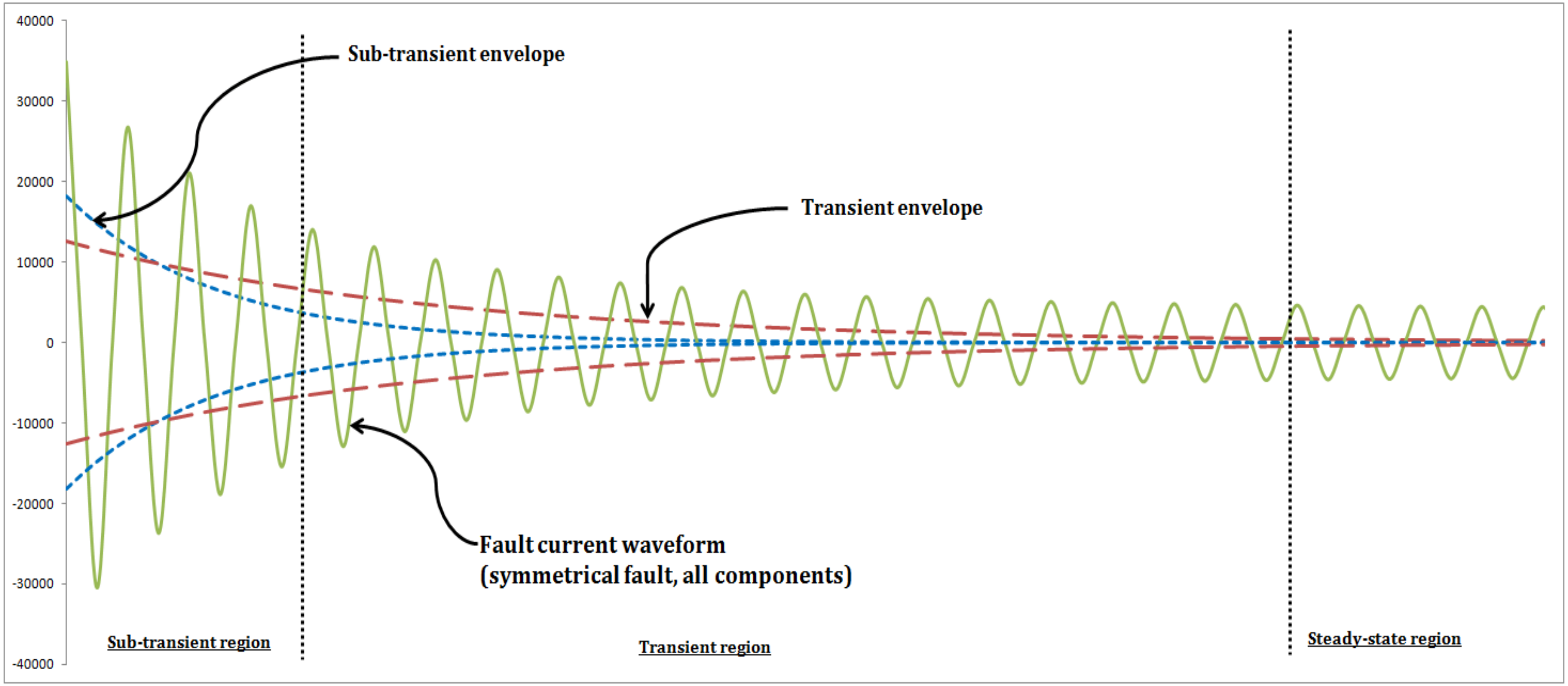
What is Fault Level?

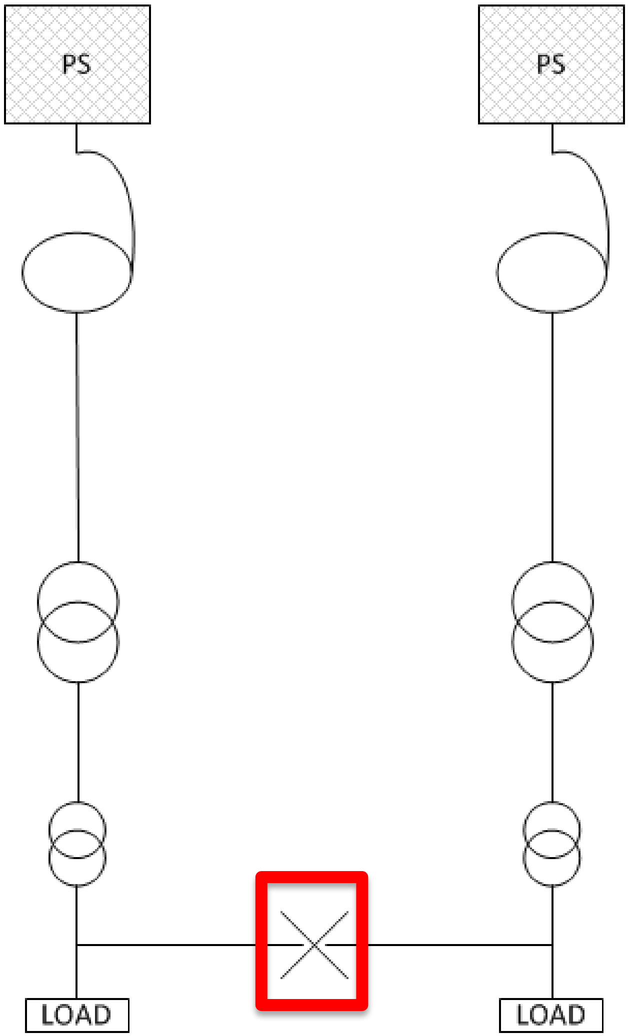
<u>How is it generated and changed?</u>



What is Fault Level?

How is it generated and changed?




PS
PS
LOAD
LOAD


Z
Z
LOAD
LOAD


Z
Z
LOAD
LOAD

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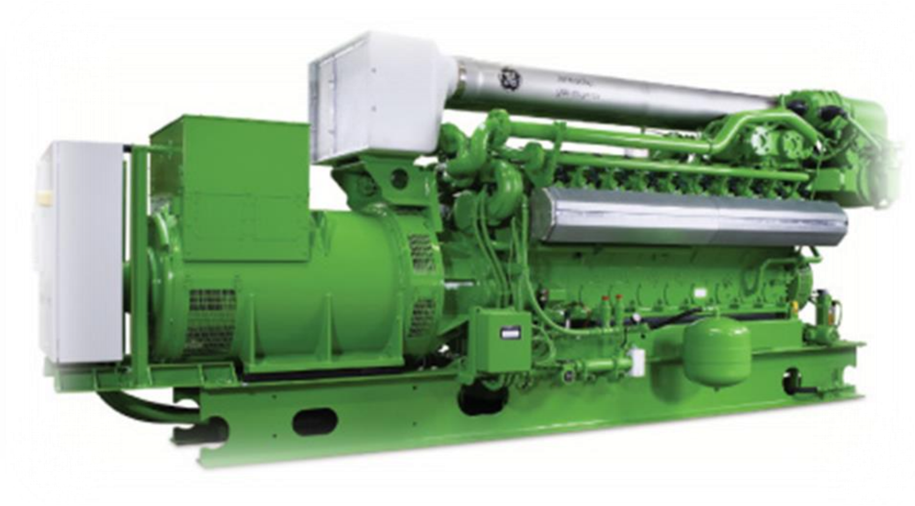
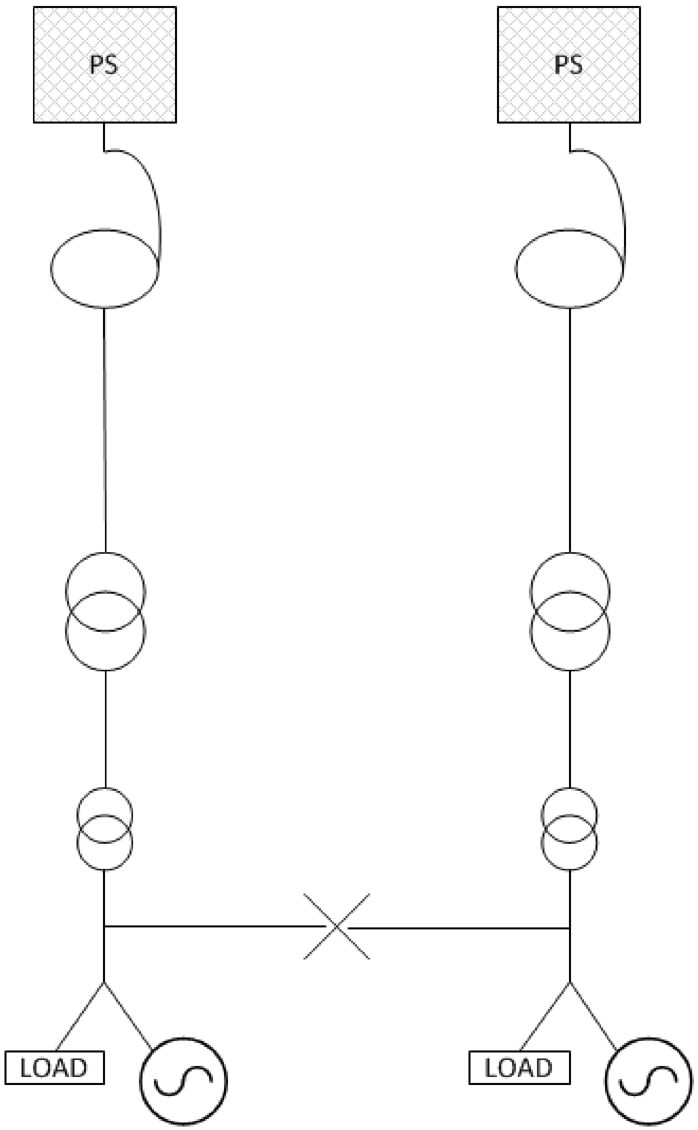
$$2I = \frac{V}{Z}$$

What is Fault Level?

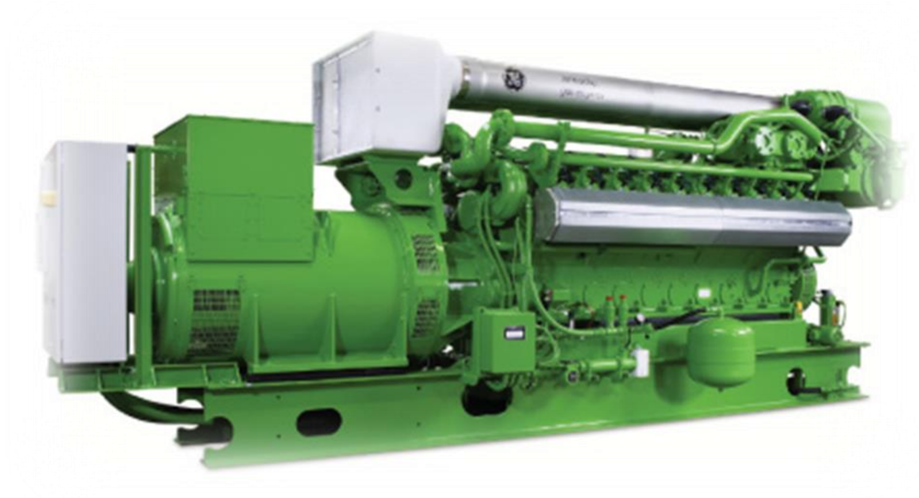
Other changes to Fault Level

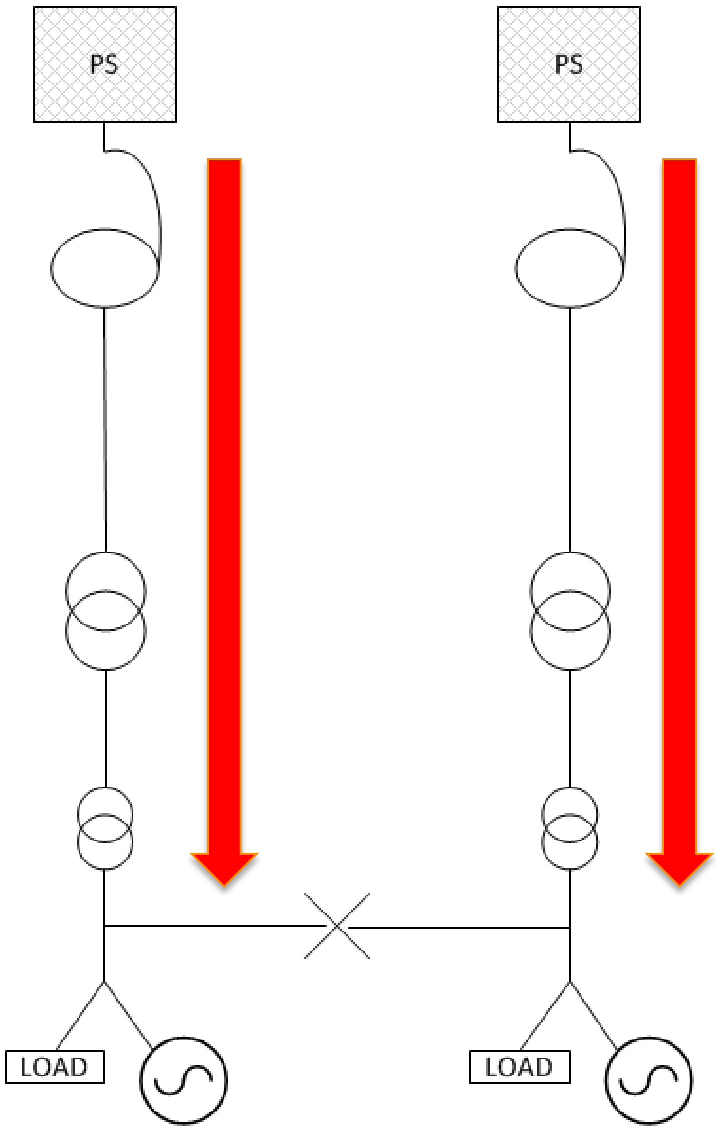




What is Fault Level?

Other changes to Fault Level





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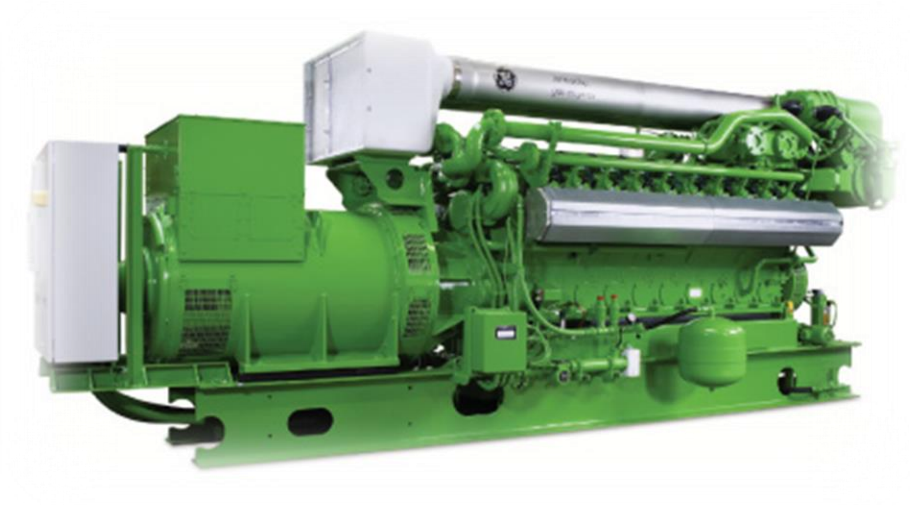
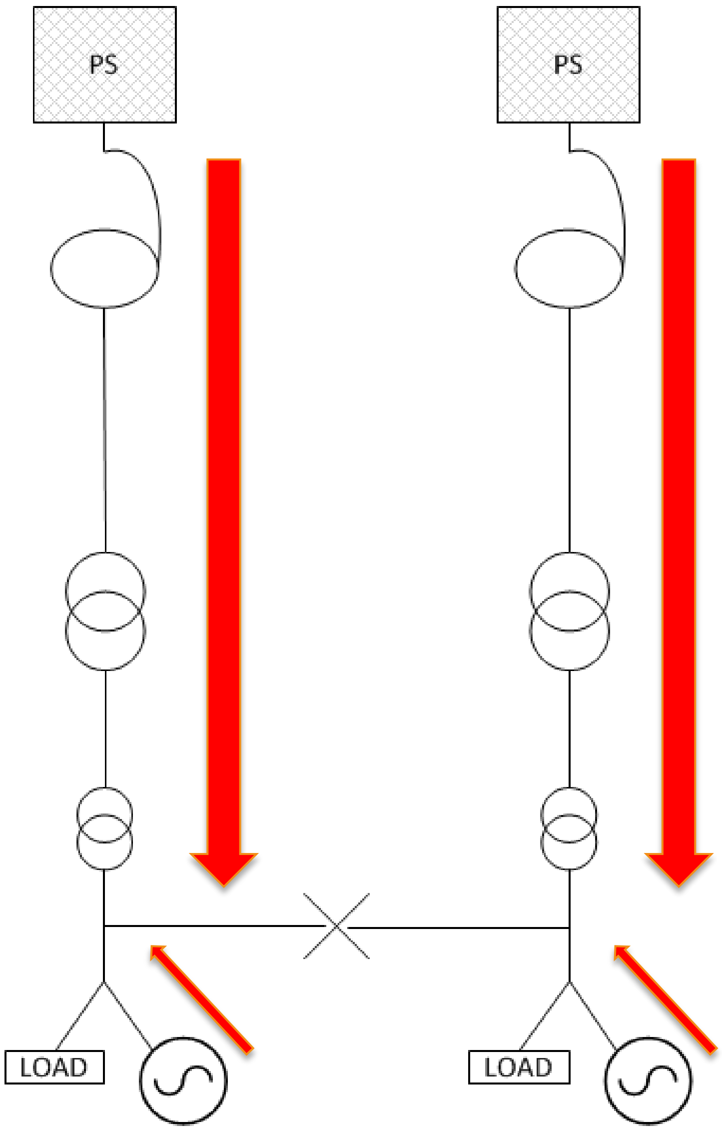
What is Fault Level?

Other changes to Fault Level





How is it going to (likely to) change?

How is it going to (likely to) change?

Average Combined Heat and Power Fault Level Infeed – **4.5MVA/MVA**

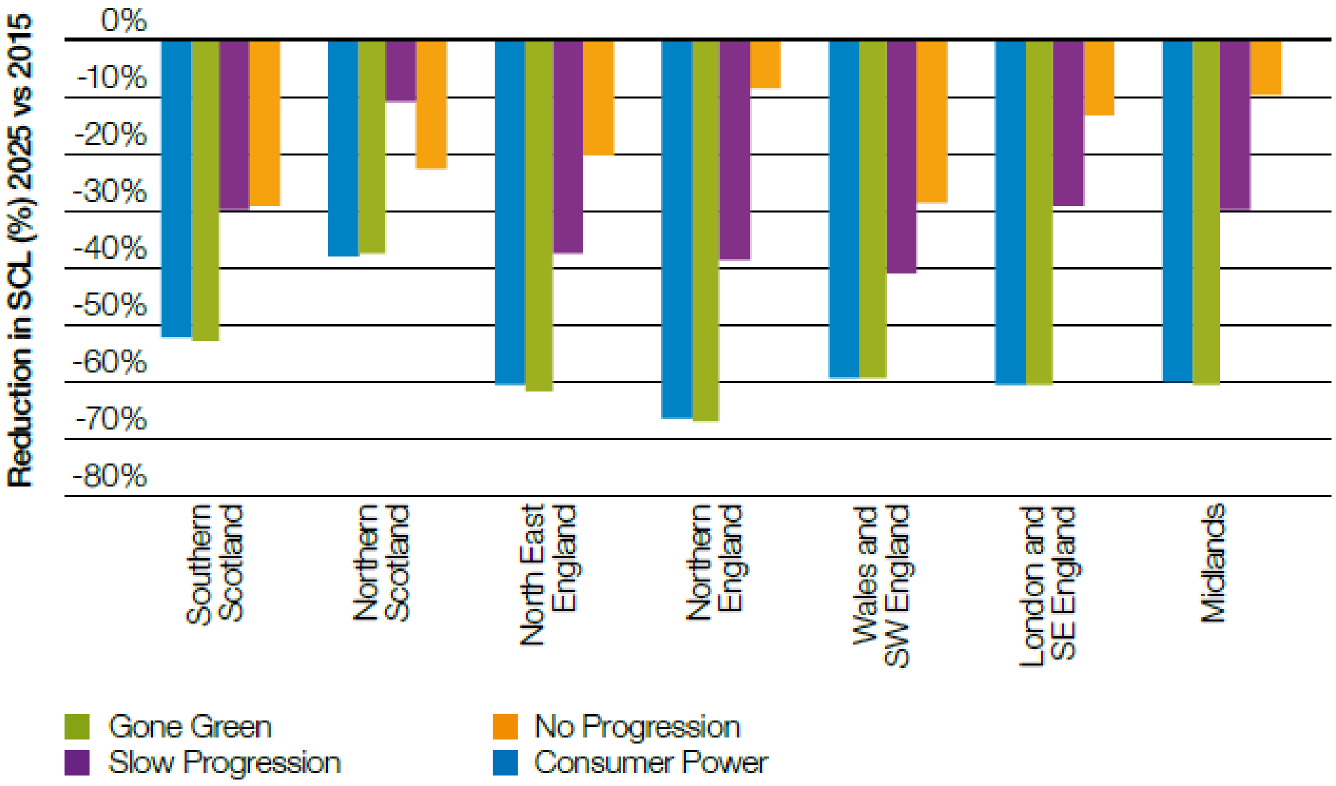
Average Inverter Fed Generator Infeed – **1.2MVA**

Even if the Power Station was equivalent to a CHP unit a 2000MW station would have an infeed value of **9000MVA**

If all that power was generated by inverter fed distributed generation the fault level infeed would be reduced by **6600MVA** to **2400MVA**

How is it going to (likely to) change?

National Grid's projection of fault level reduction from 2015 to 2025



What does this mean?

Short Term

Centralised Generation and Distributed Generation

What does this mean?

<u>Medium Term</u>

Reduced Centralised Generation and Increased Distributed Generation

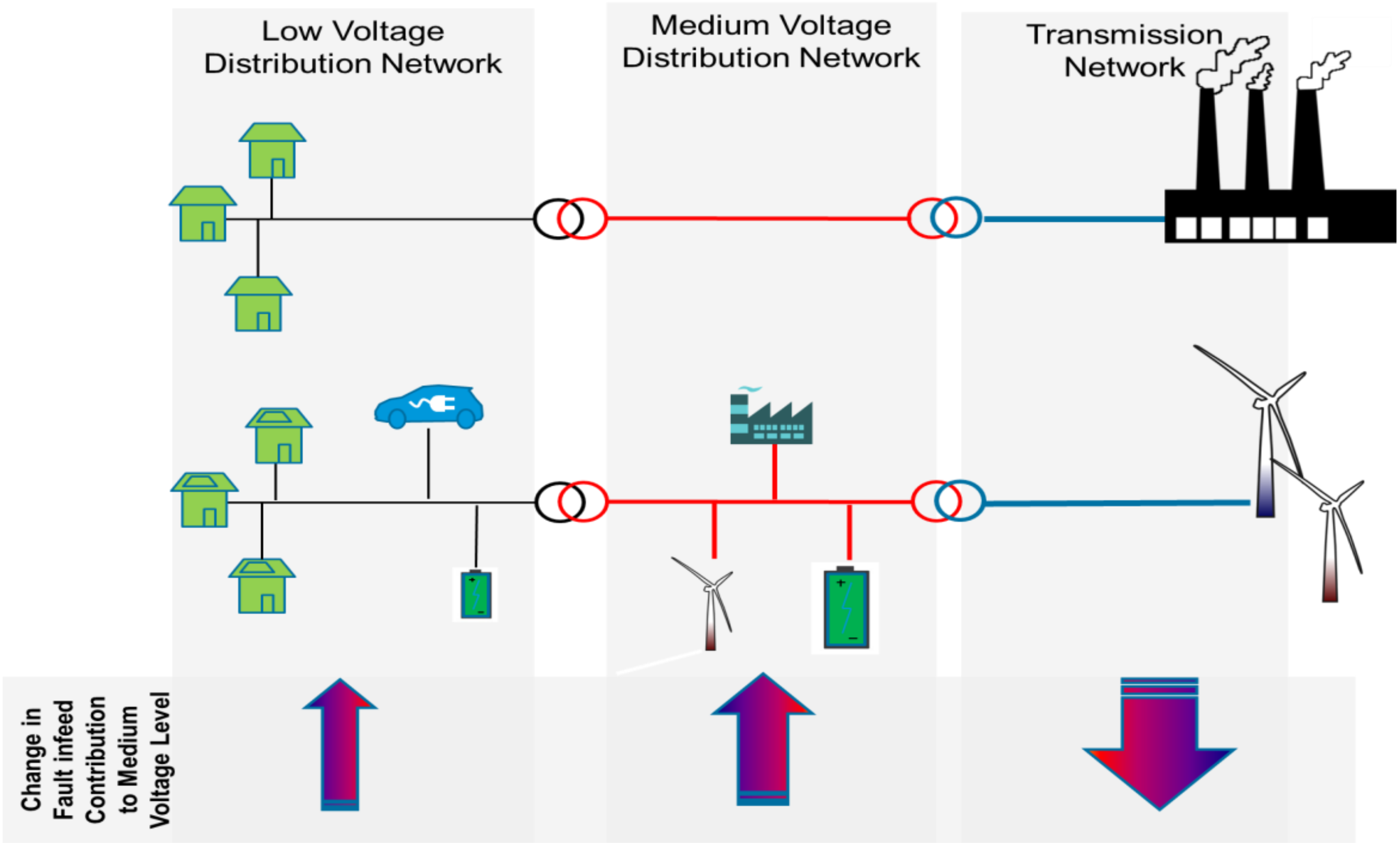
What does this mean?

Long Term

Minimal Centralised Generation and Dominated Distribution Generation

What does this ACTUALLY mean?

Distribution Networks of the Future



FlexDGrid Project?

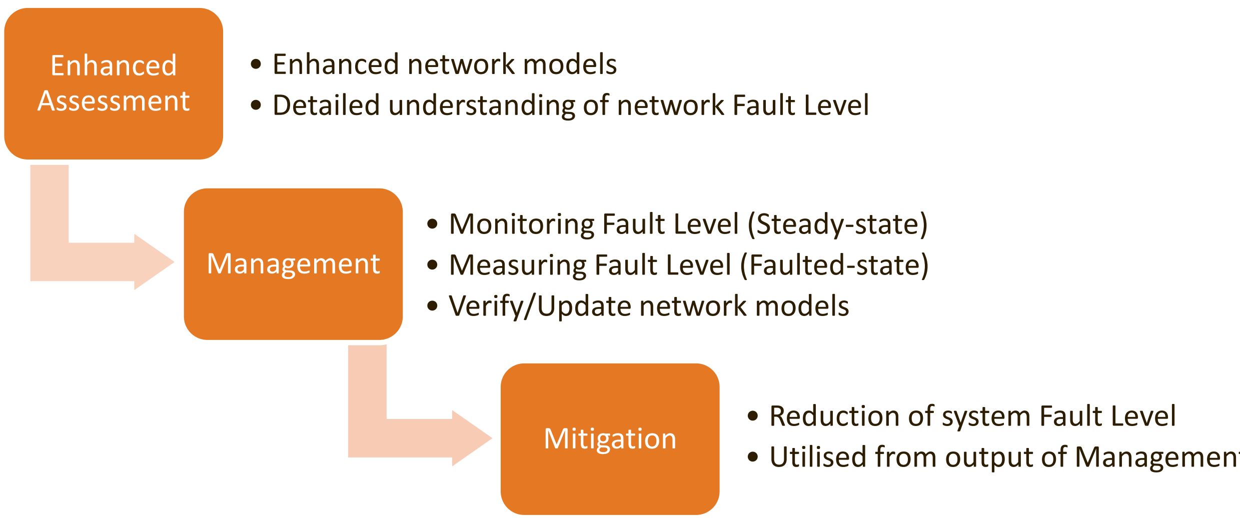
What are we doing?
Understanding, Managing and Reducing the Fault Level on an electricity network

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

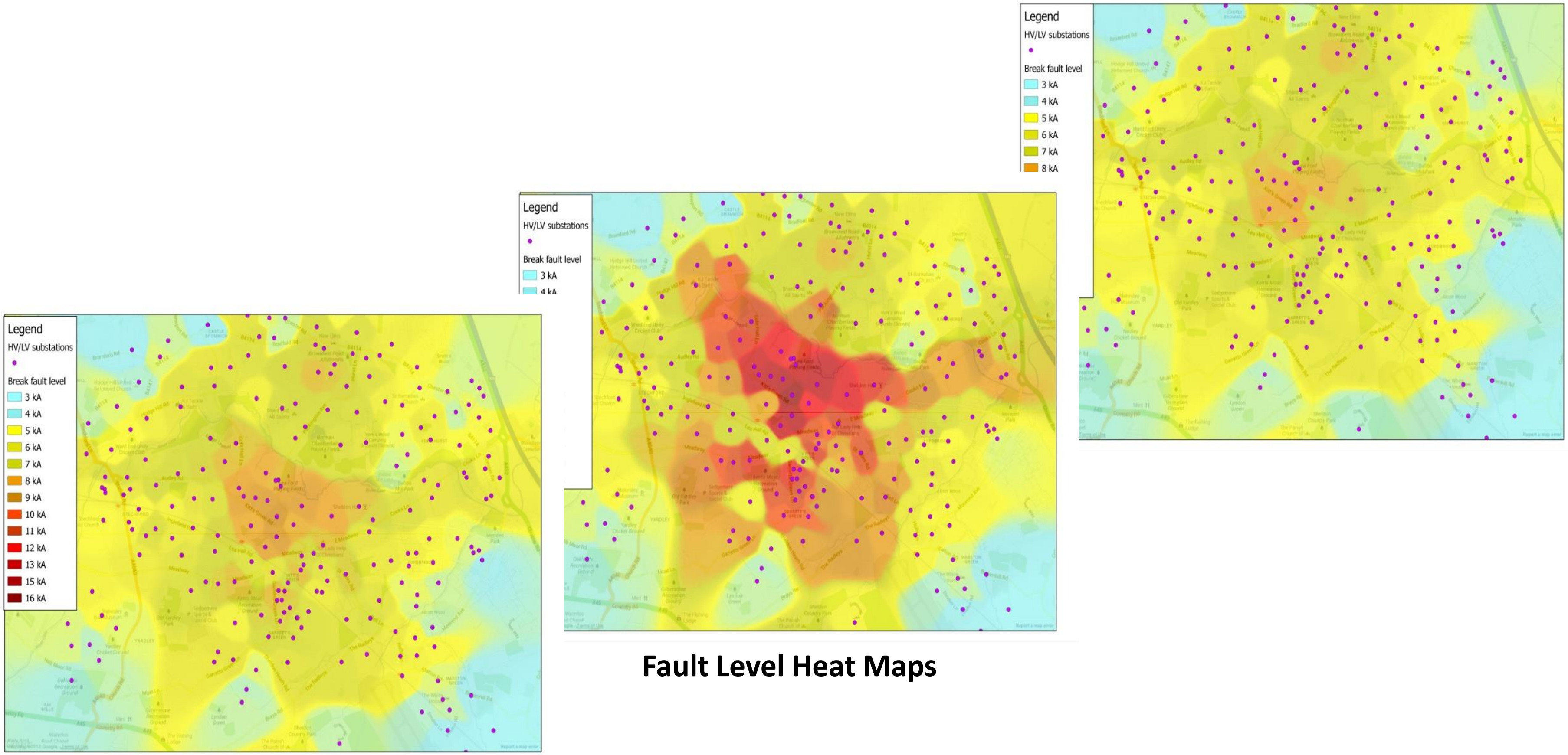
What is FlexDGrid?

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.

FlexDGrid Effect on Fault Level



Fault Level Heat Maps

Thank you for listening

Any questions?

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Enhanced Fault Level Assessment

Ali Kazerooni

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

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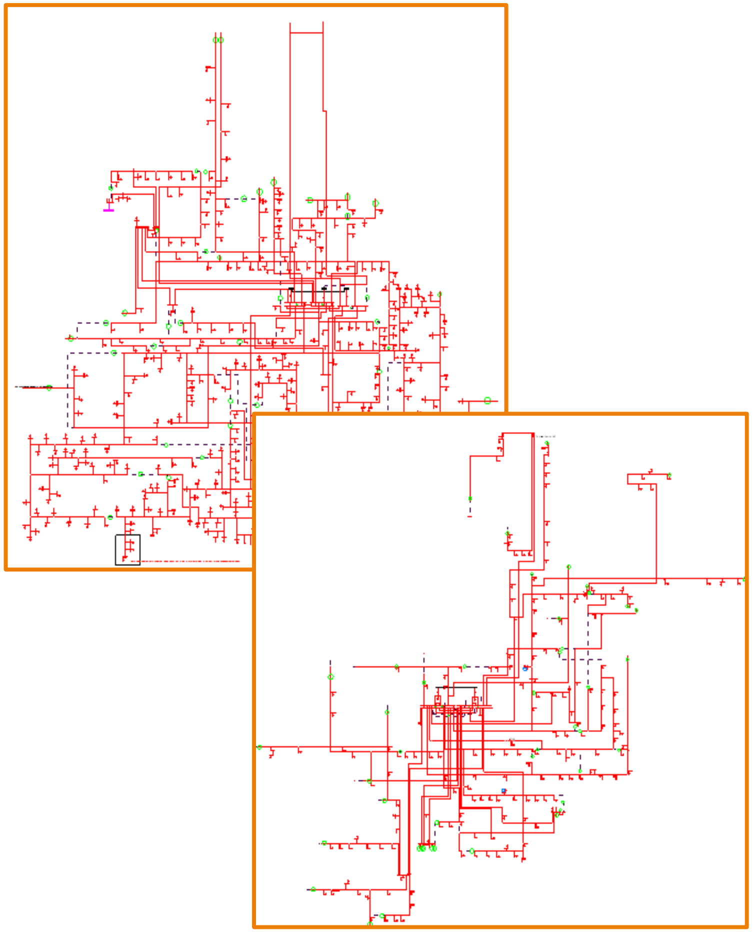
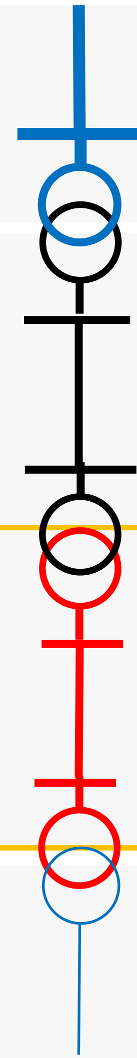
Introduction

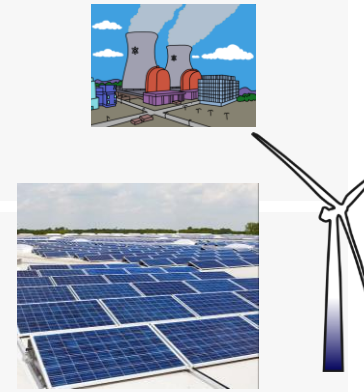
- Methodology to develop the computer model of 11kV networks
- Fault level assessment sensitivity analysis and review internal policy documents;
- Tools and methodologies for an enhanced fault level calculations
- Tools and computer models for assessing the impact of FCLs on network fault levels

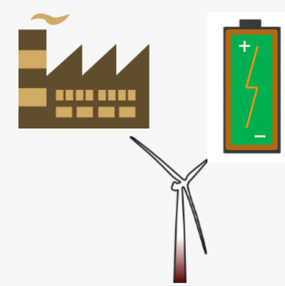


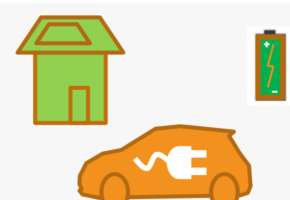
Computer models



	Computer model
Transmission networks 400, 275 kV	Available and updated regularly
Distribution networks (EHV) 132 kV, 66 kV	Available and updated regularly
Distribution networks (HV) 33 kV, **11kV** , 6.6 kV	Not always available or updated regularly
Distribution networks (LV) 0.4 kV	Almost not available







Developing computer models - Methodology

Select the power system analysis software

PSS®E 32

- EHV (132, 66kV) model was available
- ER G74 script was already developed

Identify appropriate/updated databases

- Network connectivity's
- Conductor types
- Demand
- Generation

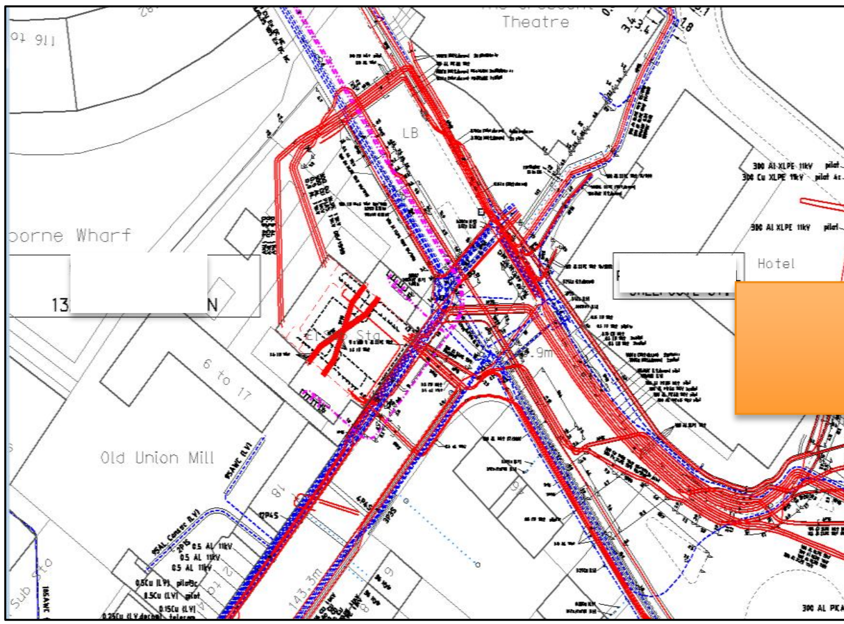
Develop conversation algorithm and tools

- A tool and methodology can be used for other parts of network
- Easy to use and accessible to everyone

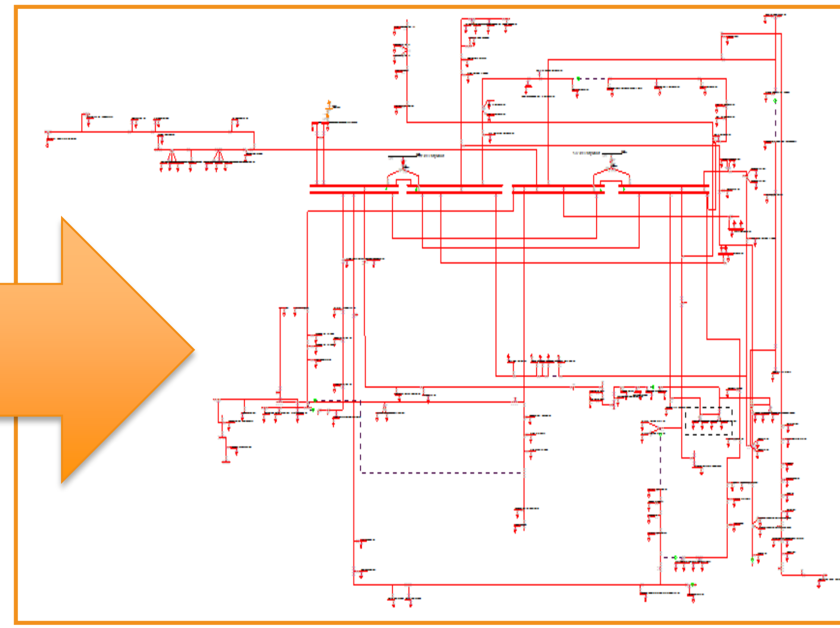
Integration into existing EHV model

- Integrated model from grid supplied points to secondary substations
- Interconnection between primary substations through 11 kV network

Developing Computer Models - Methodology

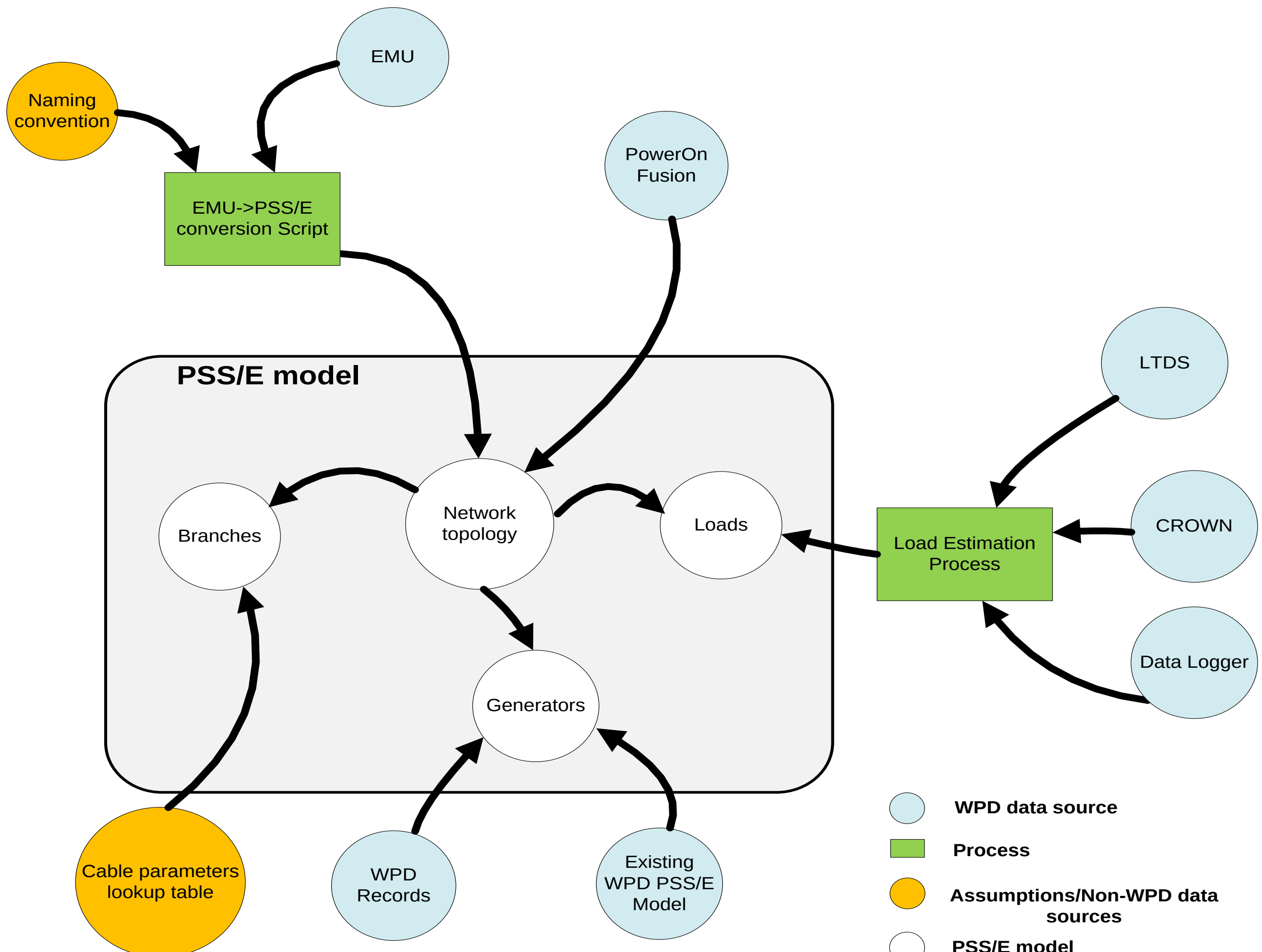


EMU

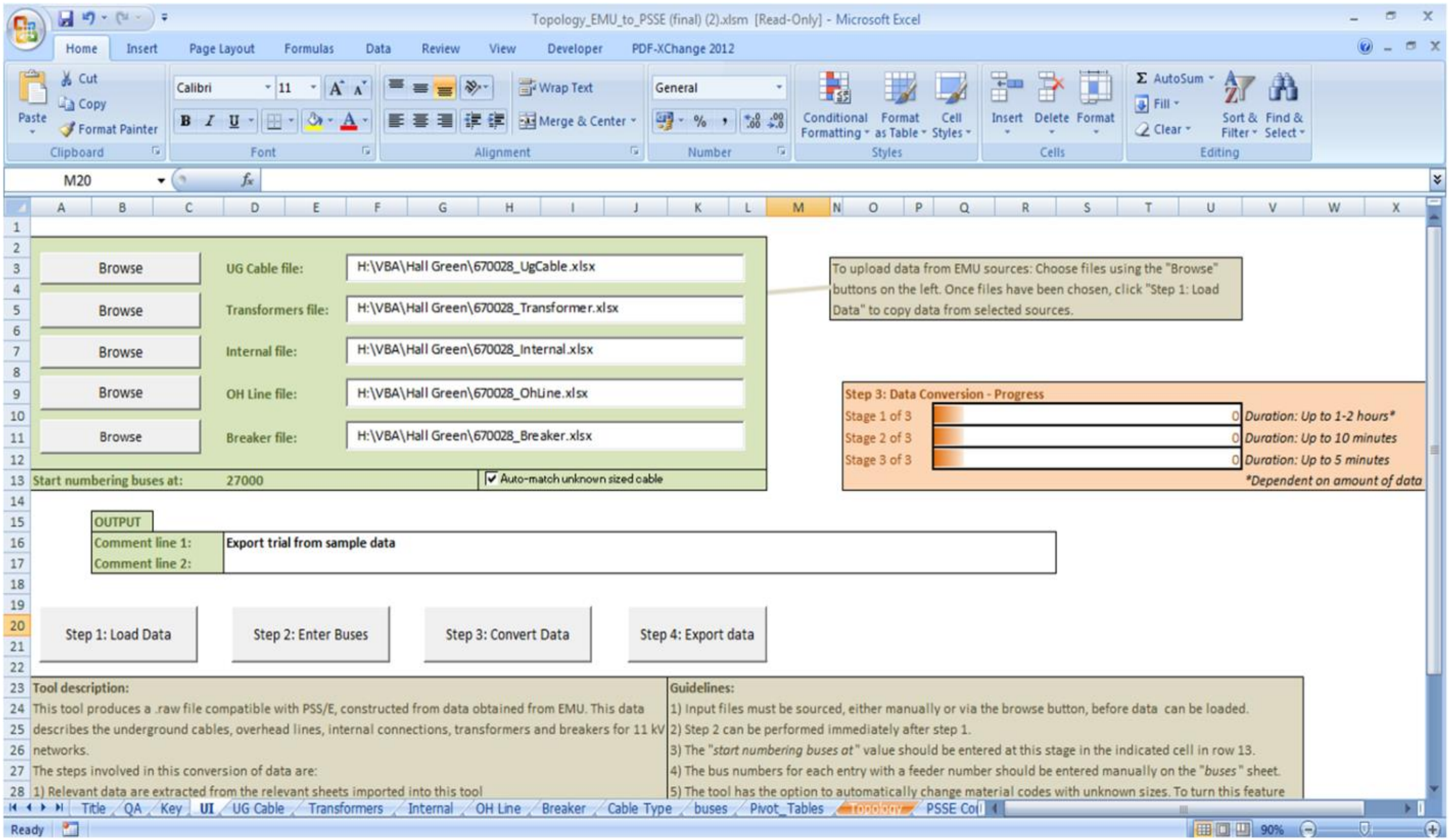


PSS/E

Developing Computer Models - Methodology



Developing Computer Models – Conversion Tool



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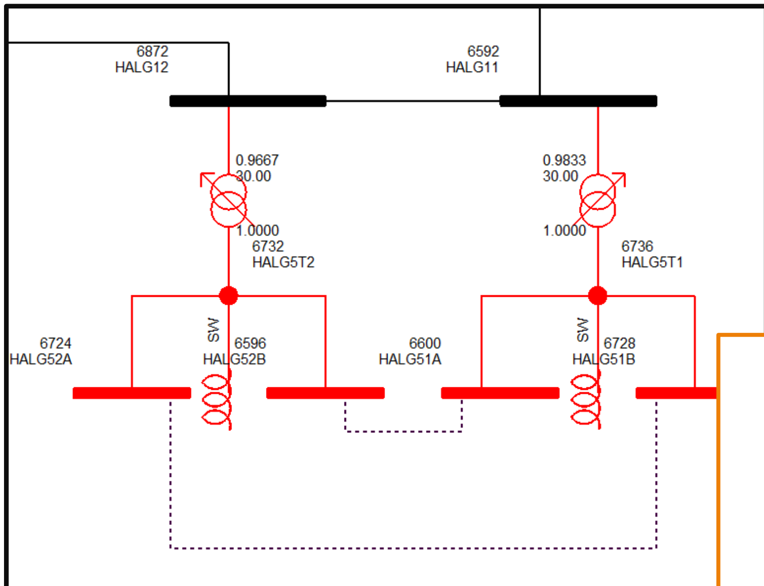
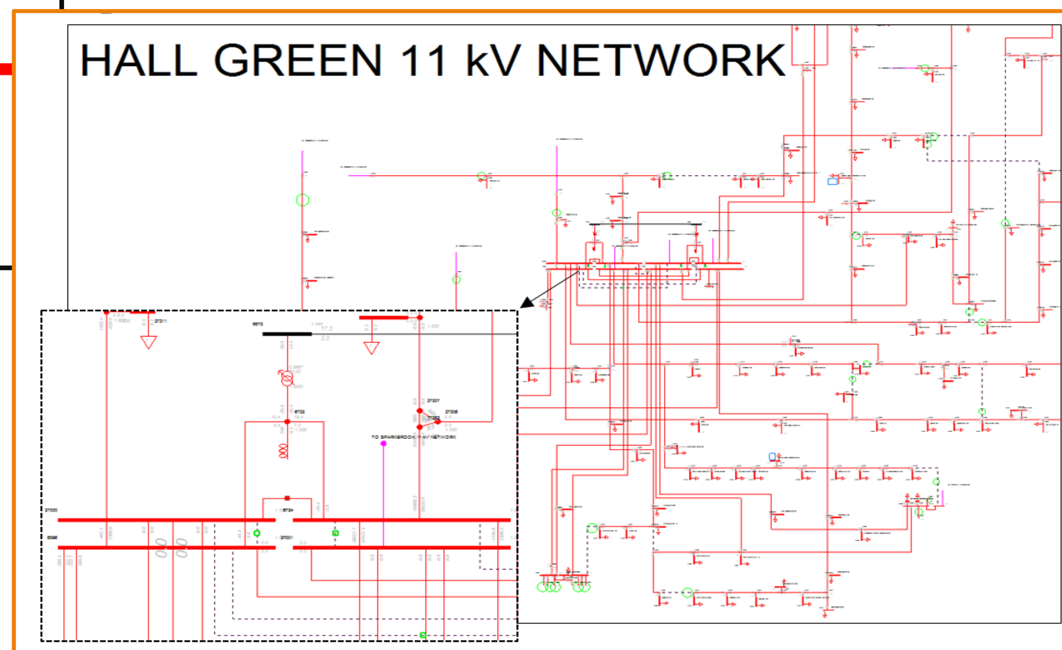
Developing Computer Models – Integration into EHV Model





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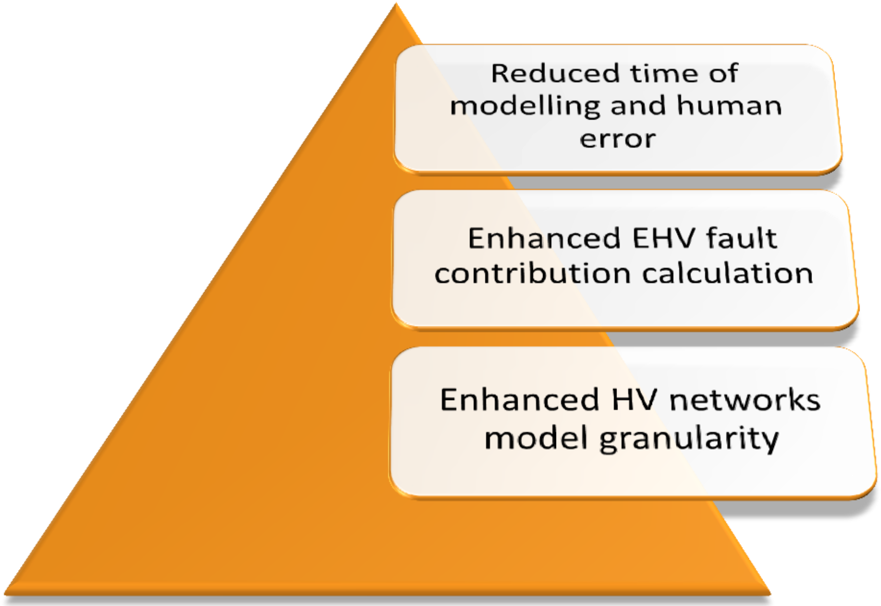
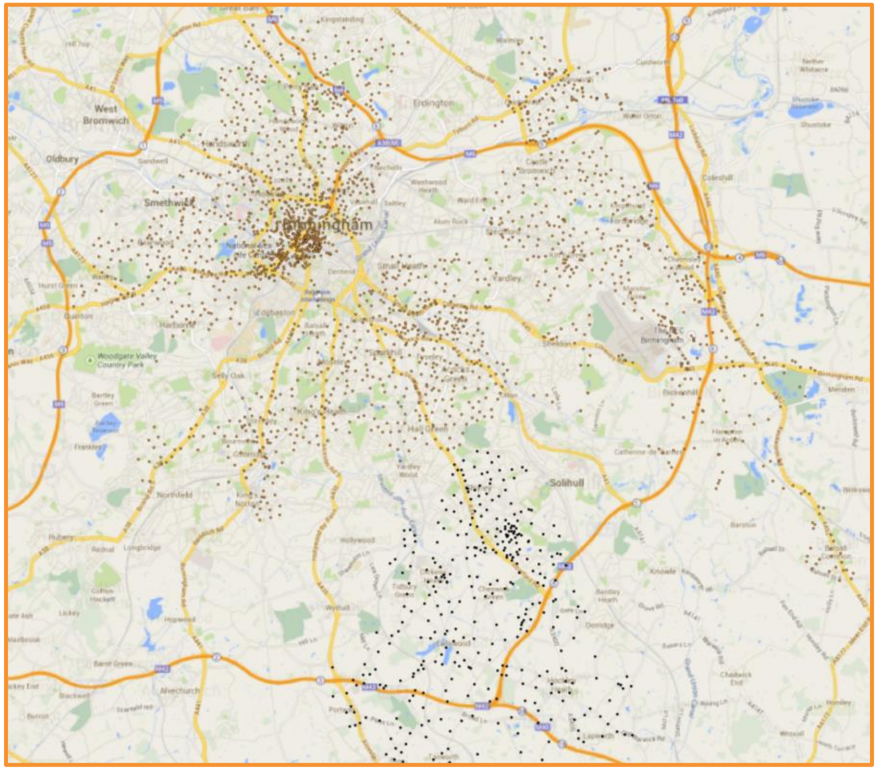
Developing Computer Models - Outcomes

- **15** primary substations
- **3,041** secondary substations
- and **1,878** km HV circuits





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Fault Level Analysis Tools

- Power systems analysis software are not available to everyone
- Access to network data may not be consistent
- Time and effort required to gather data can cause delay in connection offer

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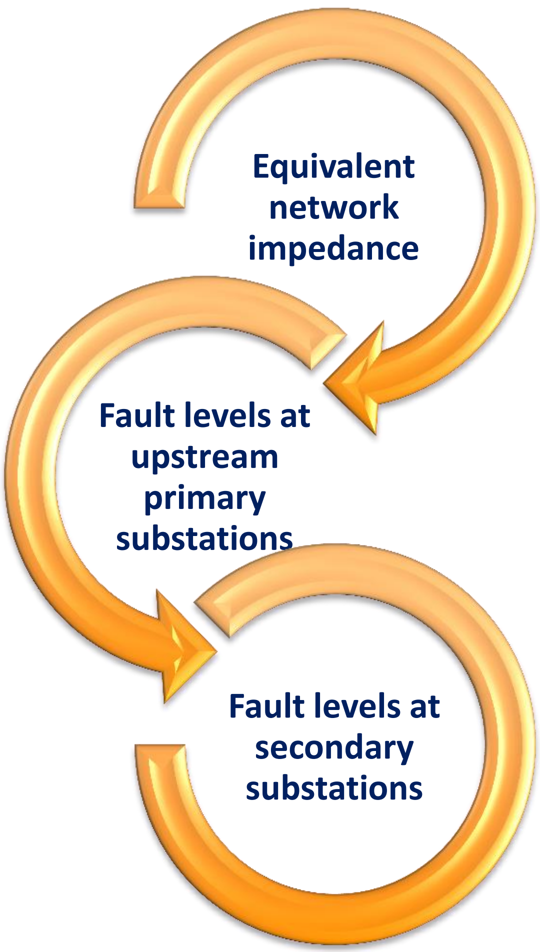
Fault Level Guidance Tools

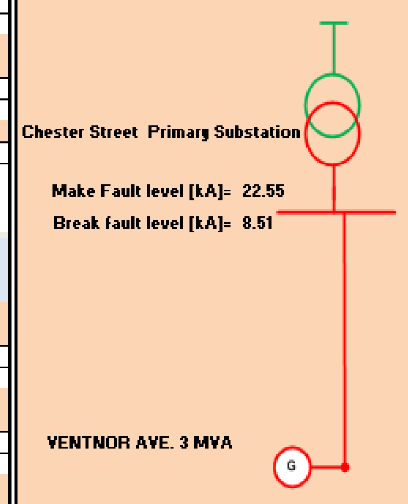


Fault level estimation - Generation Connection

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

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

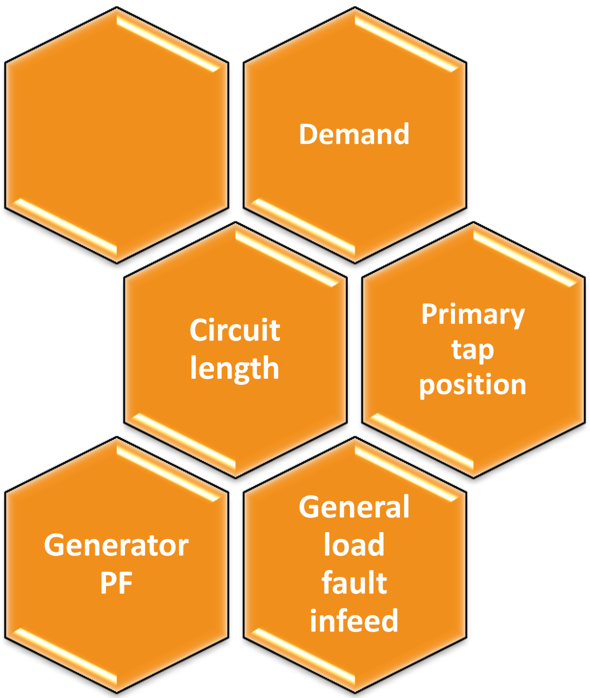
Generation connection @ VENTNOR AVE.

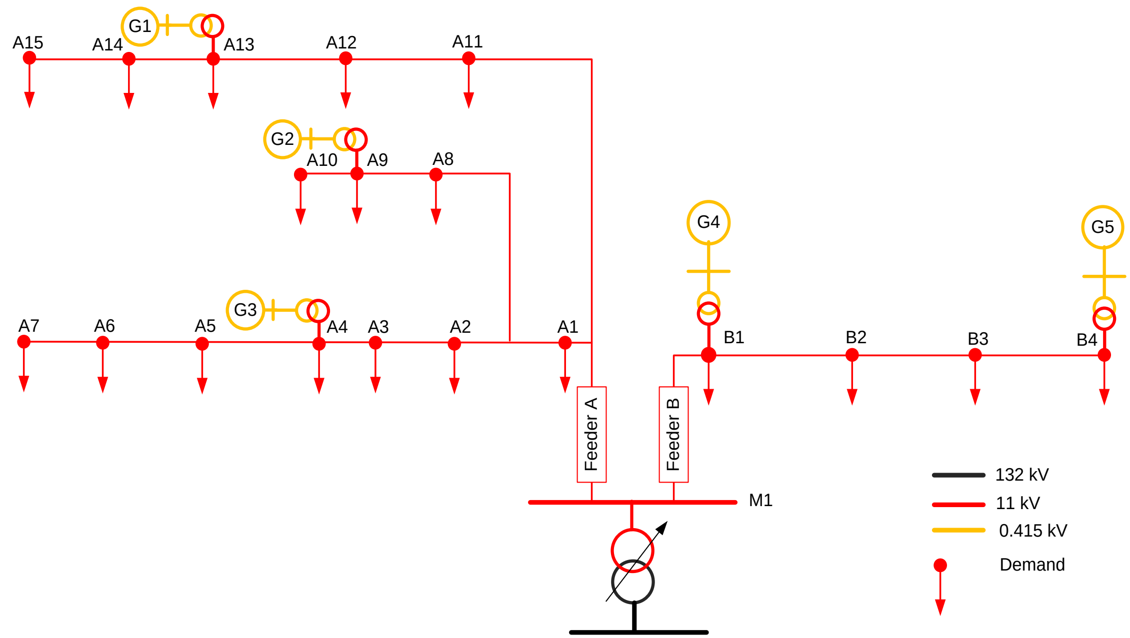


Issued by	Name
Date	02 March 2014

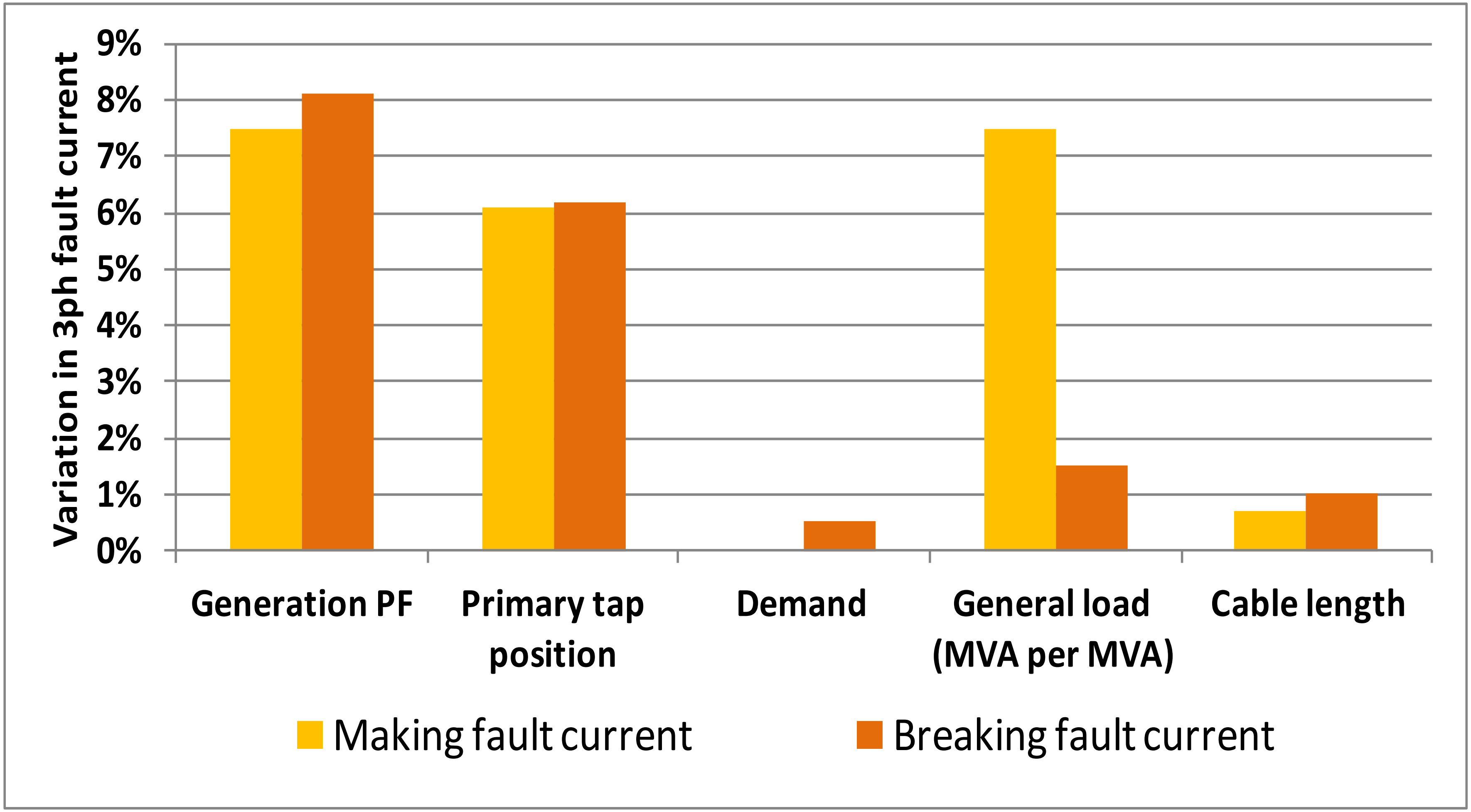
Email the results (*.pdf)

Fault Level Calculation Sensitivity Analysis

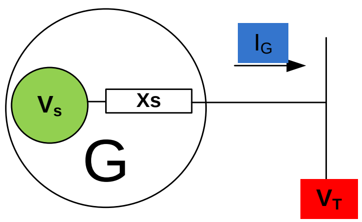


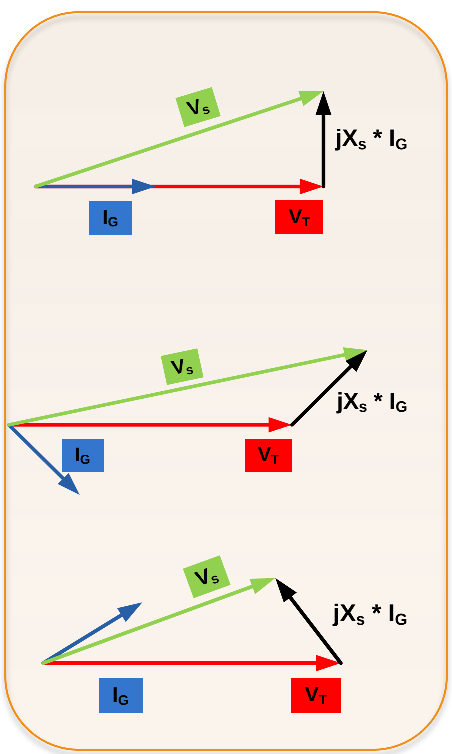


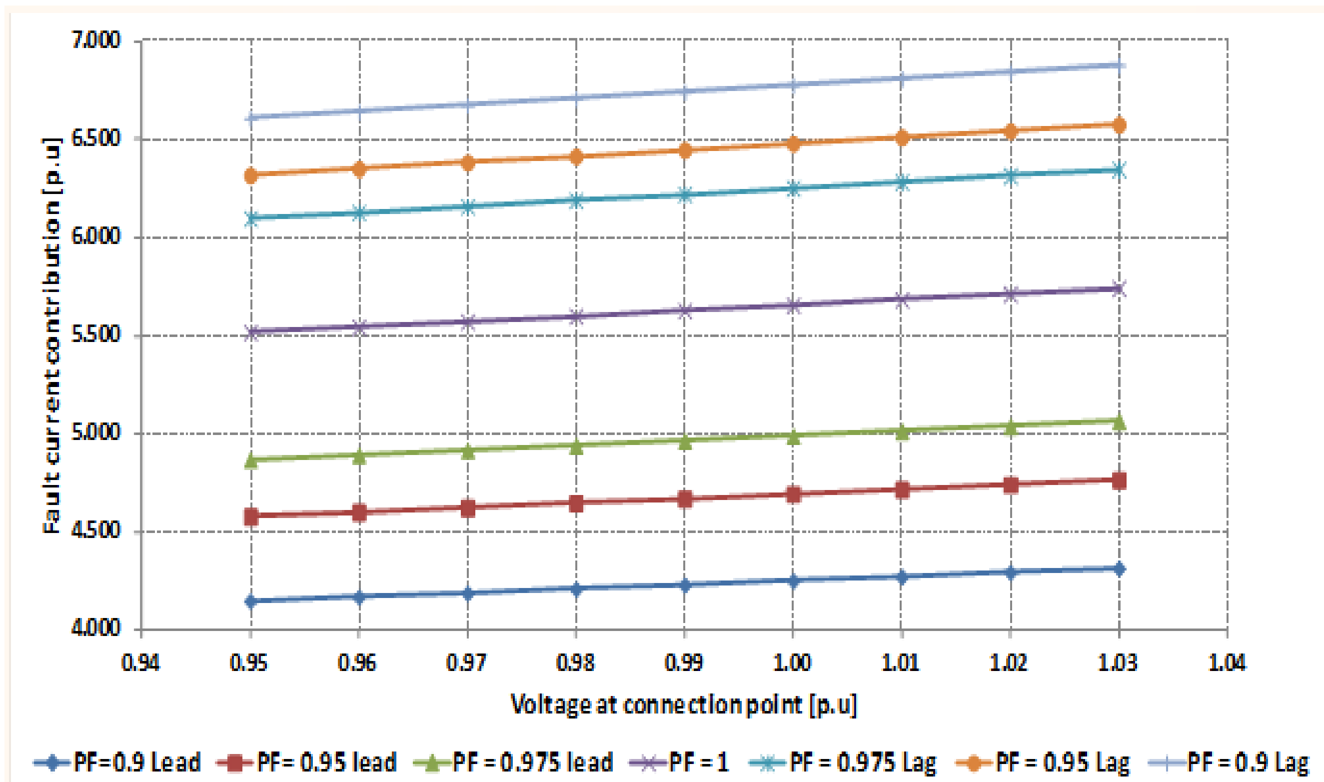
Fault Level Calculation Sensitivity Analysis



Fault Level Sensitivity Analysis – Generation PF







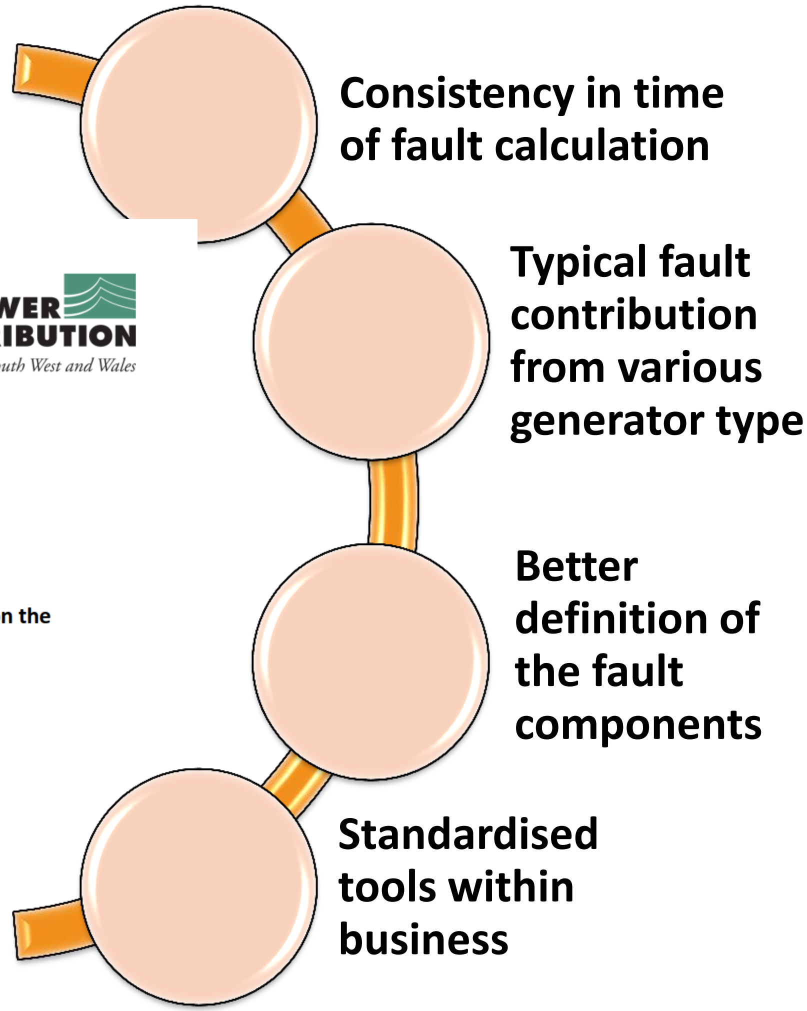
Fault Level Calculation Policy Document


WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE: SD7F/2

Determination of Short Circuit Duty for Switchgear on the WPD Distribution System



Enhanced fault level assessments

- A test bed for model validation through fault level monitoring
- Models and tools for FCL impact desktop studies

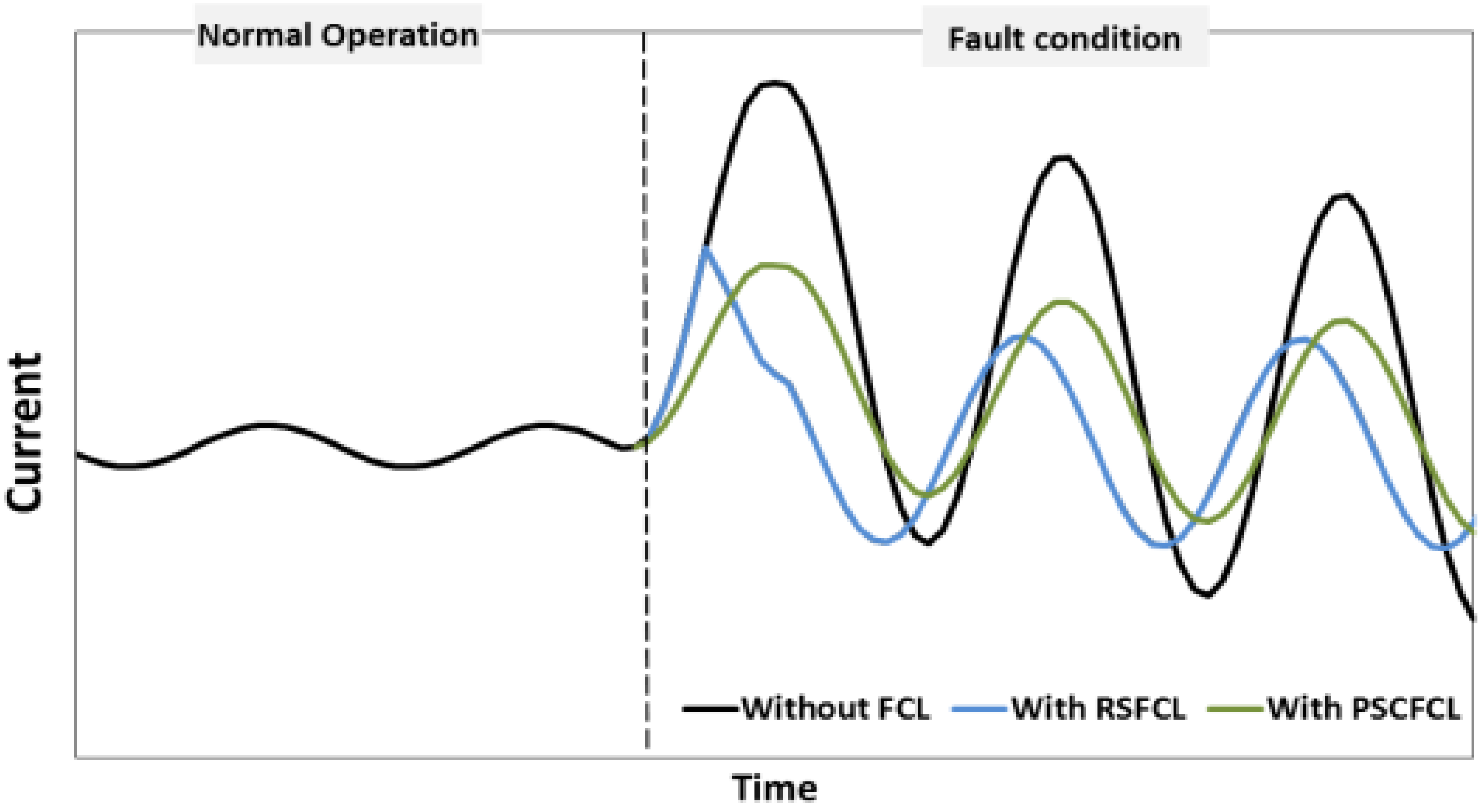
Fault level management

Fault level mitigation

FCL Modelling - Challenges

- PSCFCL , RSFCL are now live assets and need to be considered in fault level assessment
- 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



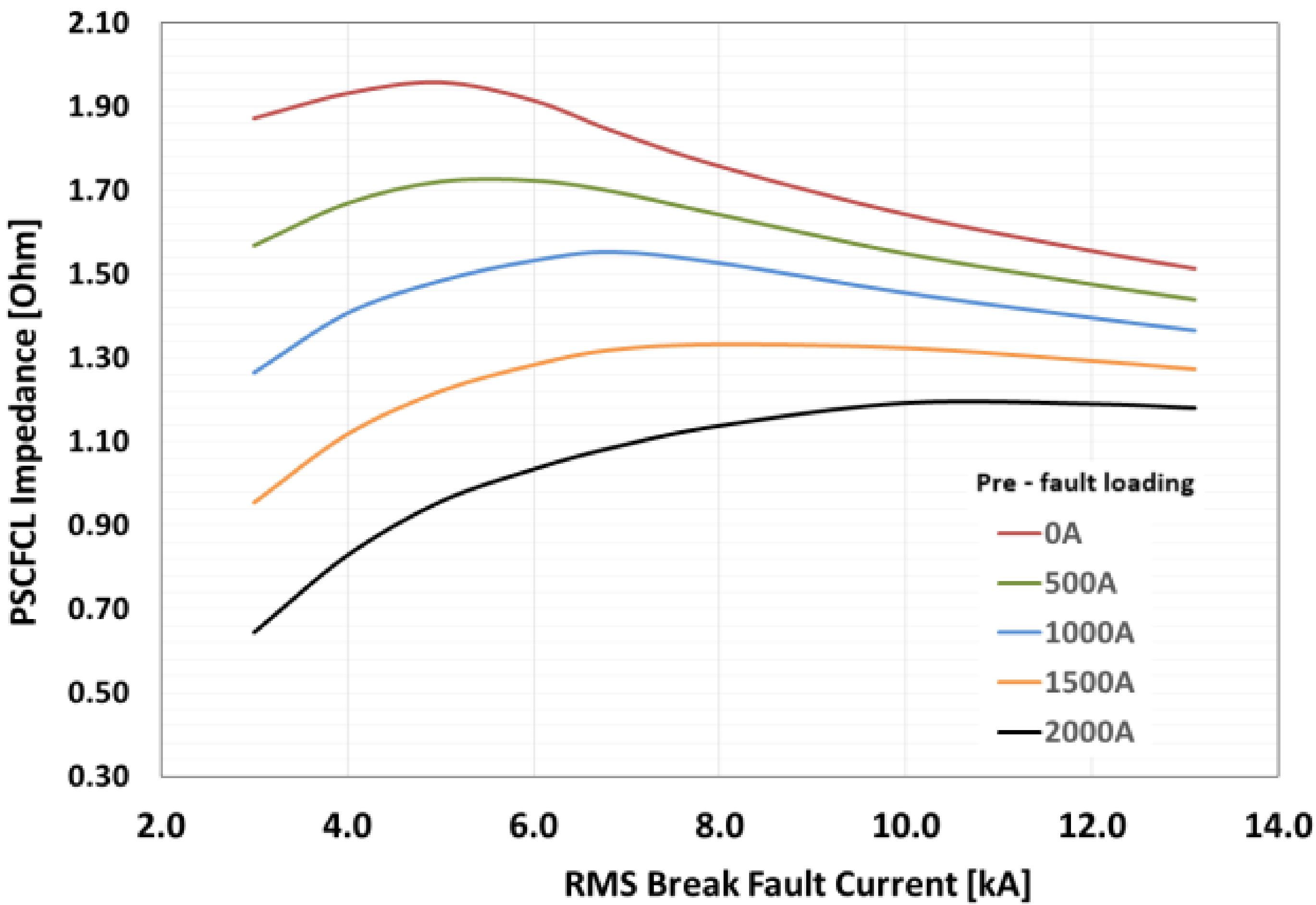
FCL Modelling – Static Modelling

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

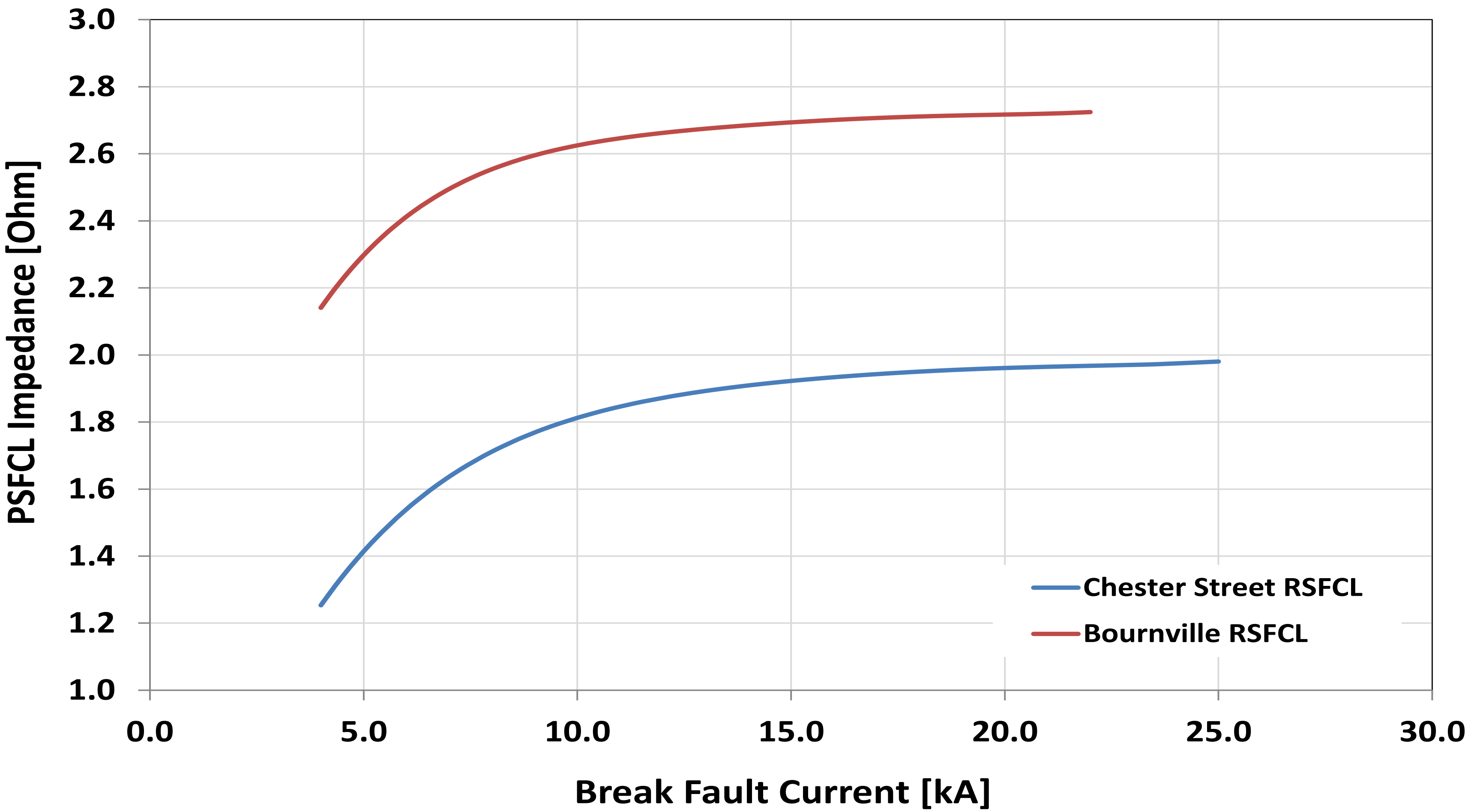
Stage I – Obtain device specific impedance data and create impedance look-up tables for prospective Make and Break fault currents.

Stage II – Deploy the FCL impedance estimator in static short-circuit calculations.

Impedance at Breaking Time (70ms) - PSCFCL

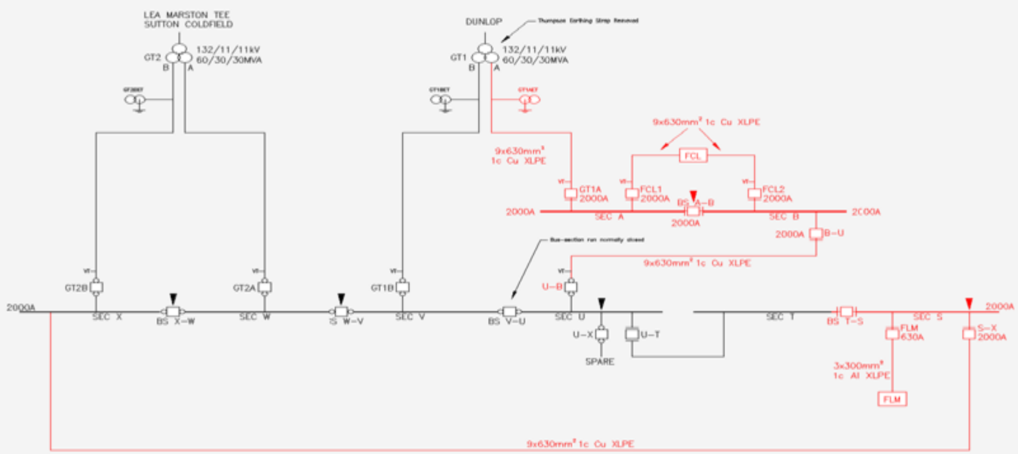


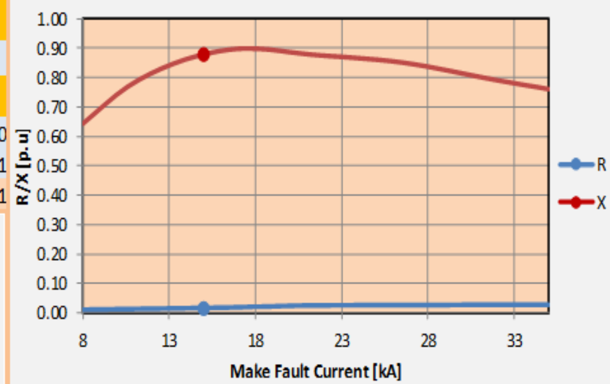
Impedance at Breaking Time (70ms) - RSFCL

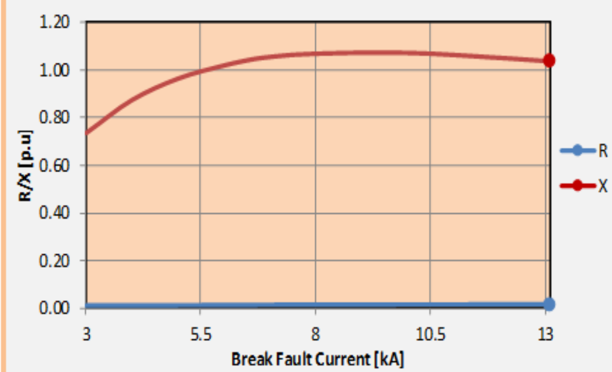


FCL Impedance Estimator

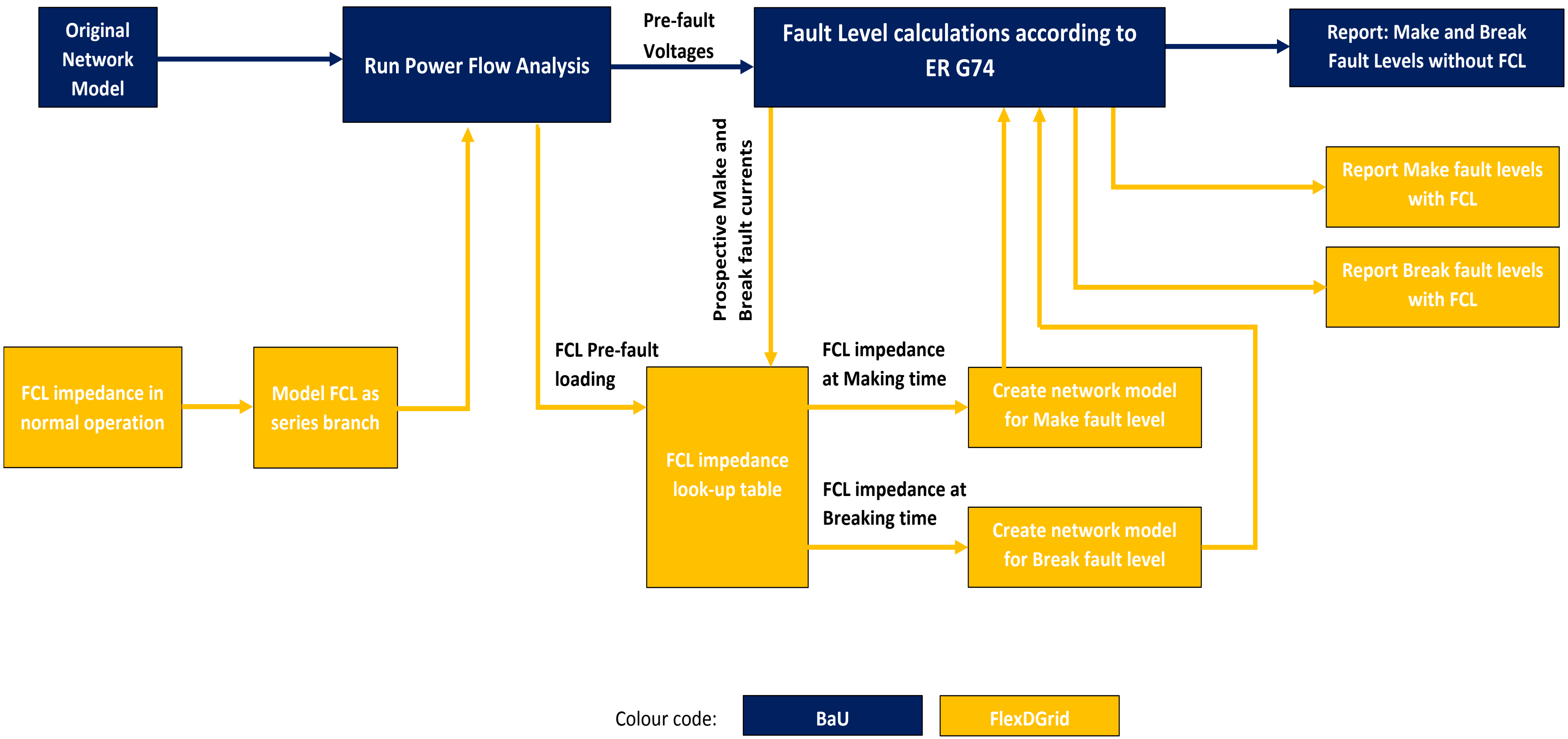
WESTERN POWER DISTRIBUTION FLEXDGRID	Fault current limiter technology							
	Pre saturated Core FCL Castle Bromwhich							
Network conditions			**R[p.u]**	**X[p.u]**	**R[Ohm]**	**X[Ohm]**	**Base Units**	
Pre-fault FCL Loading	1600	A					Sb[MVA]	100
Prospective Make Fault Current	15.0	kA	0.01	0.88	0.02	1.06	Vb[kV]	11
Prospective Break Fault Current	13.1	kA	0.01	1.04	0.02	1.25	Zb[Ohm]	1.21

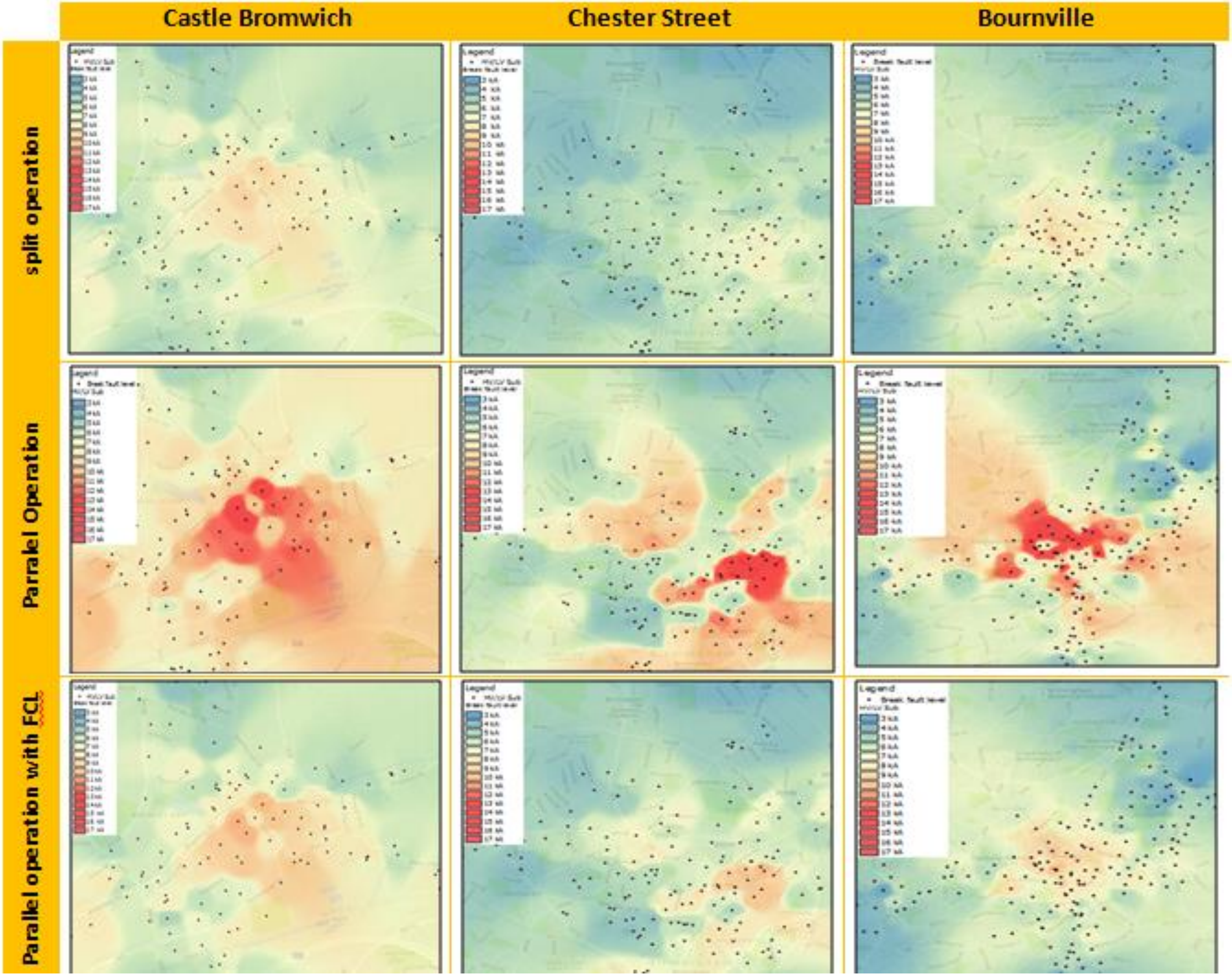






FCL Modelling - Methodology




Castle Bromwich
Chester Street
Bournville
split operation
Parralel Operation
Parallel operation with FCL

Thank you for listening

Any questions?

WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Closedown Dissemination Event
12th July 2017

Fault Level Measurement
- Design and Implementation

Neil Murdoch

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

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 Beta Overview

Aim of method Beta:

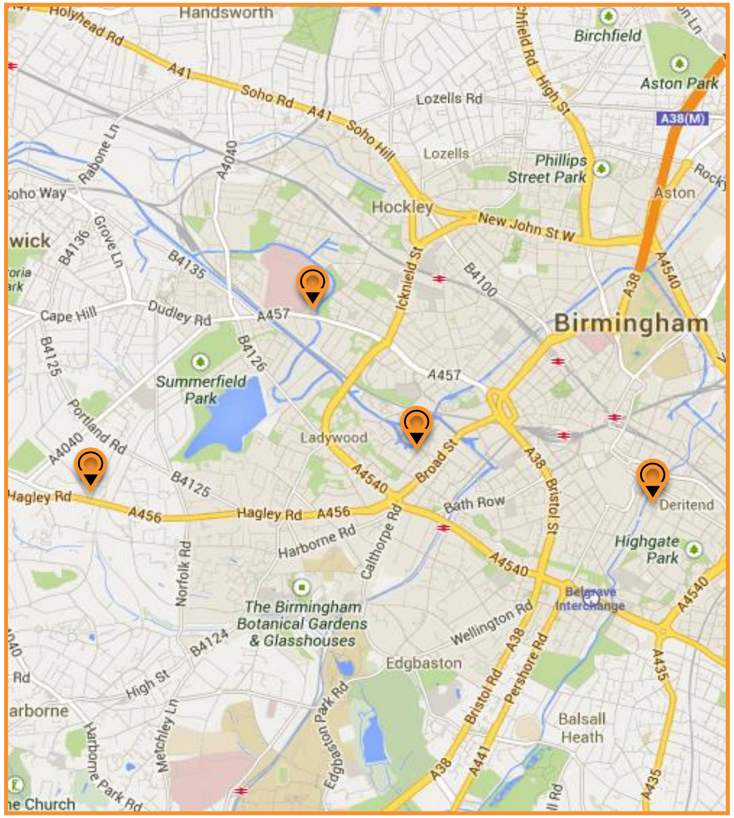
Installation of Fault Level Measurement Technology to determine the actual real time substation Fault Level.

- Build on knowledge learned through previous projects
- Install FLM technology in 10 substations
- Use knowledge captured to update WPD modelling policies
- Develop control procedures based on customer Fault Level Contribution

Site Selection

- 18 substations identified in and around Birmingham with FL issue

- 10 sites for FLM, selection based on:
  - Availability of Space
  - Network Connection
  - Substation Access
  - Investment Plans
  - Auxiliary Equipment



Selected Sites

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

Partnership led by S&C Electric supported by Outram Research, Nortech and HVR Resistors.

S&C ELECTRIC COMPANY
Excellence Through Innovation

Outram Research Limited

HVR INTERNATIONAL

nortech

Active Fault Level Monitor

- Originally developed as part of the Teir 1 LCNF Project “active Fault Level Monitor”
- Device comprises
  - S&C Electric IntelliRupter
  - Outram Research PM7000
  - Nortech Envoy
  - HVR Resistor Bank

S&C IntelliRupter PulseRecloser

Operation

- 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

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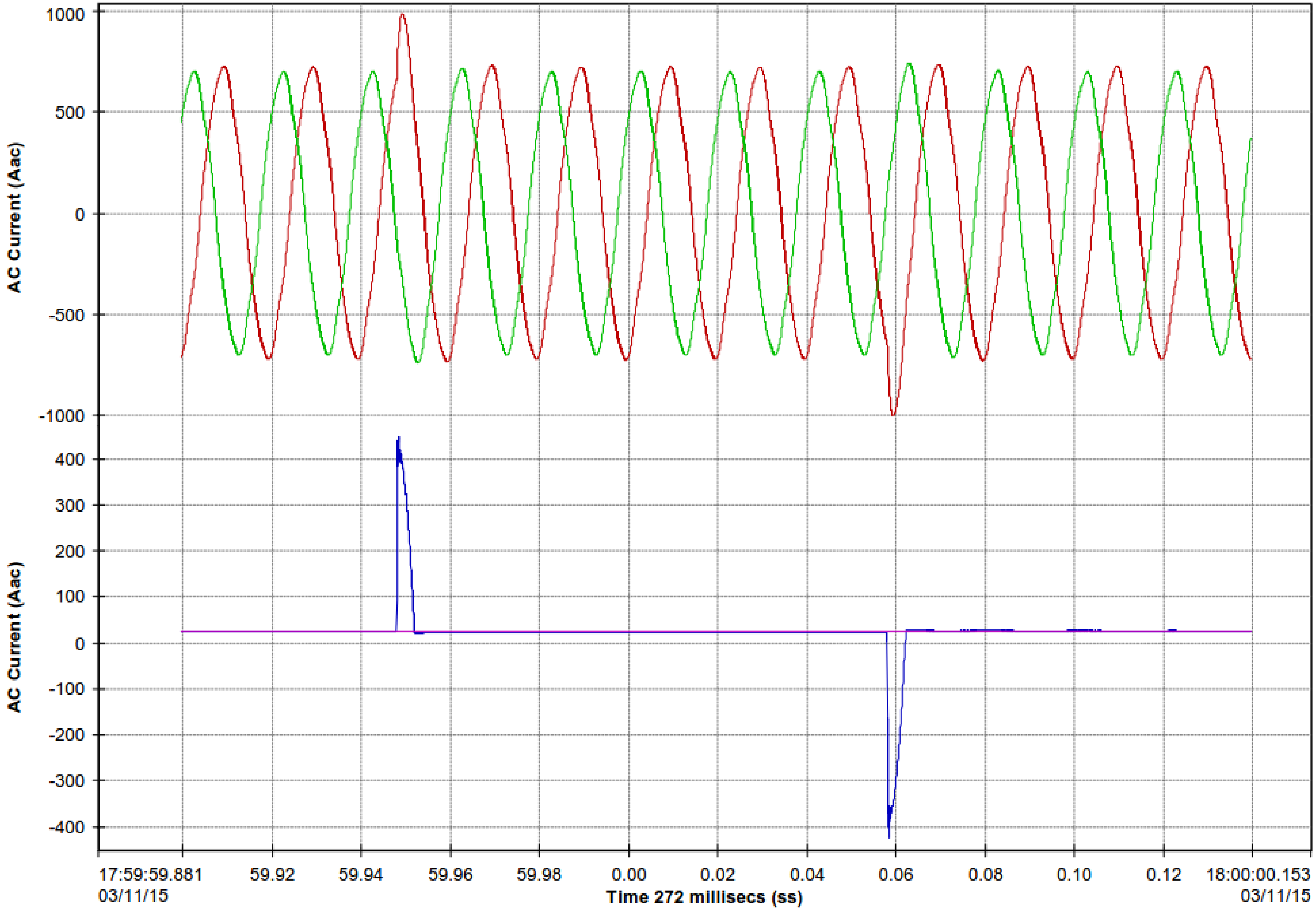
FLEXDGRID

Outram Research PM7000

Operation

- Monitors Voltage and Current flows through AFLM and substation transformers.
- Measures disturbance on waveforms caused by general switching and by AFLM to determine the substation fault level
- Can distinguish between upstream contribution through primary transformer and contribution from the 11kV network
- Also used to monitor network circulating current to determine if a parallel is made between two transformers

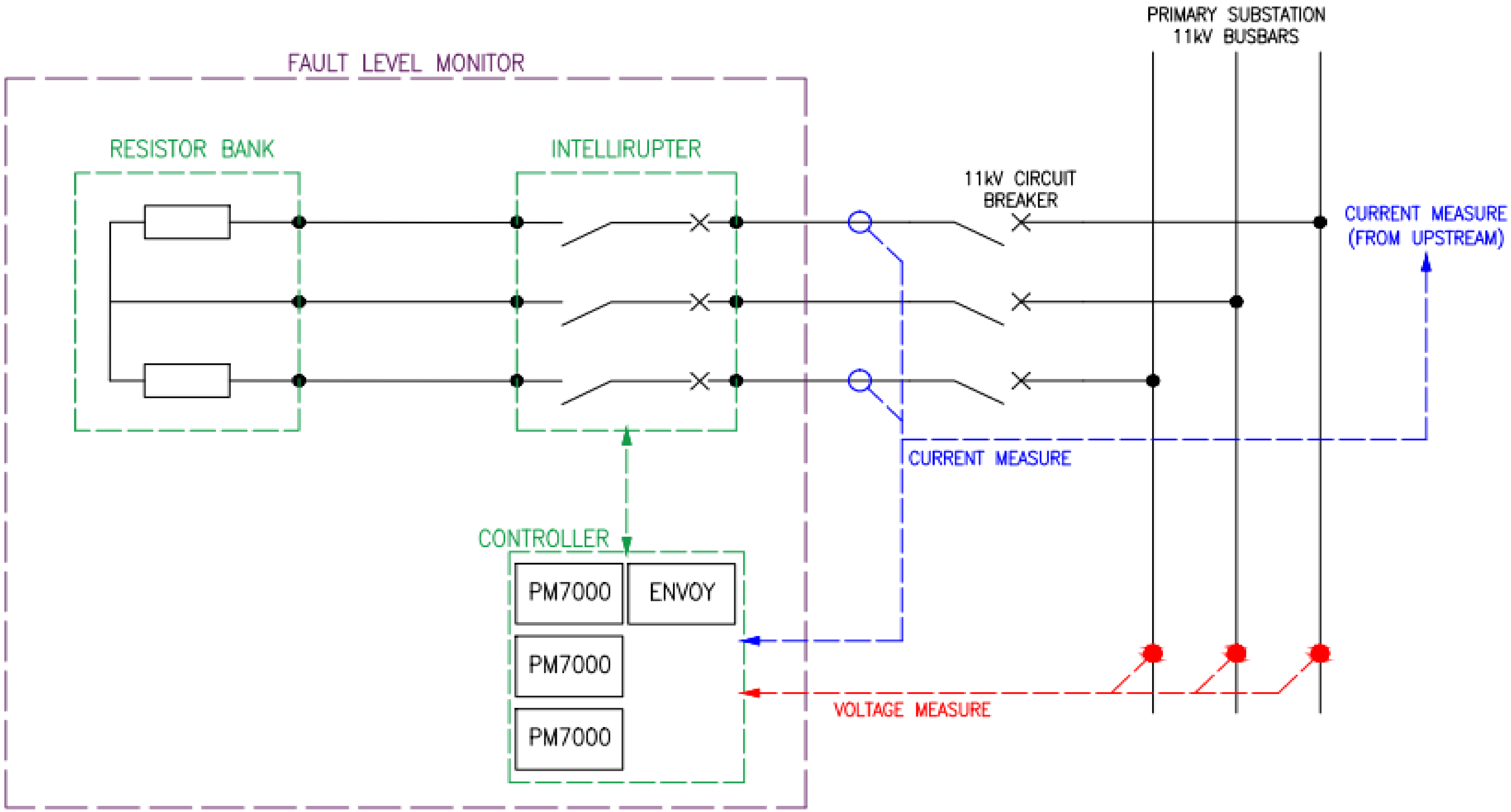
Dual Path PM7000 AFLM Waveform



Nortech Envoy

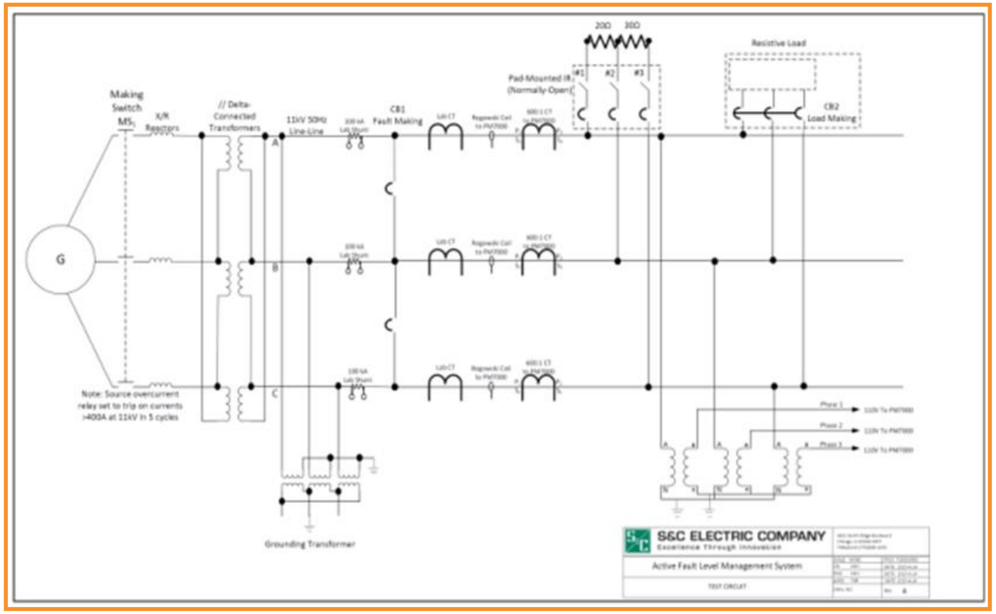
- Central controller for AFLM operation
- Collects and transmits the real time data back to WPD control
- Programmed to operate device at pre defined interval or on-demand through WPD Network Management System

Single Line Diagram of AFLM



Testing – Chicago May 2015

- Testing carried out in S&C's High Voltage Laboratory
- Aim to prove accuracy of device is within 5% under a variety of network conditions



Testing Results

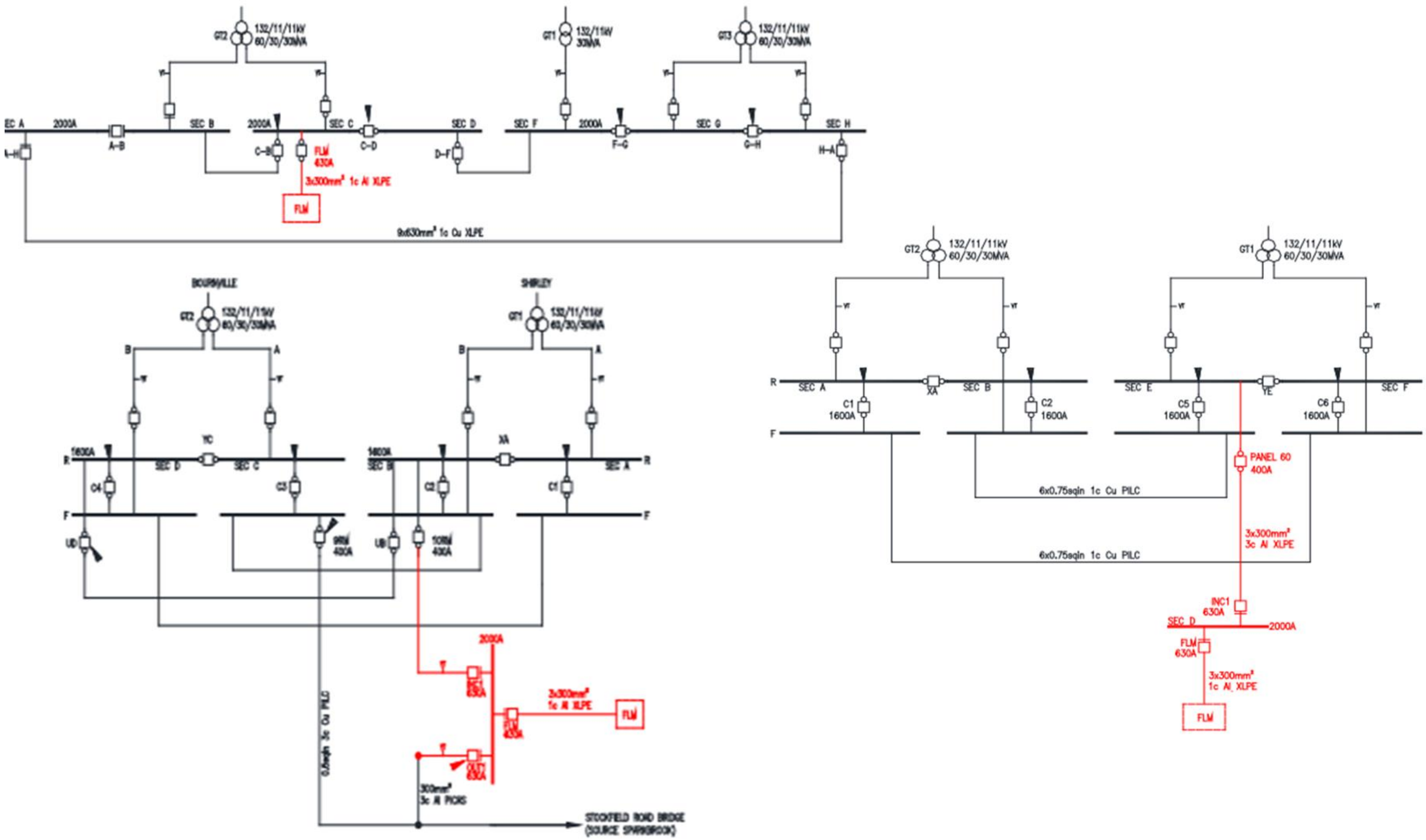
Test #	Lab Trace ID	Peak I (10ms) error (%)	RMS I (90ms) error (%)
4	90	4.4%	-2.3%
3	92	1.9%	-2.8%
4	93	2.1%	-4.6%
3	95	4.6%	-2.8%
4	96	-2.5%	-8.6%
4	100	3.9%	-8.2%
3	102	2.1%	-4.4%
		2.4%	-4.8%
8	107	3.4%	-0.9%
9	108	6.9%	-2.8%
8	110	3.4%	-1.8%
8	118	2.4%	-4.8%
9	119	-3.8%	-8.7%
8	121	4.9%	-1.9%
9	122	-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%
- 50Ω resistance gave poor results due to smaller disturbance
- Red values outside accuracy. Caused by rapid frequency drop unique to laboratory and not a feature of real network

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

Example Connections



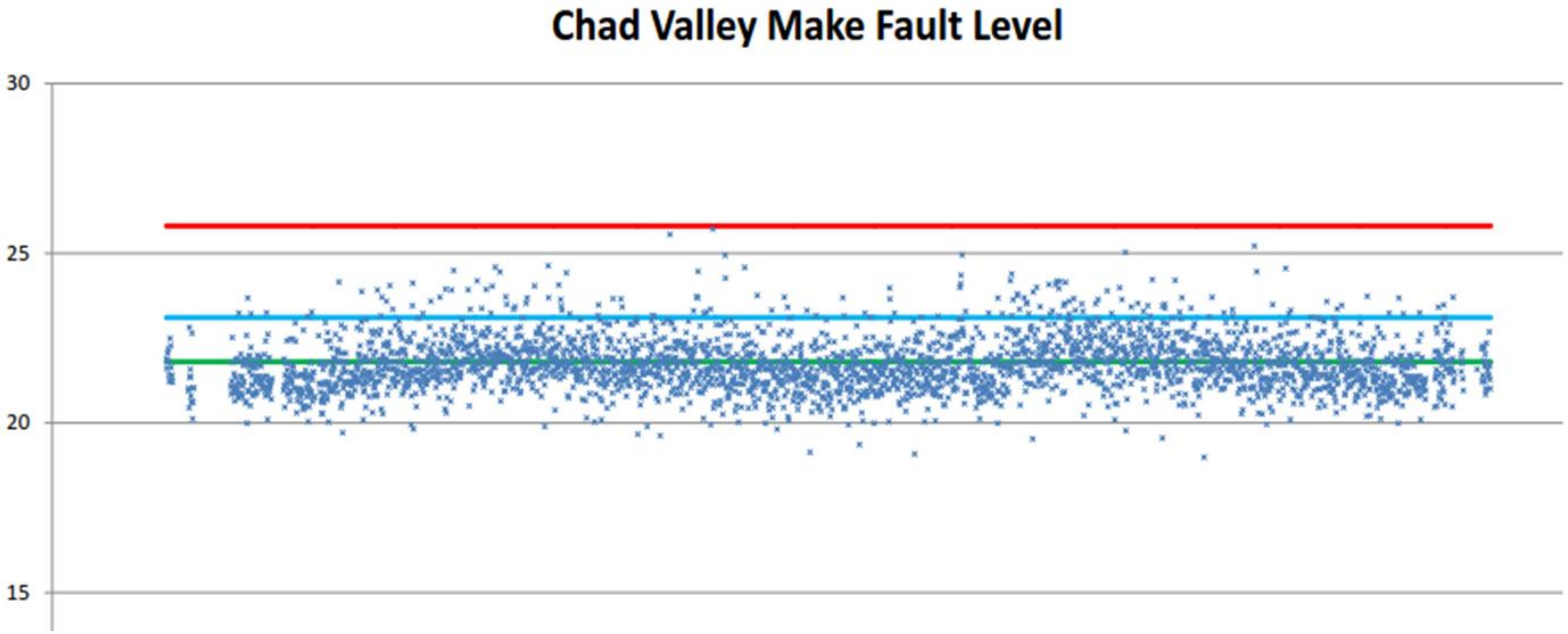
Installation Pictures

Installation Pictures

Data Captured

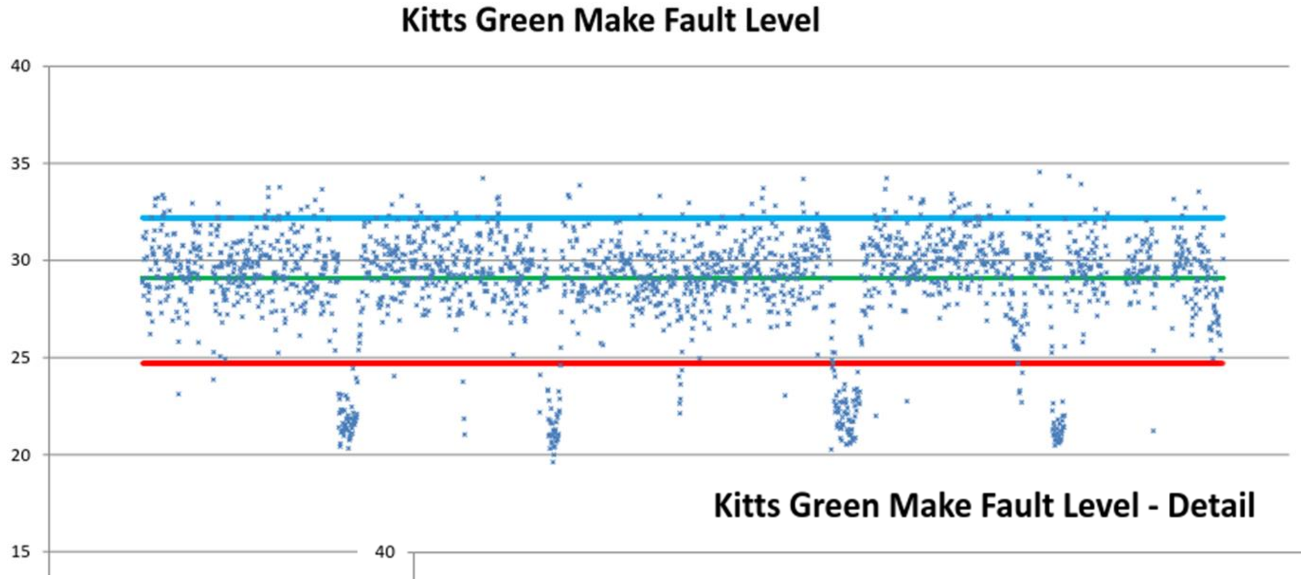
- Using 12 months of fault level data from AFLMs
- 95^{th} percentile fault level was calculated for each AFLM
  - Provides a conservative value for maximum fault level
- Comparison made to design fault level and existing modelled fault level
- % available headroom calculated at each substation based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

Data Graphs

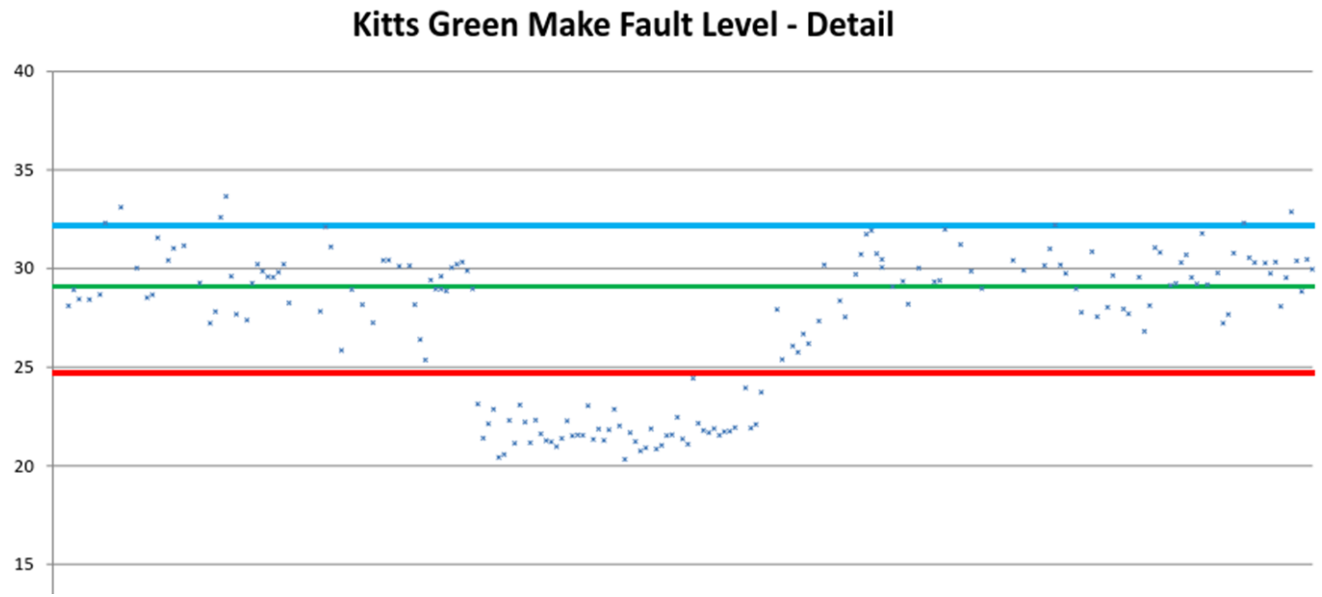


- Red line is existing modelled Fault level
- Green line is average of all AFLM results and the blue line is the 95th percentile value

Data Graphs



Kitts Green Make Fault Level
40
35
30
25
20
15



Kitts Green Make Fault Level - Detail
40
35
30
25
20
15

Overall Results – Make Fault Level Change

	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%

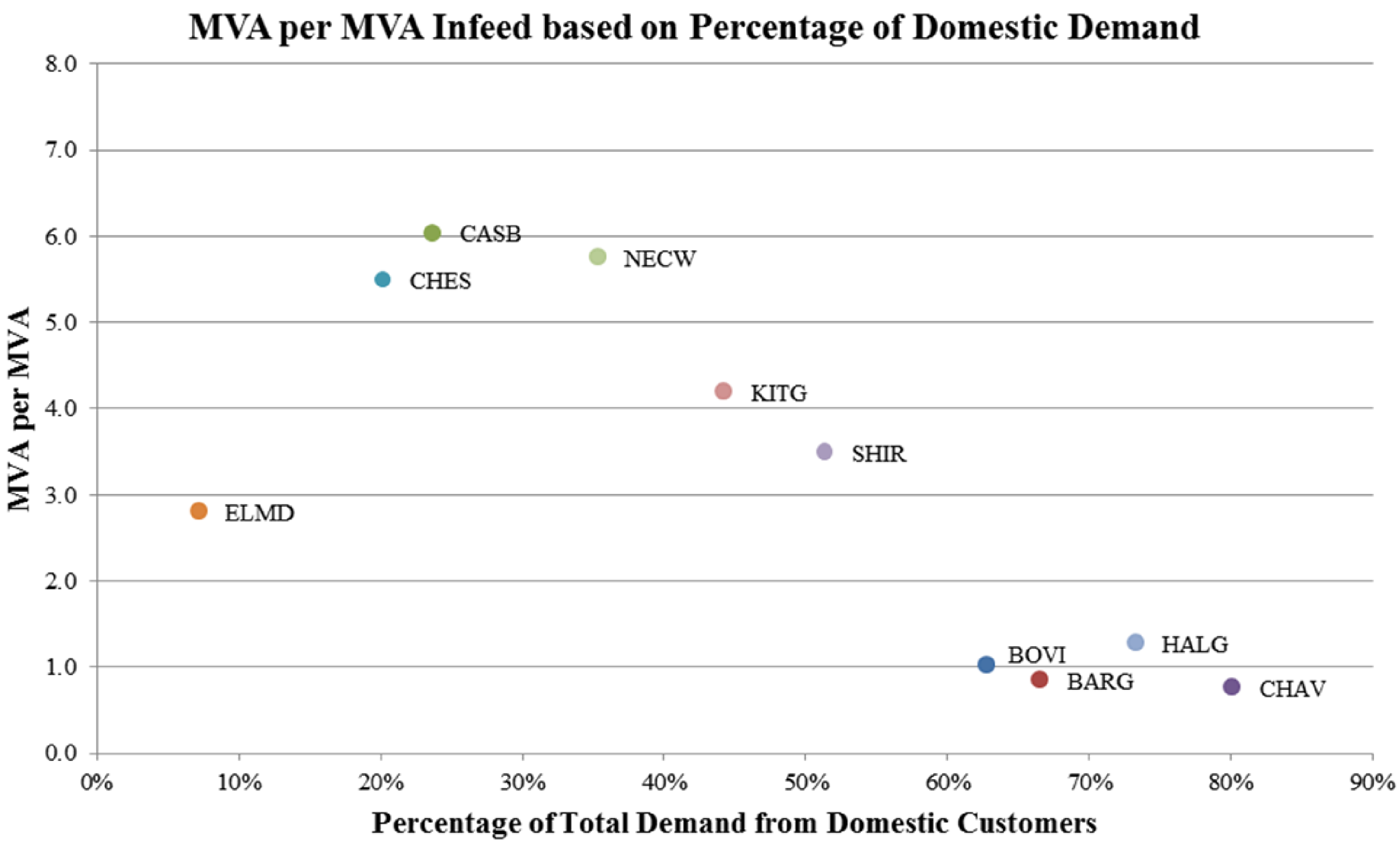
Overall Results – Break Fault Level Change

	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 Analysis

- Project aim to challenge load infeed assumptions for fault level calculations defined by G74
- Use advanced models combined with AFLM data to determine fault contribution from 11kV network
- Combined with substation load information to generate template for application of learning to substations outside project

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

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

Thank you for listening

Any questions?

Lunch

Resume at 13.15pm

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HEAT AND POWER FOR BIRMINGHAM

Closedown Dissemination Event
12th July 2017

Fault Current Limiters

- Design and Implementation

Neil Murdoch

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Introduction

- Overview
- Fault Level Issues
- Traditional Reduction Solutions
- Fault Current Limiters
  - Technologies
  - Connection Options
  - Specification
  - Design/Testing/Install

FlexDGrid – Method Gamma

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

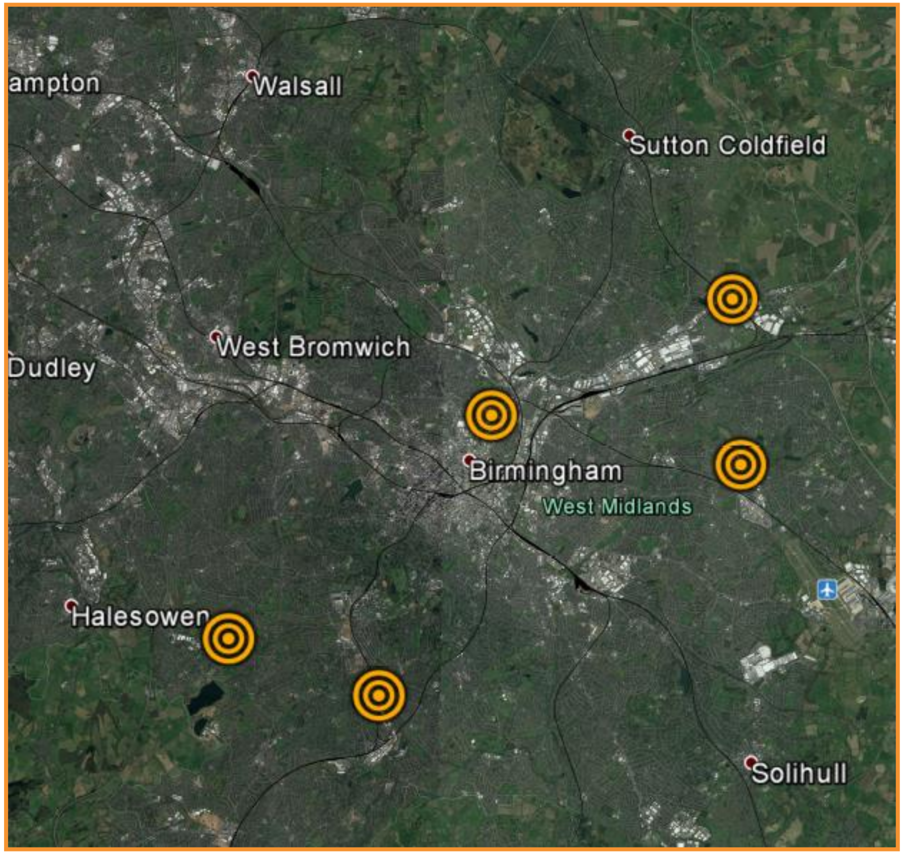
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

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

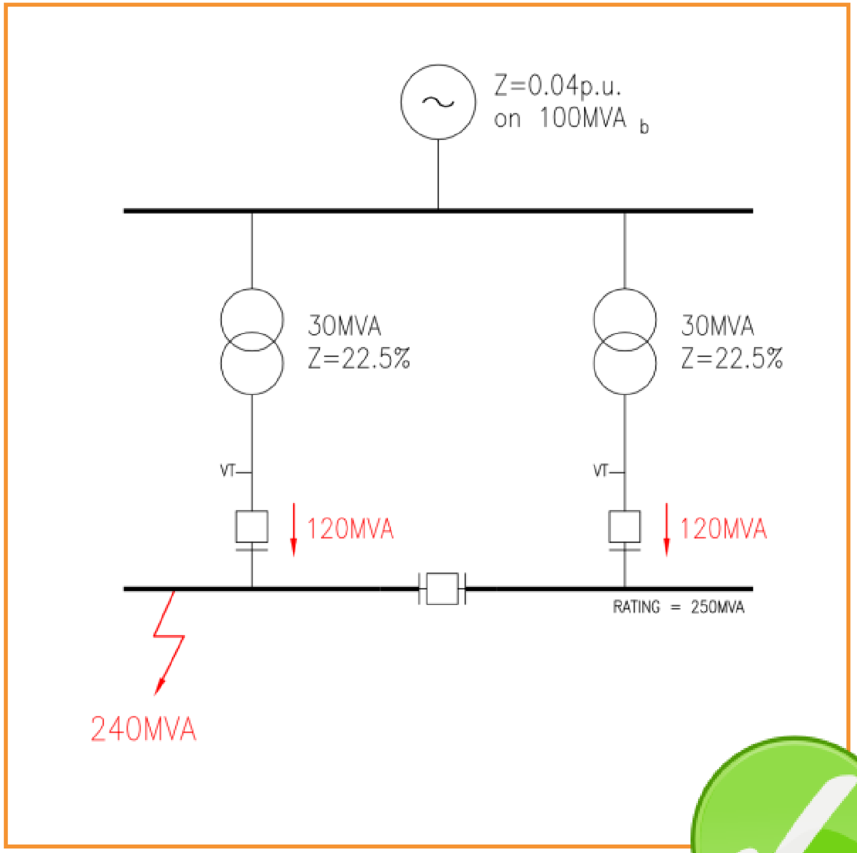
Overview

- Method Gamma aimed to trial three different Fault Current Limiter (FCL) technologies
- FCLs have now been connected at three 132/11kV substations in Birmingham
- The connection of the FCLs has released 52MVA of generation capacity on the 11kV network



Fault Level Issue

- Substation with two 30MVA transformers in parallel
- LV switchgear is rated at 250MVA
- Maximum Fault Level (Break) is 240MVA
- Only 10MVA spare Fault Level capacity for generation



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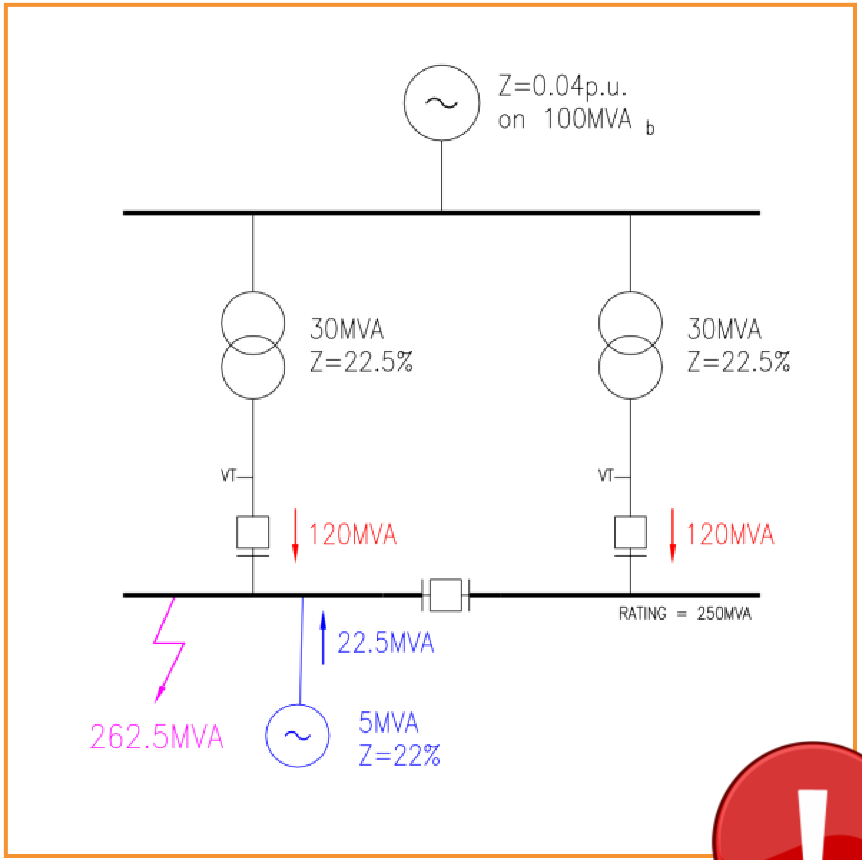
Fault Level Issue

- New 5MVA CHP generator wishes to connect
- System study reveals that Fault Level is now above rating
- An option is required to reduce the Fault Level



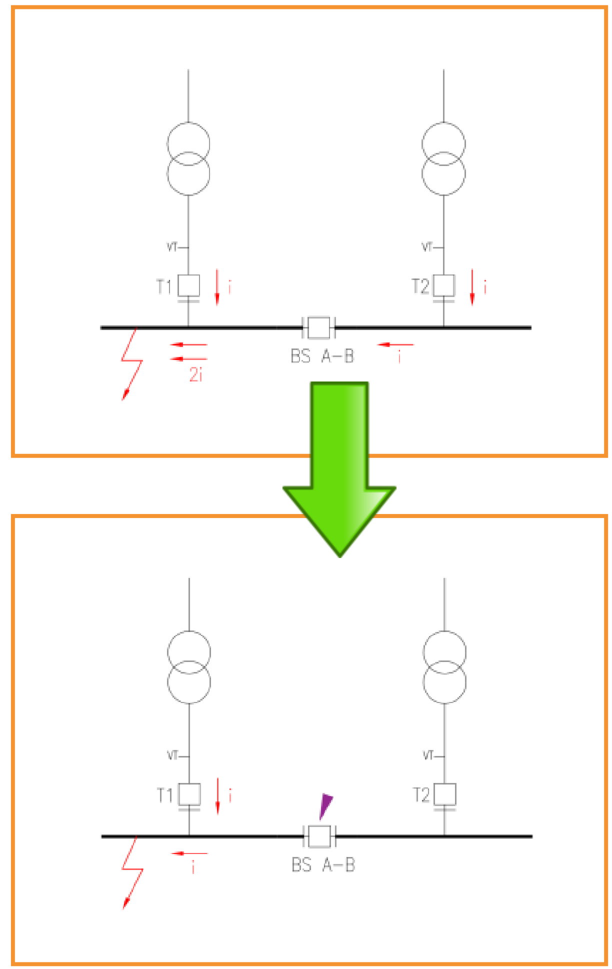
Traditional Fault Level Reduction – Option 1

Open Bus-Section

- Simplest method is to open the bus-section and split the path

Significant reduction in Fault Level

Reduces security of supply (Increase in Customer Interruptions)



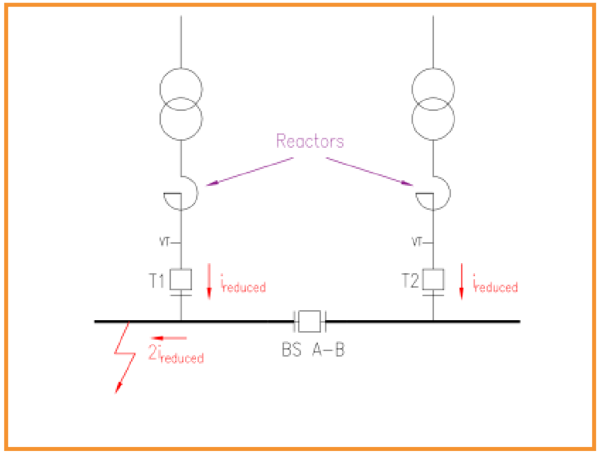
Traditional Fault Level Reduction – Option 2

Reactor

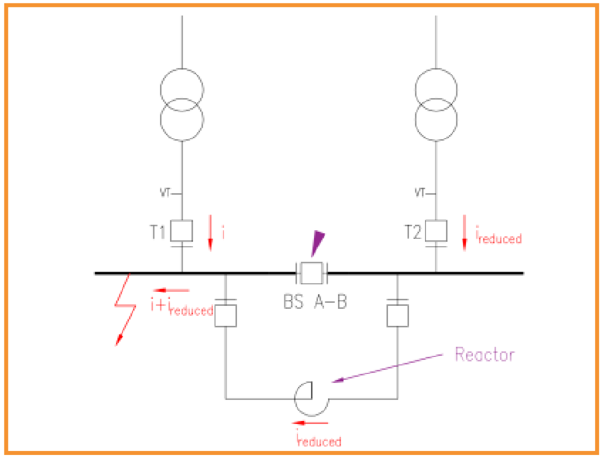
- Installation of reactors in the bus-section or incoming feeders

Moderate reduction in Fault Level

High losses, static impedance



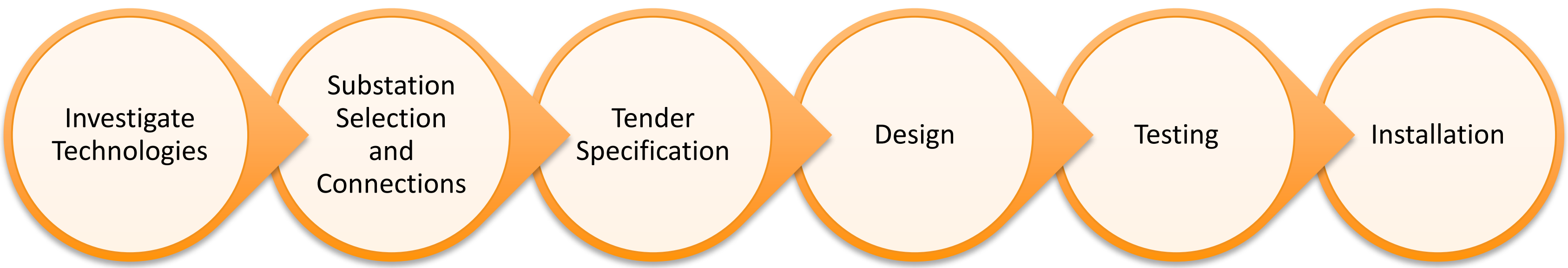
Reactors in series with transformers



Reactor across bus-section

FlexDGrid - Fault Current Limiters

- FlexDGrid aimed to overcome the limitation of traditional methods of fault level mitigation
- The process below was followed for trialing technologies



FCL 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

FCL Technologies

GridON – Pre-Saturated Core FCL

Nexans – Resistive Superconducting FCL

GE/Alstom – Power Electronic FCL

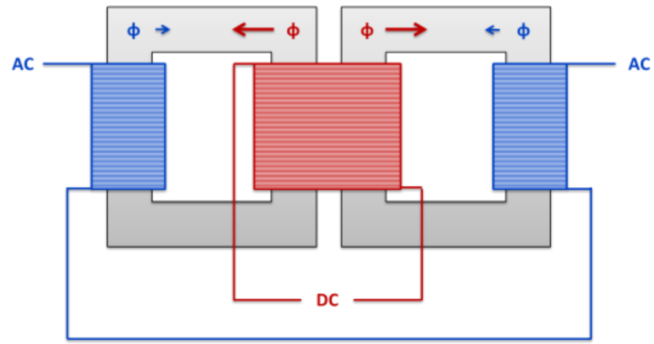
FCL Technologies – Pre-Saturated Core FCL

- The Pre-Saturated Core FCL (PSCFCL) acts like a "smart reactor"
- Comprises both AC and DC windings
  - The DC winding adjusts to keep the impedance of the PSCFCL low under normal conditions
  - When a fault occurs on the AC network the automatically changes to a present a higher impedance

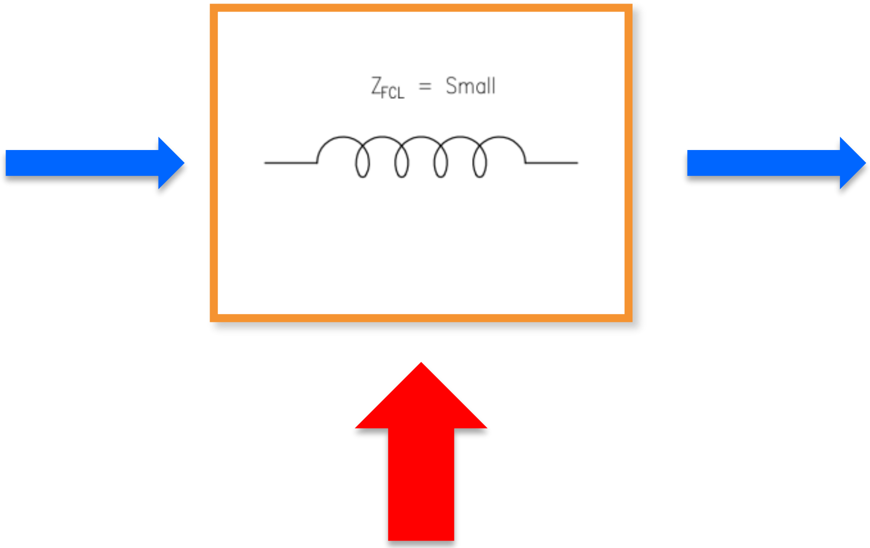
GridON
Protecting the Grid. Wisely.

WILSON TRANSFORMER
THE TRANSFORMER PEOPLE

FCL Technologies – Pre-Saturated Core FCL



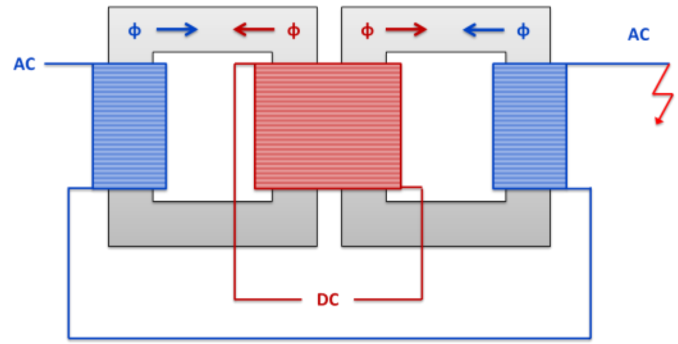
Normal 11kV AC current



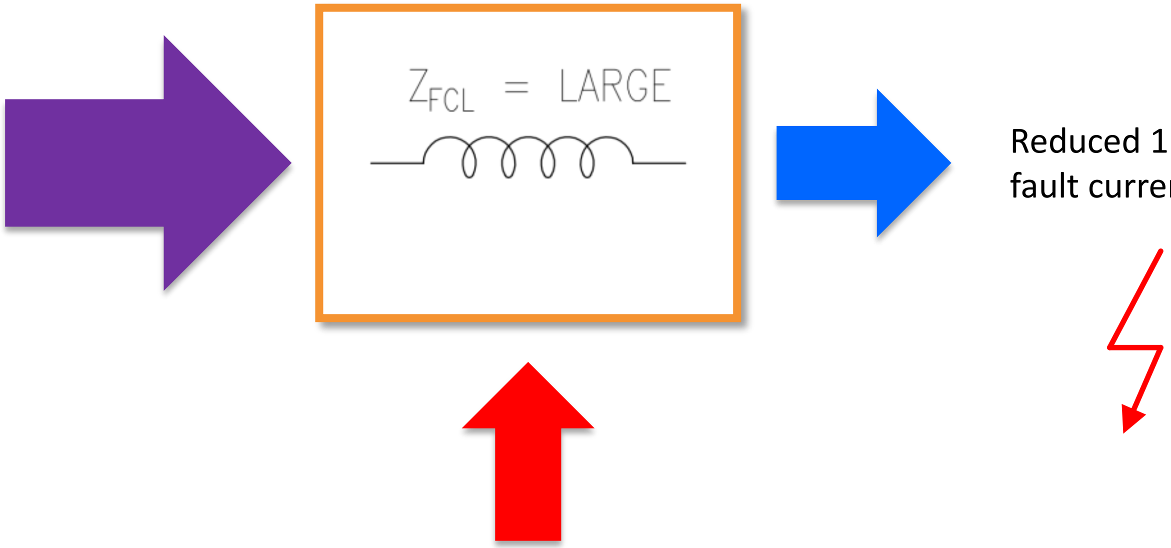
Normal 11kV AC current (low losses)

DC bias current

FCL Technologies – Pre-Saturated Core FCL



Prospective 11kV AC fault current



Reduced 11kV AC fault current

DC bias current

FCL Technologies – Pre-Saturated Core FCL

- Power Rating: 38MVA (2000A)
- Fault level reduction: 44%
- Impedance:
  - 0.18 p.u. (normal)
  - 1.0 p.u. (fault limiting)
- Mass: 170 Tonnes
- Dimensions (LxWxH): 6.4 x 4.5 x 5.3 m

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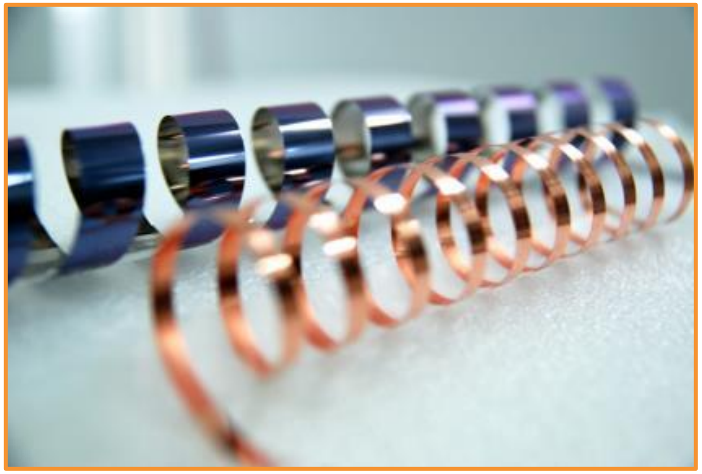
FCL Technologies – Resistive Superconducting FCL

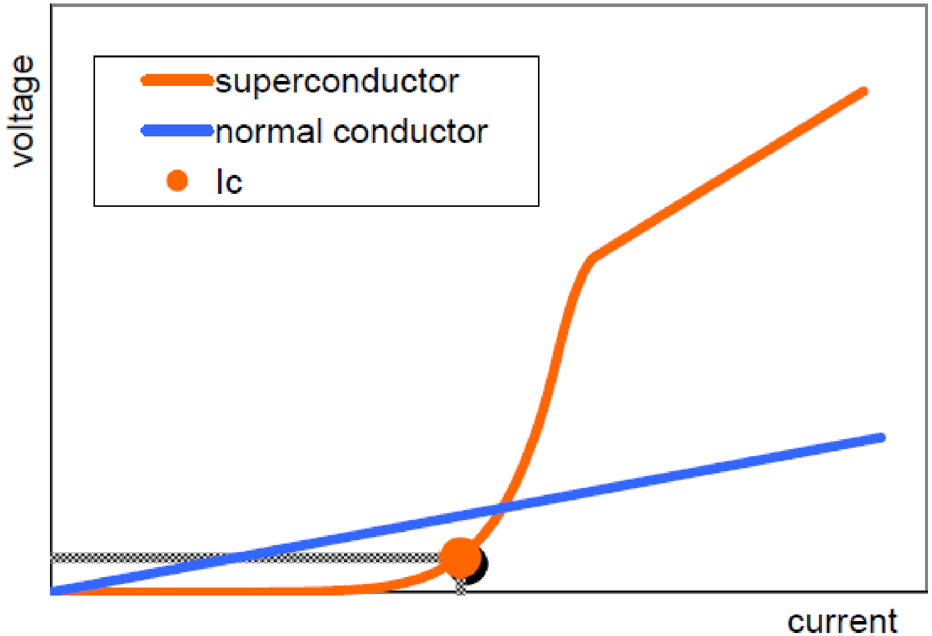
- The Resistive Superconducting FCL exploits the properties of a High Temperature Superconductor (HTS)
- HTS is assembled within a cryostat and kept at very low temperature (72K = -201°C) by using liquid nitrogen
- Normally the RSFCL presents very low impedance to the network
- The HTS becomes hot during faults resulting in a high impedance

Nexans



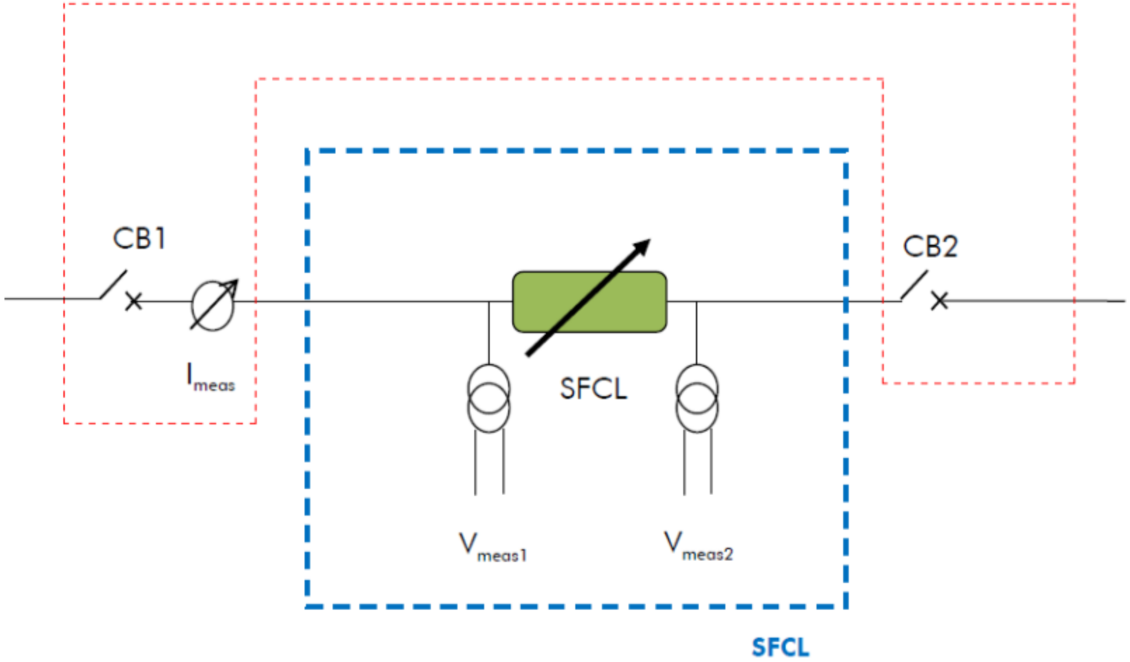
FCL Technologies – Resistive Superconducting FCL

- At low current the RSFCL operates in the superconducting range of the HTS
- As current increases so does the temperature of the HTS
- At the critical current (I_c) the HTS operates outside the superconducting range and “quenches”
- This causes the impedance of the RSFCL to dramatically increase



FCL Technologies – Resistive Superconducting FCL

- When the RSFCL quenches, the temperature of the HTS increases
- To prevent damage to the HTS, the RSFCL has to disconnect



FCL Technologies – Resistive Superconducting FCL

- Power Rating: 30MVA (1600A)
- Fault level reduction: 50%
- Impedance:
  - 0 p.u. (normal)
  - 2.18 p.u. (fault limiting)
- Mass: 30 Tonnes
- Dimensions (LxWxH): 8.1 x 4.6 x 3.2 m

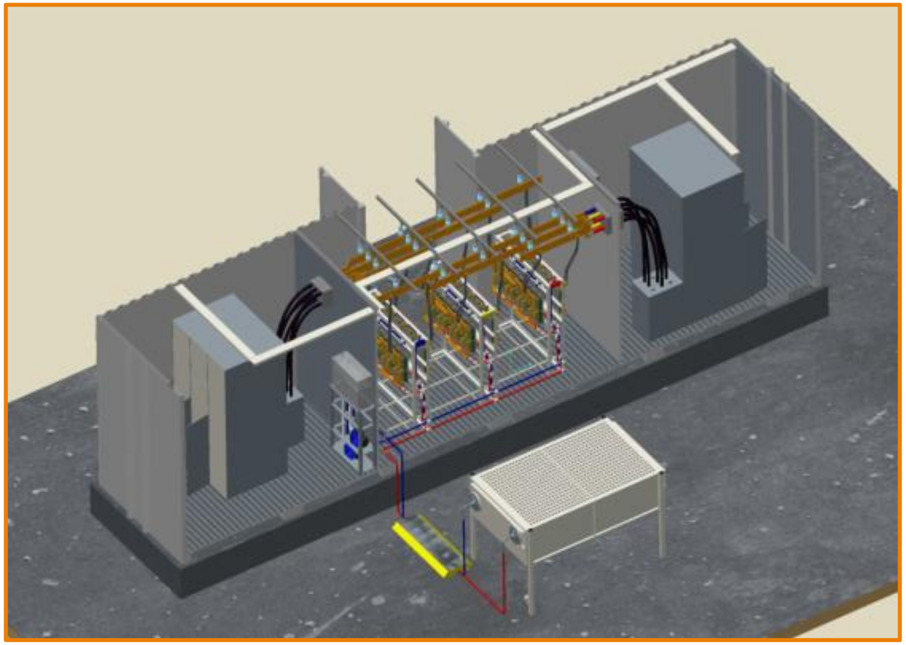
FCL Technologies – Power Electronic FCL

- GE proposed an FCL that could rapidly “switch” fault current instead of limiting it
- The device was based upon power electronic IGBTs already used in their VSC demonstrator project (ex-Alstom Grid)
- The PEFCL was designed to “sense” fault current and disconnect before the first peak of fault current

FCL Technologies – Power Electronic FCL

- 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

- However, knowledge from the project has been shared with other DNOs (including UKPN – PowerFul-CB)



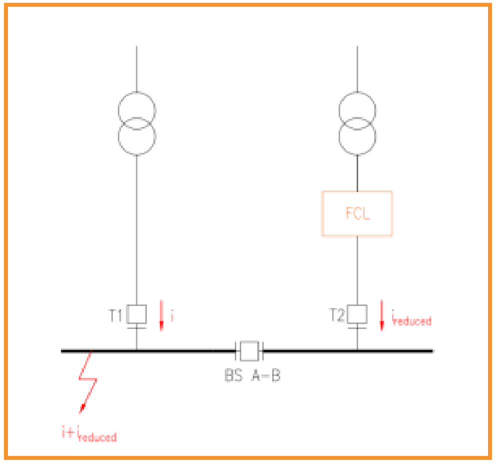
Connecting FCLs

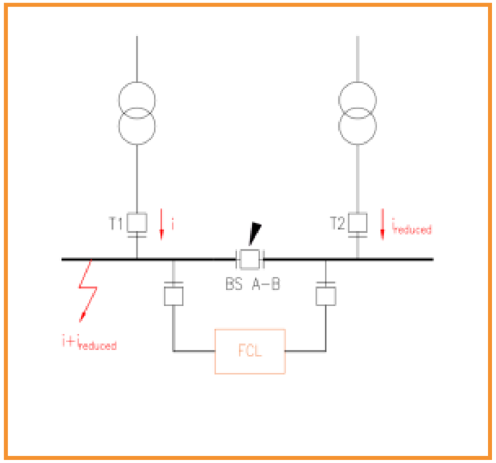
- There a number of options for connecting FCLs

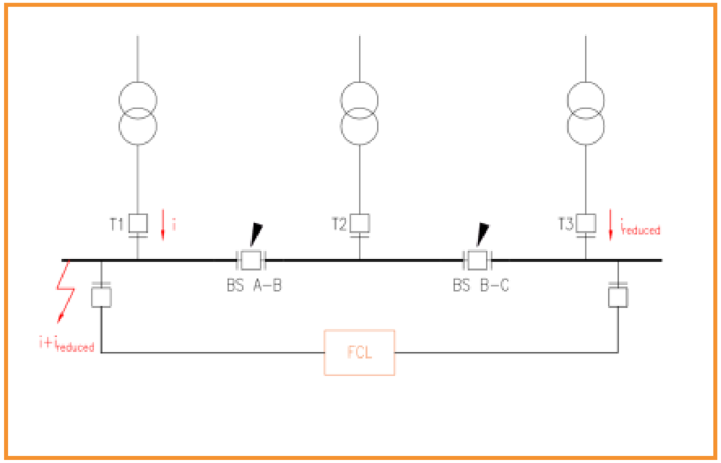
- Options may differ depending on:
  - Network configuration
  - FCL operation
  - Balance of load

Connecting FCLs

- Three integration options for FCLs:
  - In series with a transformer
  - Across a bus-section
  - Within an interconnector



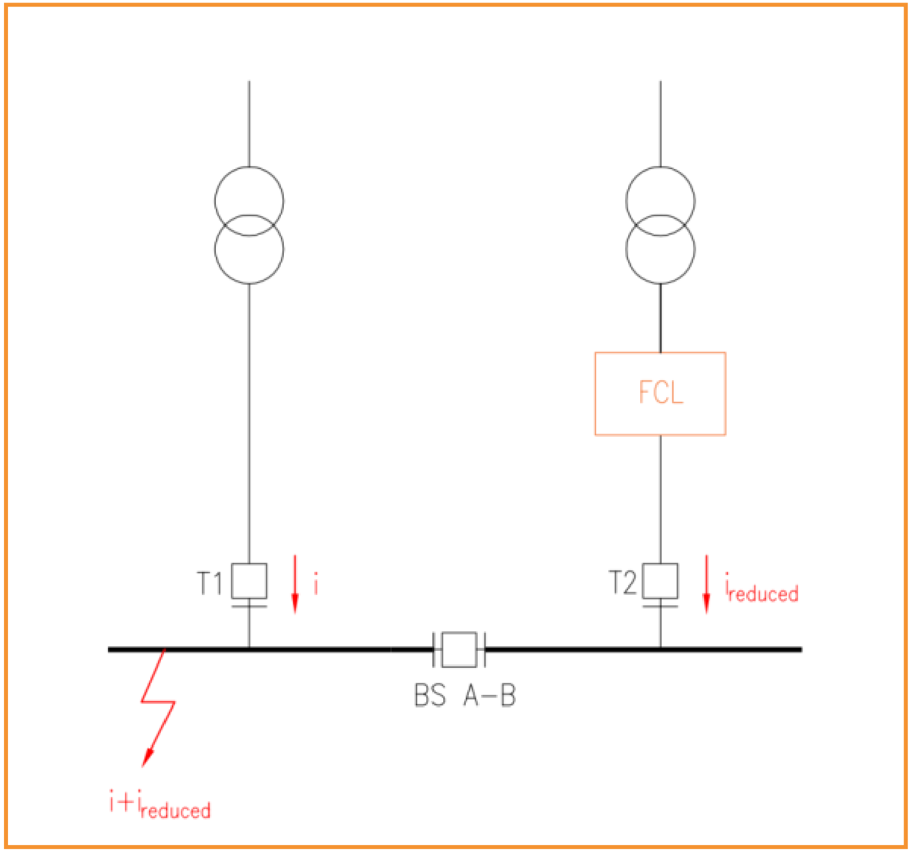




Connecting FCLs

In-series with transformer

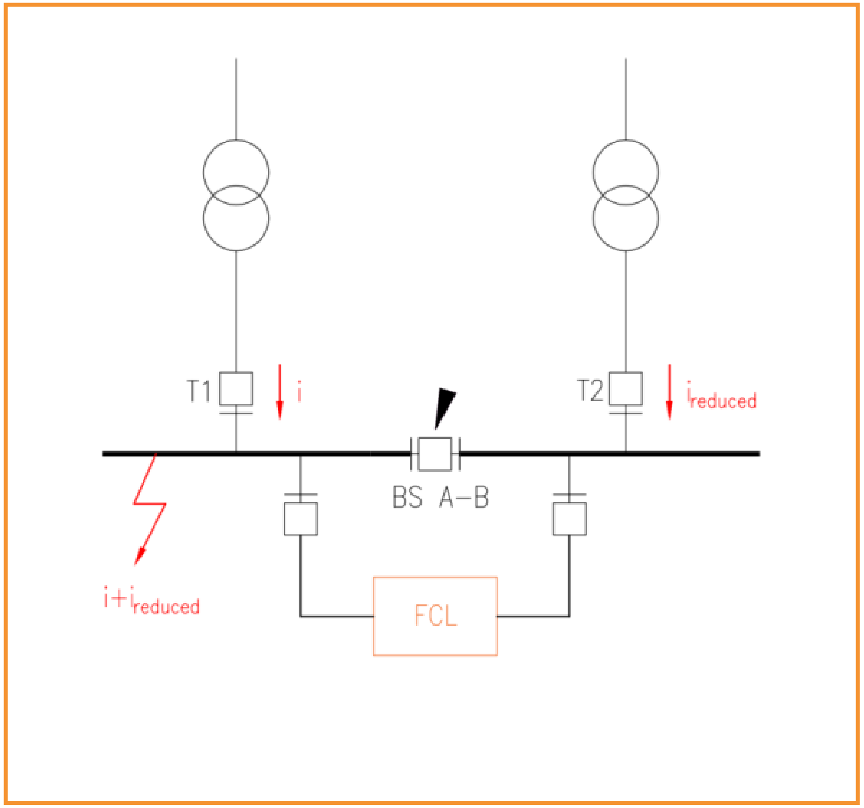
- Parallel of T1 and T2
- Transformer protection has to be modified
- FCL has to "ride-through faults"



Connecting FCLs

Across Bus-Section

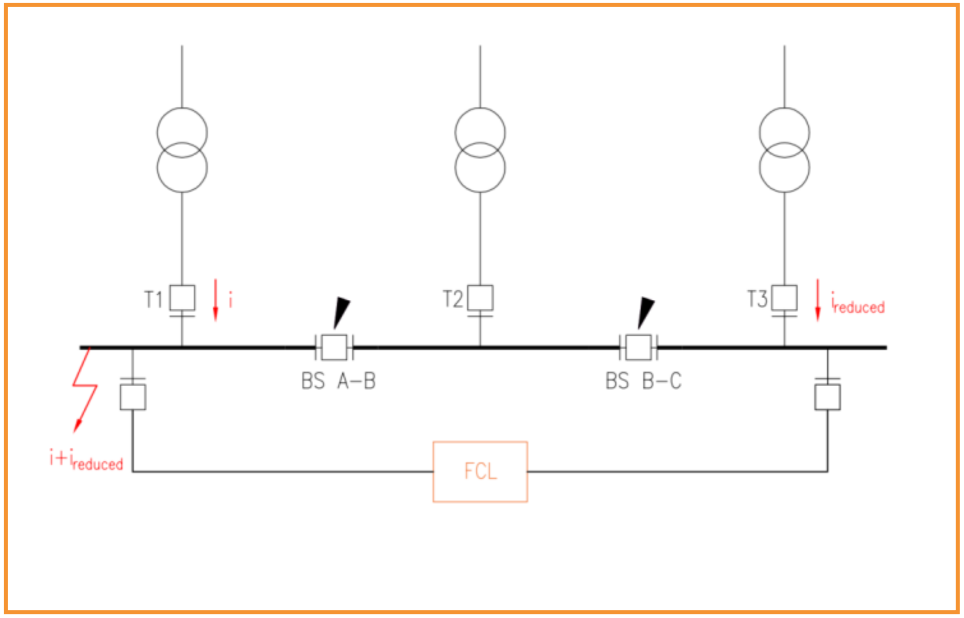
- Parallel of T1 and T2
- Requires spare CBs either side of Bus-Section
- Can disconnect after fault without disturbing incoming supplies



Connecting FCLs

Within an Interconnector

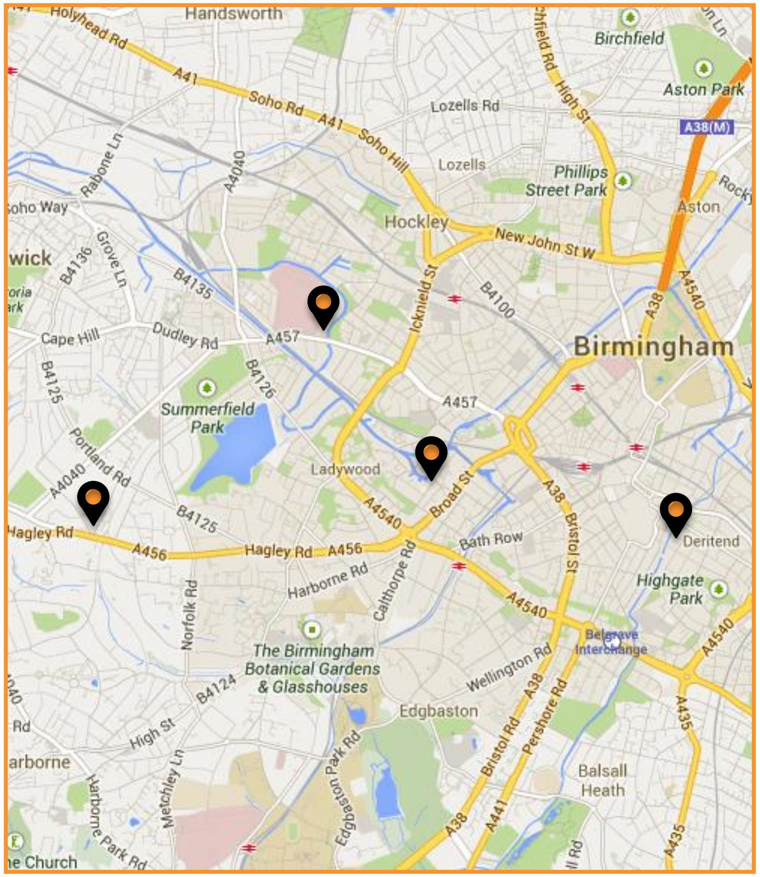
- Parallel of T1 and T3
- Existing protection can be modified
- Can disconnect after fault without disturbing incoming supplies



Substation Selection

- 18 substations identified in and around Birmingham with FL issue

- 5 sites for FCL selected:
  - Availability of Space
  - Network Connection
  - Substation Access
  - Investment Plans
  - Auxiliary Equipment

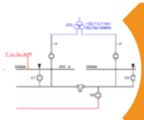


Substation Selection

Availability of Space

Network Connection

Access



Investment Plans

Auxiliary Systems

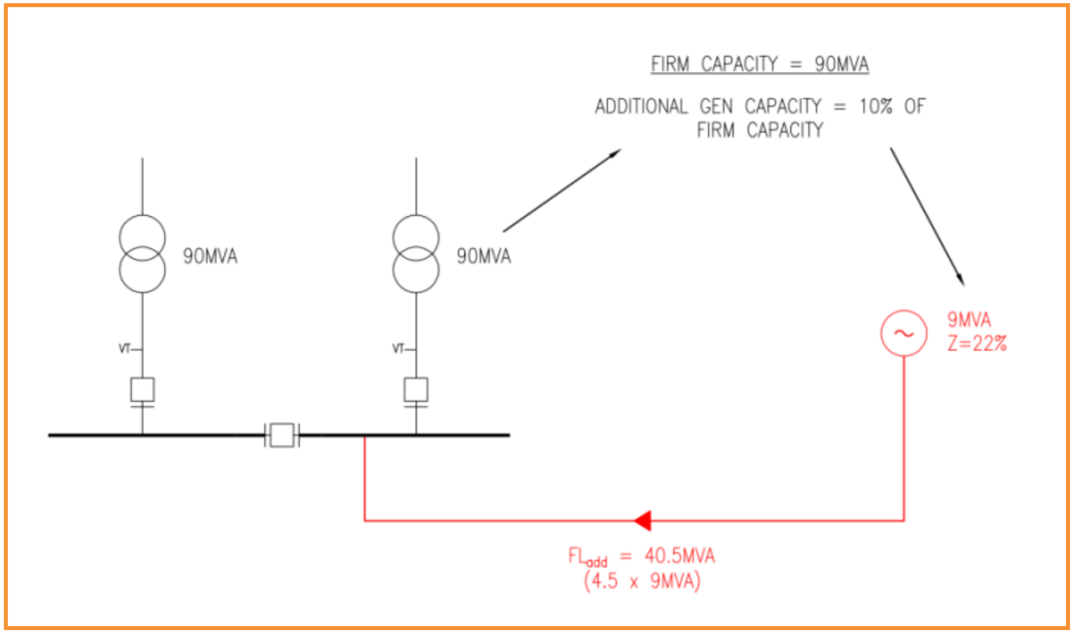
Substation Selection

- Following thorough analysis the following substations were chosen for installation of an FCL

Substation	Comments
Castle Bromwich 132/11kV	2 no. dual wound 60MVA transformers
Chester Street 132/11kV	3 no. 30MVA transformers
Bournville 132/11kV	4 no. 30MVA transformers
Kitts Green 132/11kV	3 no. dual wound 60MVA transformers
Bartley Green 132/11kV	2 no. 30MVA transformers

Specification – FL Reduction

- The required FL reduction at the chosen substations was based on the Firm Capacity
- Substations with a higher firm capacity had higher levels of reduction



Specification – FCL Requirements

- The following factors were considered when selecting FCLs

FAIL SAFE

Failure of any component must not result in FL increasing

RIDE THROUGH

Requirement to ride through faults must be considered as some FCLs have to switch off after fault

AUXILIARY SYSTEMS

Additional systems are required to control and operate FCLs

Complexity and power capacity of these systems varies between devices

FL REDUCTION

Amount of FL reduction is dependent on other factors

Larger reductions can be achieved at higher fault levels

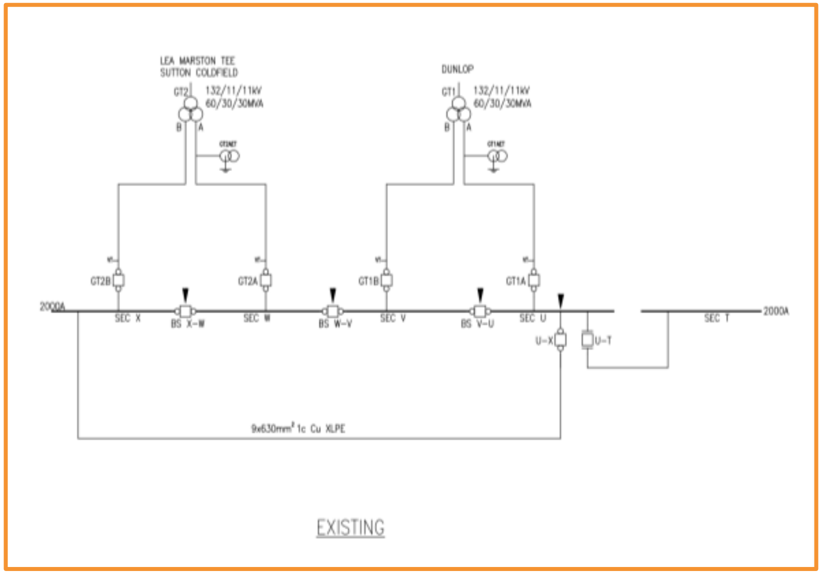
FCL Installations

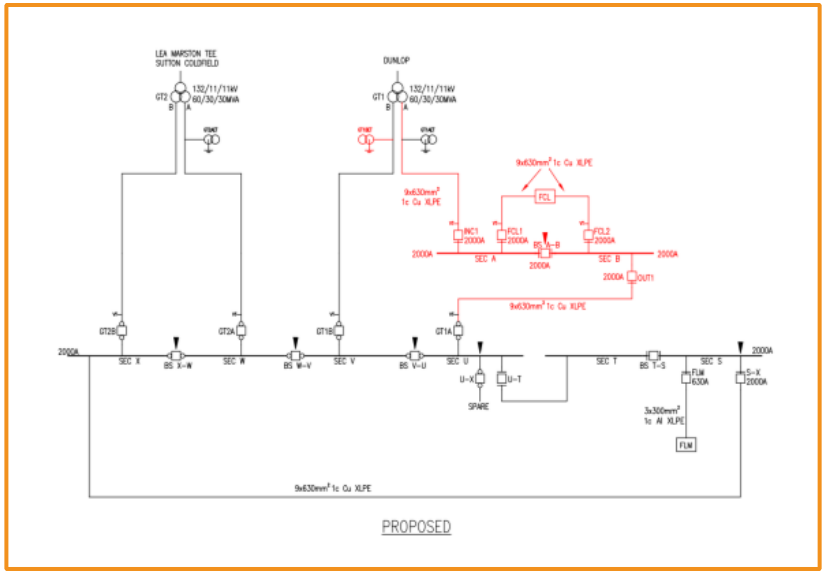
- The FCLs were allocated to the substations according to the aspects of each technology

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

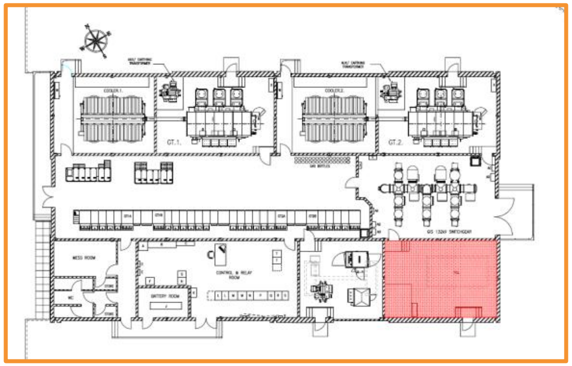
Castle Bromwich FCL Installation

- FCL was designed to be installed in the leg of GT1A
- Indoor installation with extensive modifications



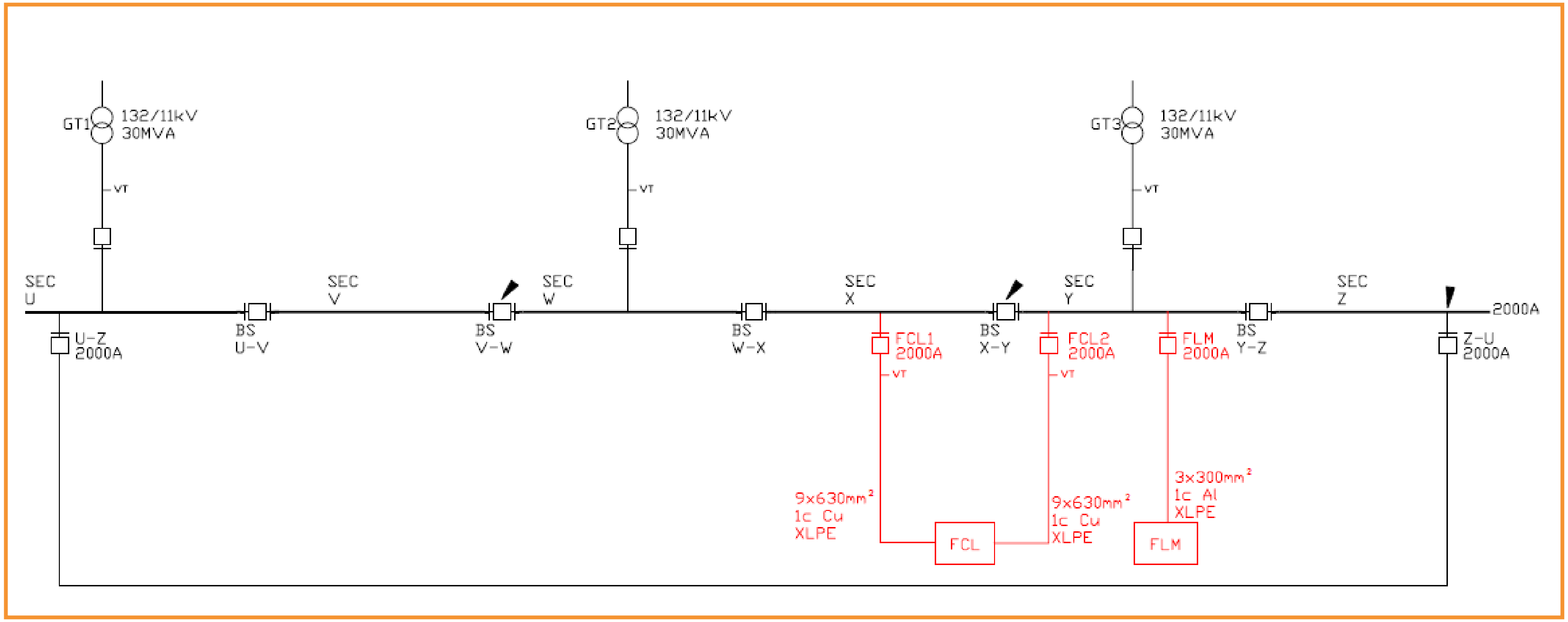


Castle Bromwich FCL Installation

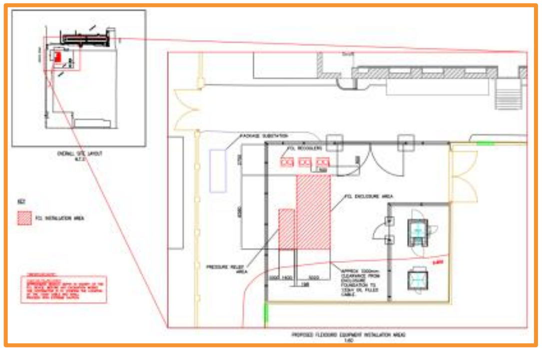


Chester Street FCL Installation

- Three Grid Transformers run in split configuration
- GT1 supplied from a separate source
- RSFCL connected across the bus-section (new switchgear)

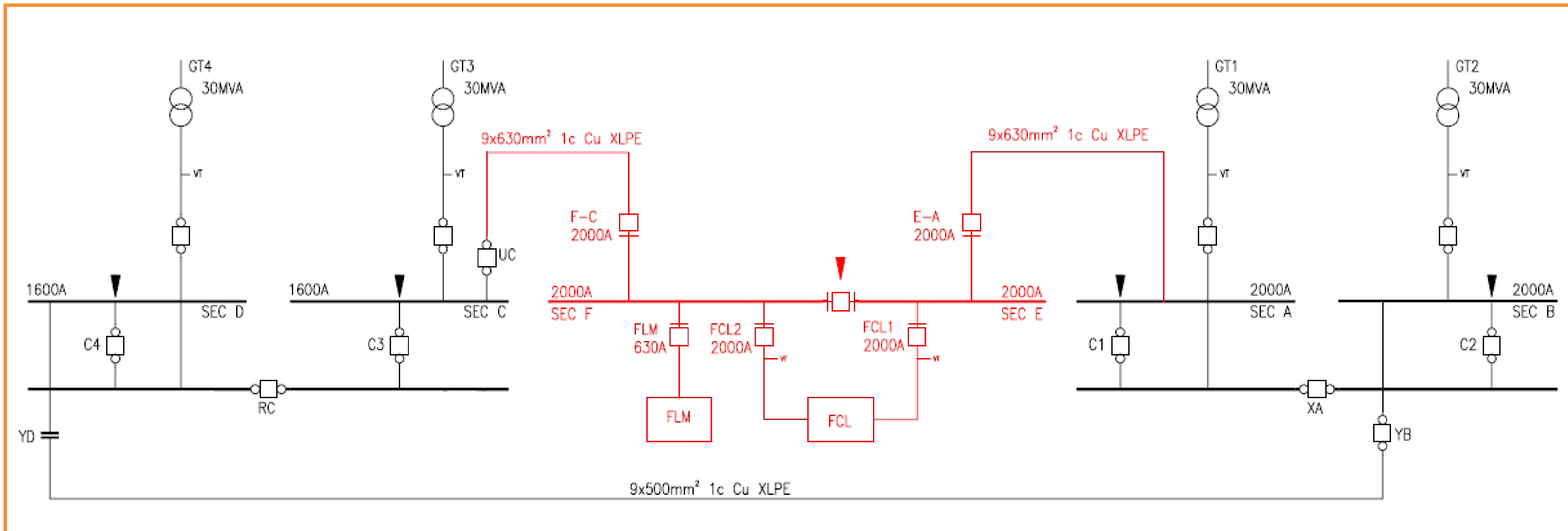


Chester Street FCL Installation



Bournville FCL Installation

- Four Grid Transformers run in split configuration
- 1960's 11kV switchgear interconnected using cables
- RSFCL connected across an 11kV interconnector



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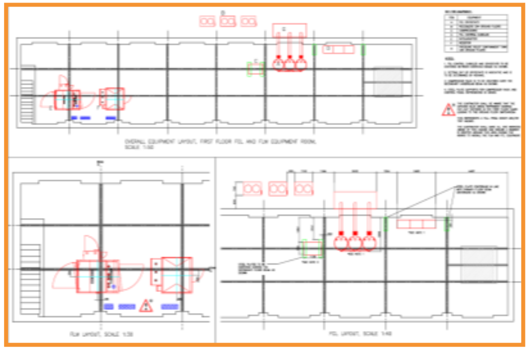
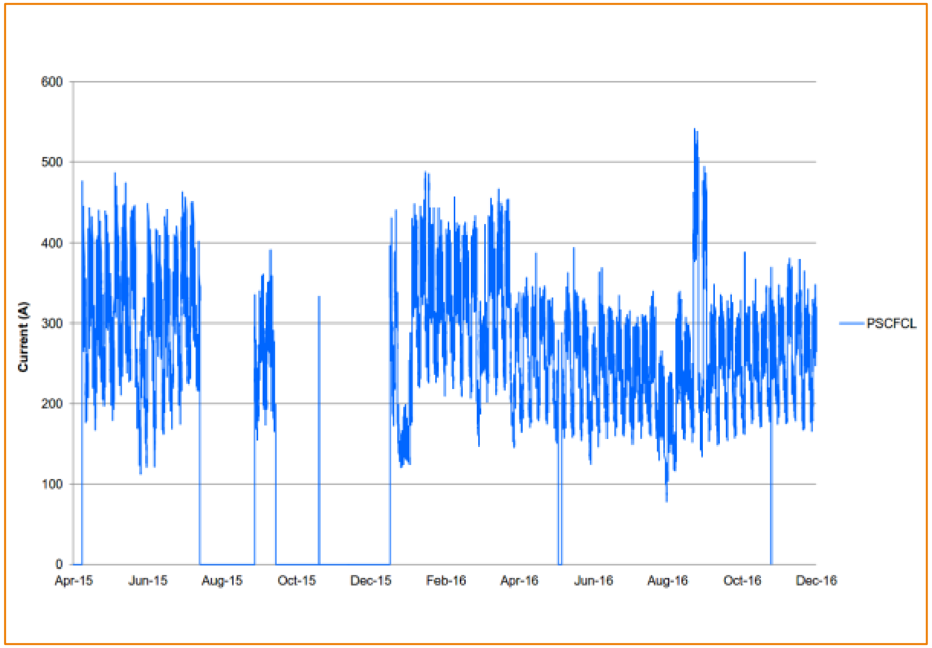
Bournville FCL Installation



Operation of FCLs

- FCLs have been successfully connected to the system
- Unfortunately no faults have occurred to verify site performance!
- As with most new technologies some issues have arisen during operation



Operation of FCLs

GridON

- Problems with DC sensing circuit. Circuit re-designed and trouble free since December 2015

Nexans

- Problems with cooling plant failures. Manufacturer has repaired. Investigating alternative cooling solution

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

<u>These issues were rectified before final testing so that the performance onsite was not affected</u>

Learning – Nexans

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

Learning – Nexans

Cooling System

Issues

- Damaged pipework during commissioning
- Water level dropping below the trip level
- Air intake becoming clogged with debris leading to inadequate air flow
- Minor helium leak due to loose connections
- Water leak at the connection
- Power supply failures

A simpler approach to the cooling system, with less moving parts, could improve reliability

Learning – Nexans

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

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**

Thank you for listening

Any questions?

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Closedown Dissemination Event
12th July 2017

Benefits – Connections and Security

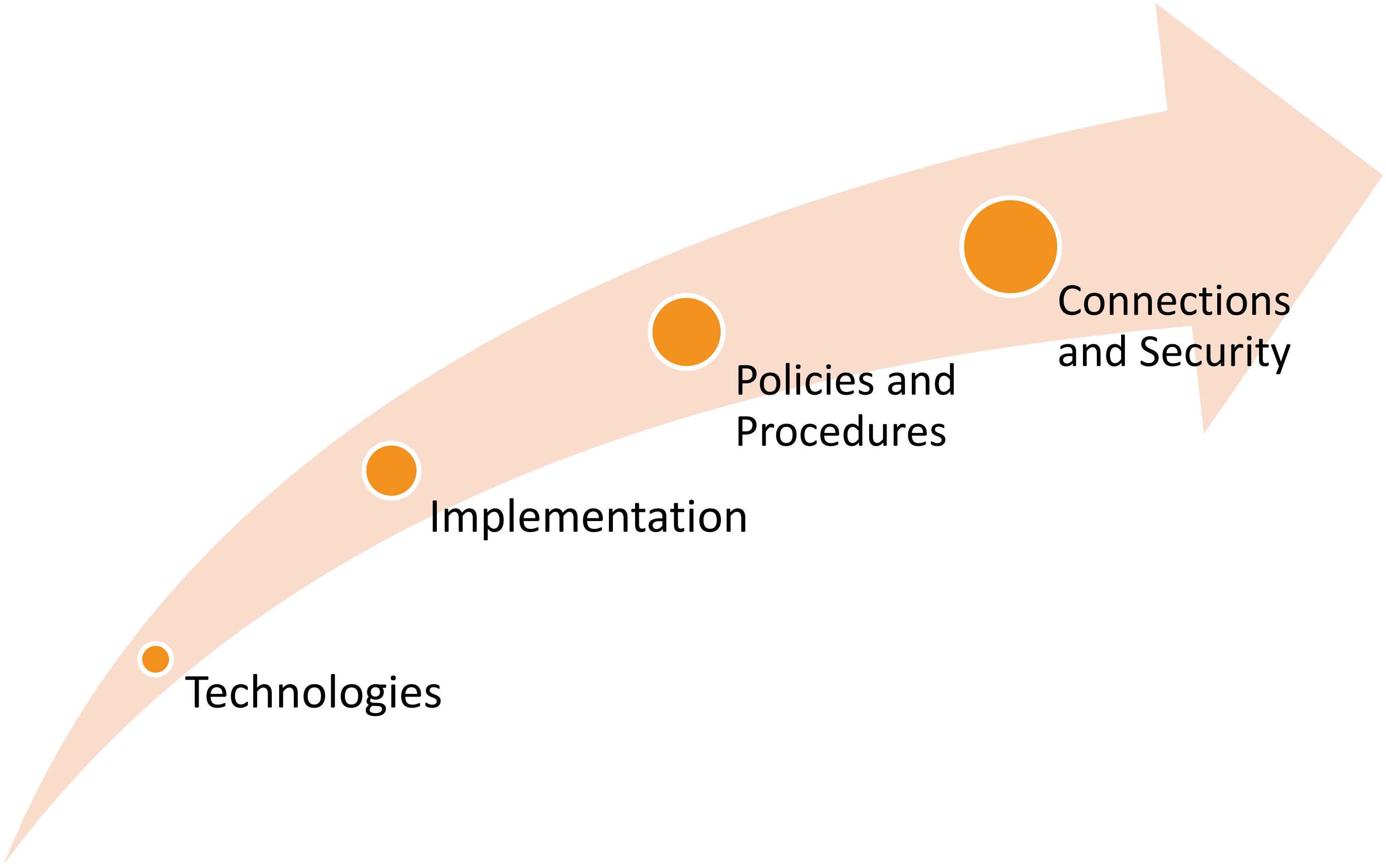
Jonathan Berry

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Benefits


Technologies
Implementation
Policies and Procedures
Connections and Security

Benefits

Enhanced Modelling:

- Further increases in modelling accuracy and consistency
    - Value to both new and existing connections
    - More accurate representation of network in all conditions
    - Consistency in system operating times
    - Increased utilisation of network assets

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Company Directive

STANDARD TECHNIQUE: SD7F/2

Determination of Short Circuit Duty for Switchgear on the WPD Distribution System

Policy Summary
This document provides guidance on calculation of fault levels so as to determine the short-circuit duty for switchgear installed on the WPD distribution networks.

Author: Jonathan Berry / Peter Aston

Implementation Date: May 2017

Approved by: Policy Manager

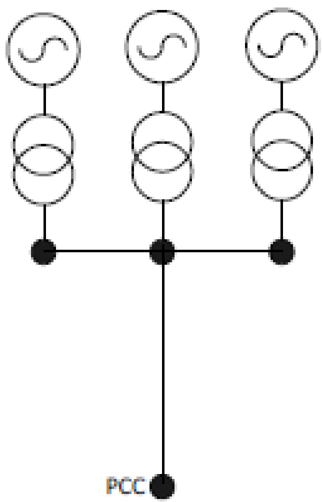
Date: 12 May 2017

NOTE: The current version of this document is stored in the WPD Corporate Information Database. Any other copy in electronic or printed format may be out of date.

ST:SD7F/2 May 2017 - 1 of 14 -

Benefits

Figure 1 - Generator and Transformer Arrangement



Once calculations indicate switchgear is above 95% of its rating it should be considered overstressed, unless detailed studies can show otherwise to a value no greater than 98% at the discretion of the Primary System Design Team Manager.

The errors inherent in any methodology and software program used, together with variance in data accuracy and assumptions, should be taken into account when undertaking any specific detailed studies where initial analysis indicates switchgear above 95% of its rating.

Table 1 – Typical parameters of the generators

Synchronous generators (11kV)					
	2 – 5MVA		5 – 20 MVA	20 – 60 MVA	
Armature Resistance [p.u]	0.0068		0.0075	0.0075	
Synchronous reactance [p.u]	1.8		2.0	2.0	
Transient reactance [p.u]	0.19		0.19	0.19	
Sub-transient reactance [p.u]	0.13		0.13	0.13	
Open circuit transient time	3		6	10	
Open circuit sub-transient time	0.04		0.06	0.07	
Synchronous generators (0.415kV)					
	100 kVA	500 kVA	1 MVA	1.5 MVA	2 MVA
Armature Resistance [p.u]	0.0077	0.0095	0.0095	0.0093	0.0074
Synchronous reactance [p.u]	2.05	2.53	2.54	2.49	1.96
Transient reactance [p.u]	0.17	0.13	0.20	0.21	0.16
Sub-transient reactance [p.u]	0.12	0.09	0.14	0.15	0.12
Open circuit transient time	0.34	1.56	2.35	3.56	4.04
Open circuit sub-transient time	0.014	0.017	0.036	0.042	0.04
Converter connected generators					
	Make Time Fault infeed [p.u]			Break Time Fault infeed [p.u]	
Battery Storage	3.0			1.2	
PV System	3.0			1.2	
Micro CHP	3.0			1.2	
Wind Turbine / DFIGs	4.0			2.0	

Table 3- Breaking time at different voltage levels

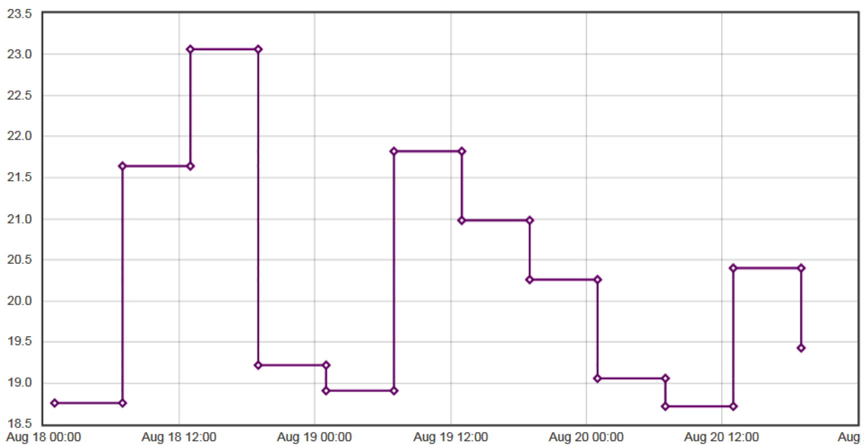
Voltage Level (kV)	Breaking time (ms)
11kV	70
33kV	70
66kV	50
132kV	50

Benefits

Real-time Fault Level Data:

- Make and Break data to validate and update network models
- Update how different loads are characterised on the system
- Increased data to inform potential network operability functionality
- Active control of customers

Benefits



CIRED 24th International Conference on Electricity Distribution Glasgow, 12-15 June 2017

Paper 0976

CHARACTERISATION OF 11KV FAULT LEVEL CONTRIBUTIONS BASED ON SUBSTATION LOAD PROFILE

Paul EDWARDS
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Jonathan BERRY
Western Power Distribution - UK
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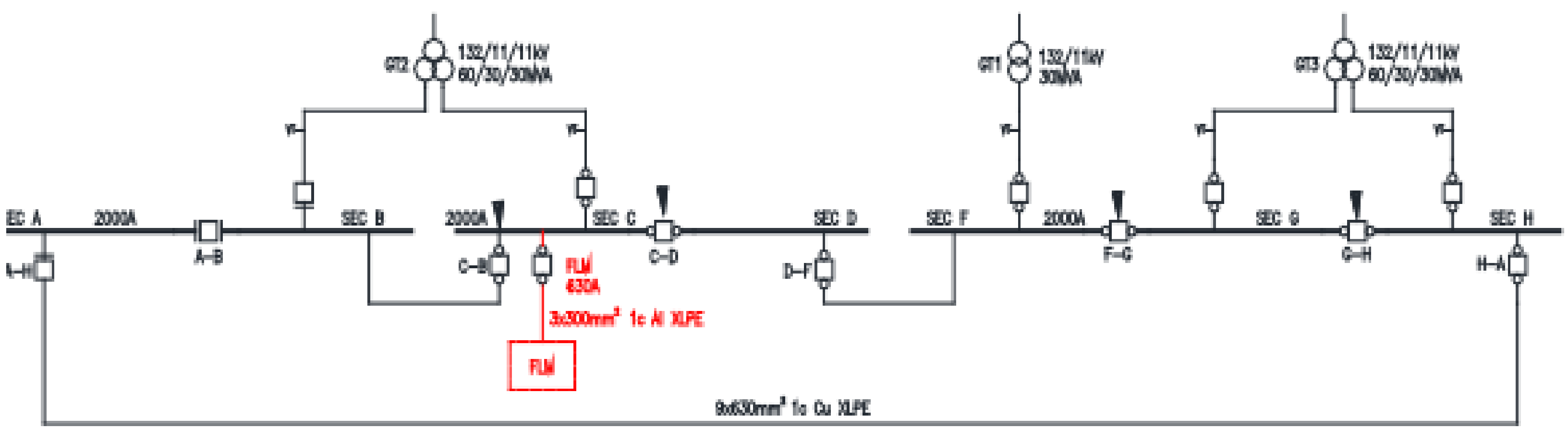
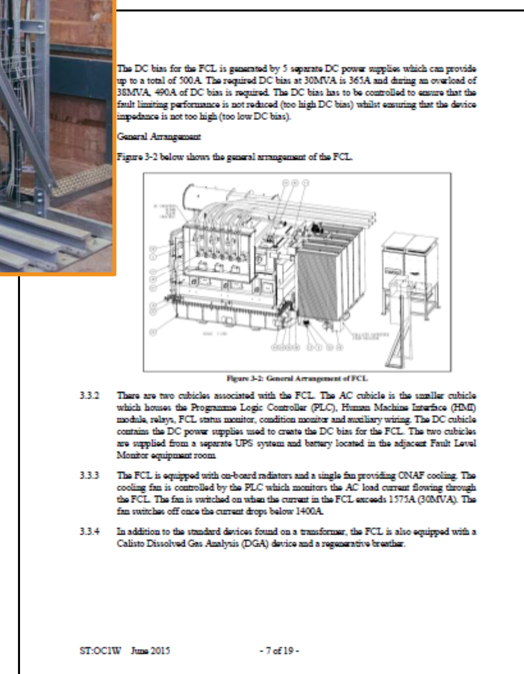
Load	G74 MVA per MVA Infeed
Majority Domestic	1.0
Split Domestic/Industrial	3.0
Majority Commercial	3.0
Majority Industrial	5.0



Benefits

Fault Current Limiters:

- Considerable fault level headroom created
- Parallel network operation enabled
- Policies and Procedures created for technologies for future use



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).

General Arrangement

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 smaller cubicle which houses the Programme Logic Controller (PLC), Human Machine Interface (HMI) module, relays, FCL status monitor, condition monitor and auxiliary wiring. The DC cubicle contains the DC power supplies used to create the DC bias for the FCL. The two cubicles are supplied from a separate UPS system and battery located in the adjacent Fault Level Monitor equipment room.

3.3.3 The FCL is equipped with on-board radiators and a single fan providing ONAF cooling. The cooling fan is controlled by the PLC which monitors the AC load current flowing through the FCL. The fan is switched on when the current in the FCL exceeds 1575A (30MVA). The 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 equipped with a Calisto Dissolved Gas Analysis (DGA) device and a regenerative breather.

ST:OC1W June 2015 - 7 of 19 -

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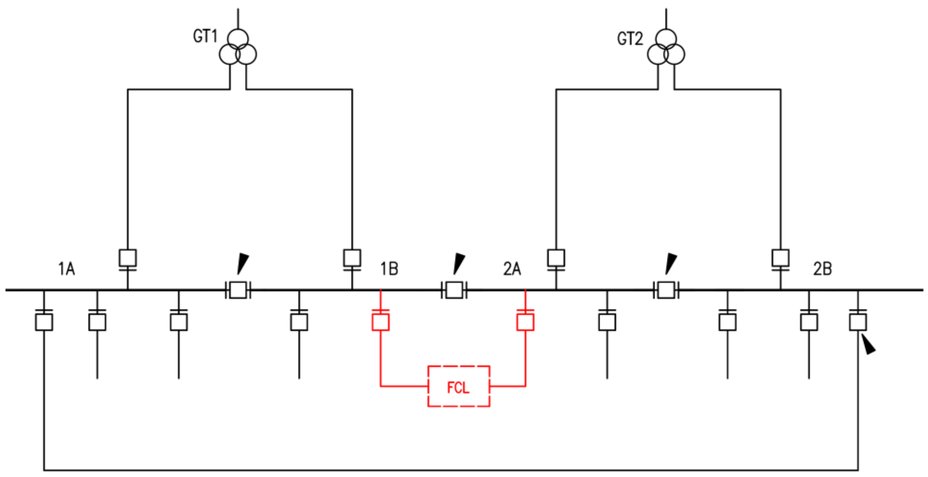
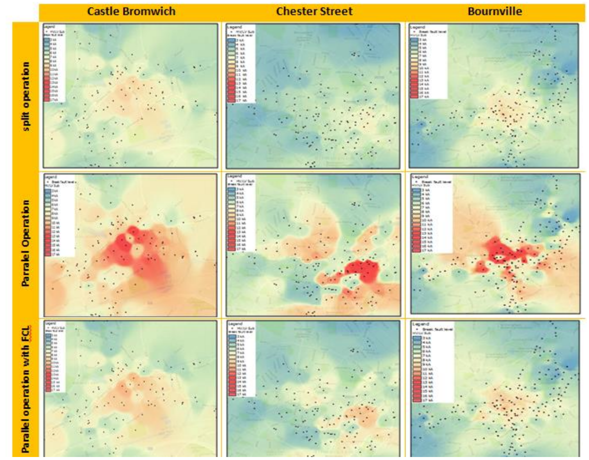
Benefits





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

Thank you for listening

Any questions?

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Closedown Dissemination Event
12th July 2017

Fault Level Monitors

Enhancing Alternative Connections

James Bennett

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

Presentation Overview

- Alternative Connections Background
- Comparison with Existing Offerings & Key Decision Points
- Soft-Intertrip ANM 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

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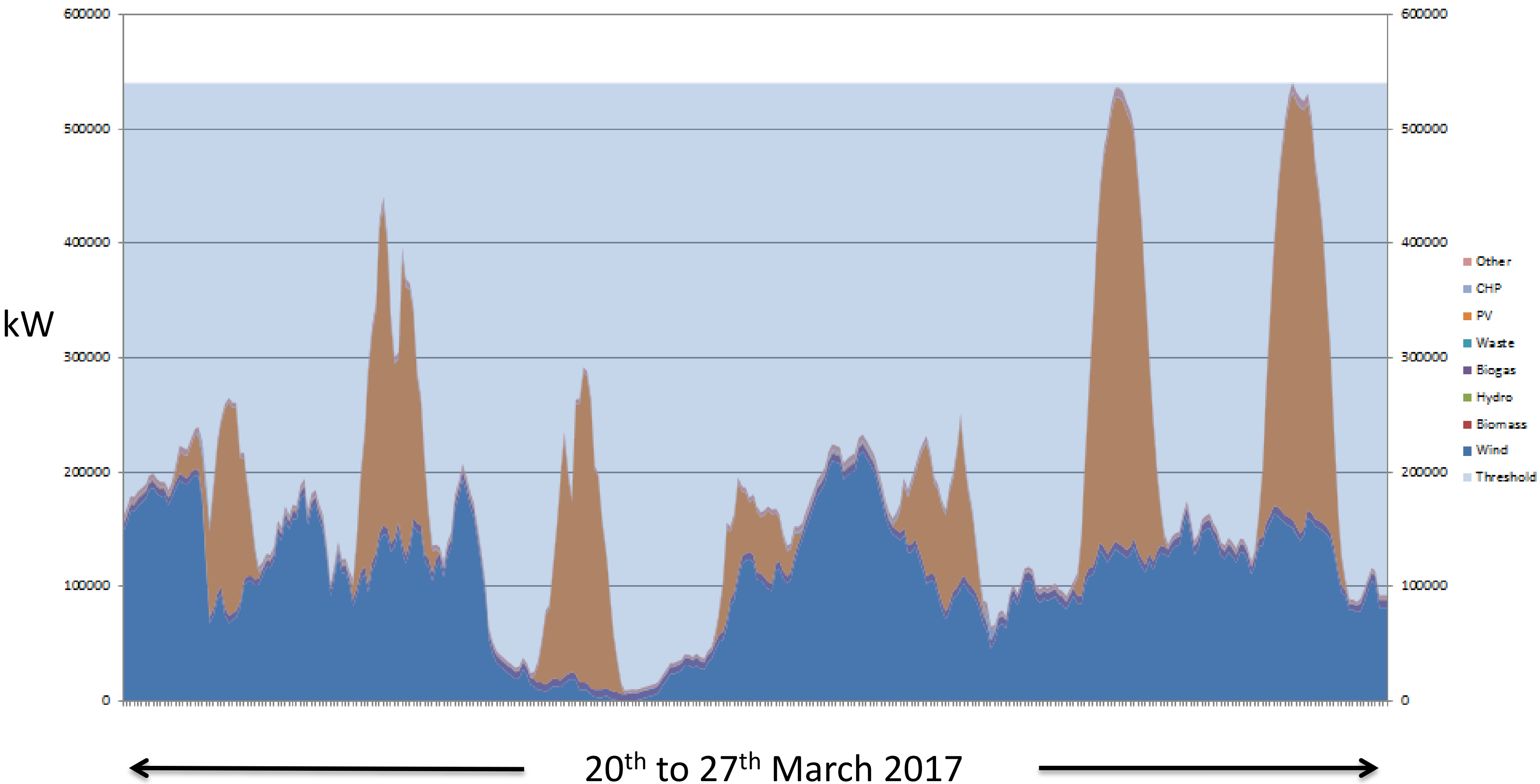
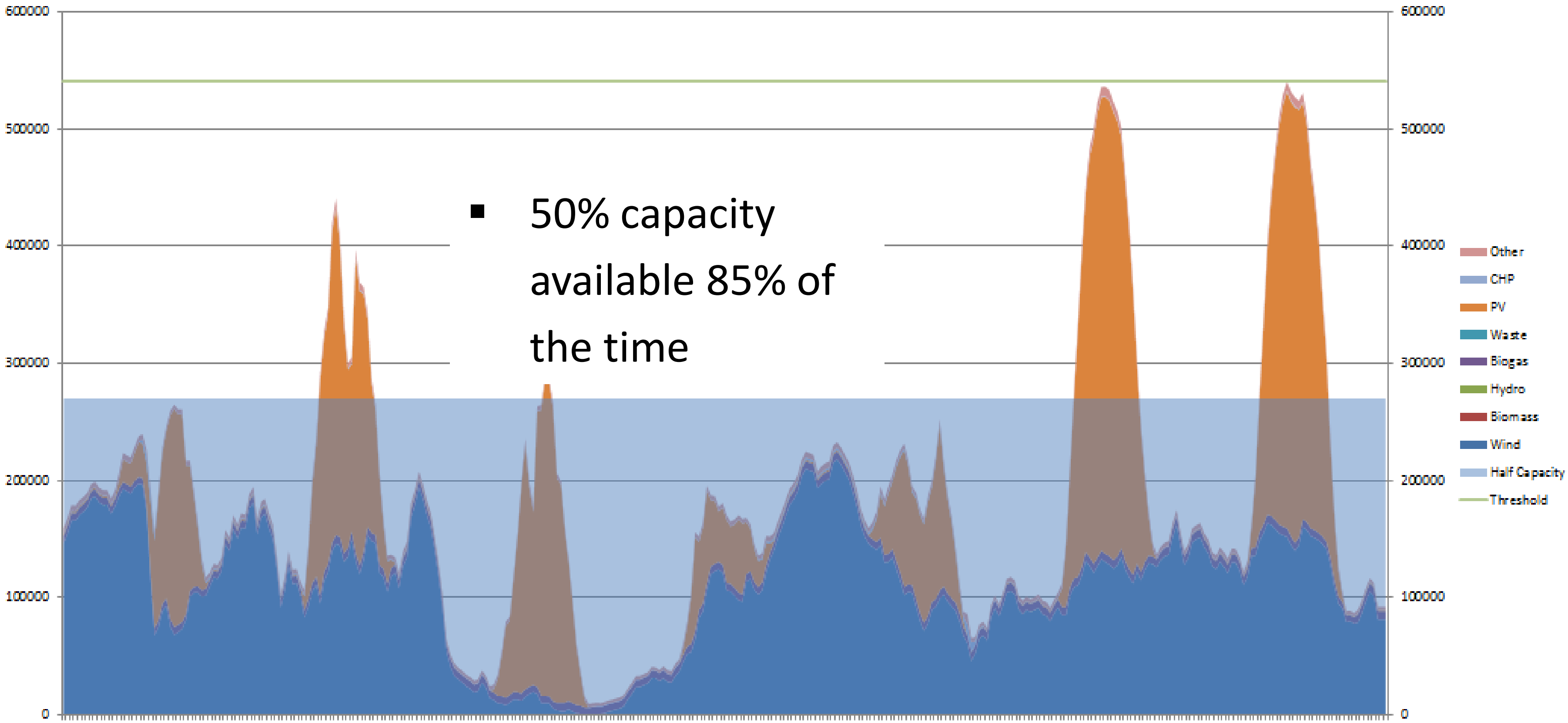
Alternative Connections



Alternative Connections

- 50% capacity available 85% of the time

kW



20th to 27th March 2017

Alternative Connections – Export Limiting

- Measures Apparent Power at Exit Point
- 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)

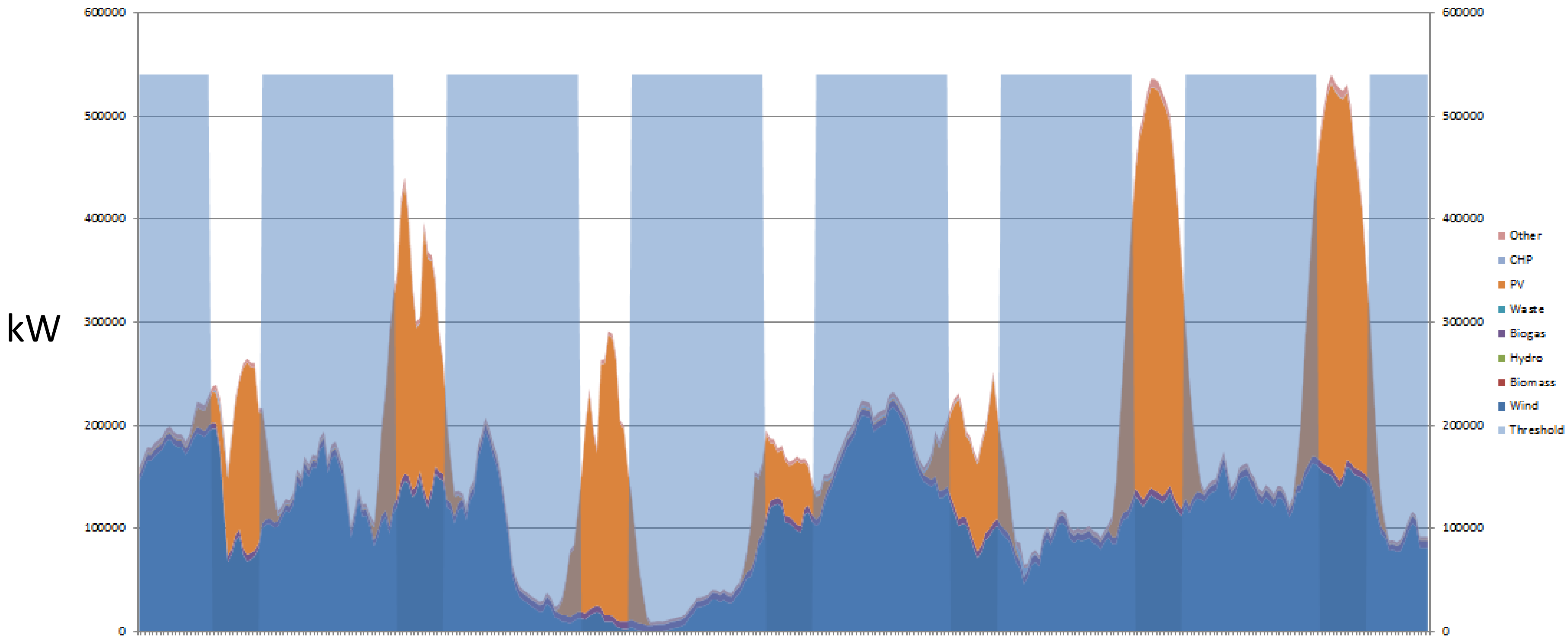
Alternative Connections - Timed

- 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



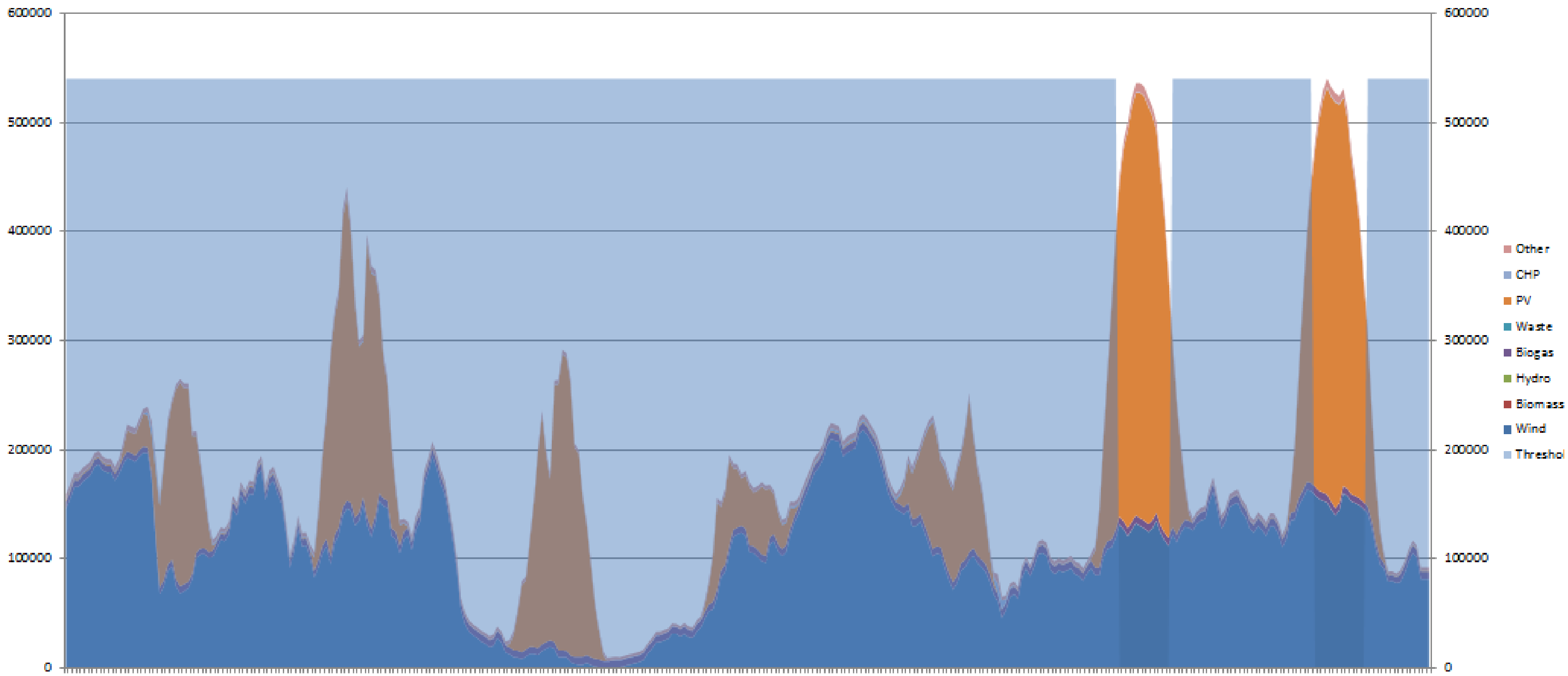
20th to 27th March 2017

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

kW



20th to 27th March 2017

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

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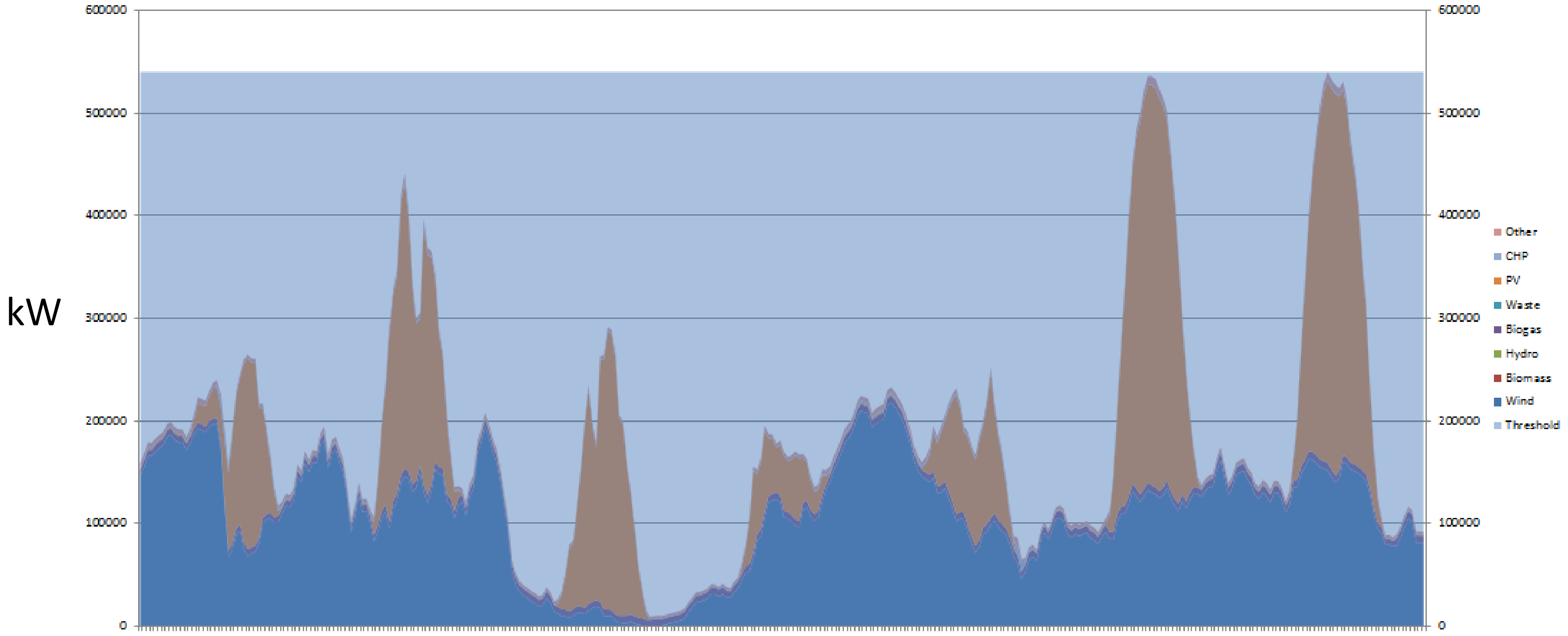
Alternative Connections – ANM



20th to 27th March 2017

Alternative Connections – FlexDGrid Fault Level

Aims

- Use the Fault Level Monitoring data to provide ‘Quicker & Cheaper’ connections for customers currently restricted by Fault Level constraints
- 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

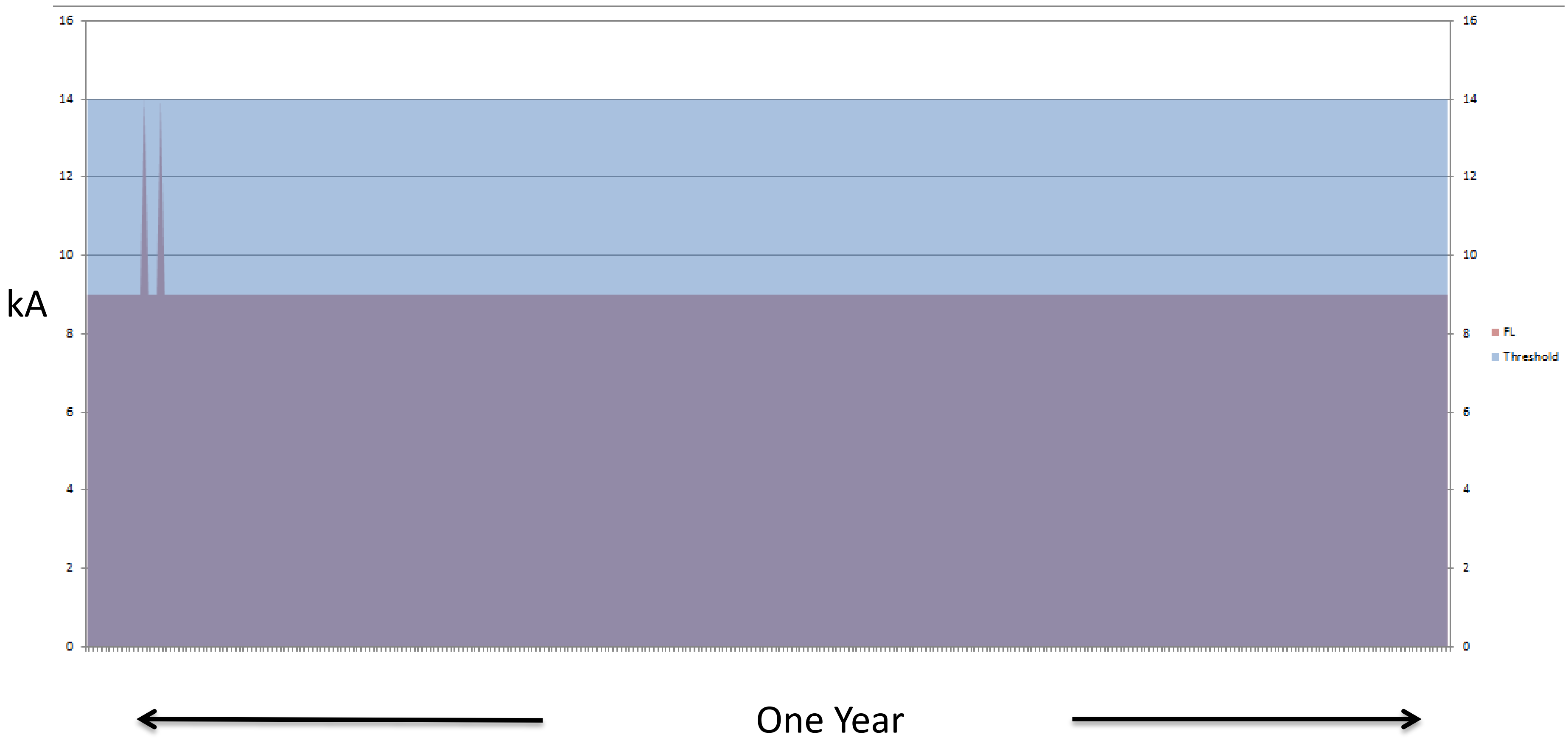
Limitations

- Constraints not seasonal or have any patterns
- Export can not be limited – Must be totally disconnected
- Measurements not 'Real-Time' in the true sense
- No fall back protection operation

Strengths

- Periods of potential curtailment known in advance

Alternative Connections – Comparisons



Fault Level – Potential Solution

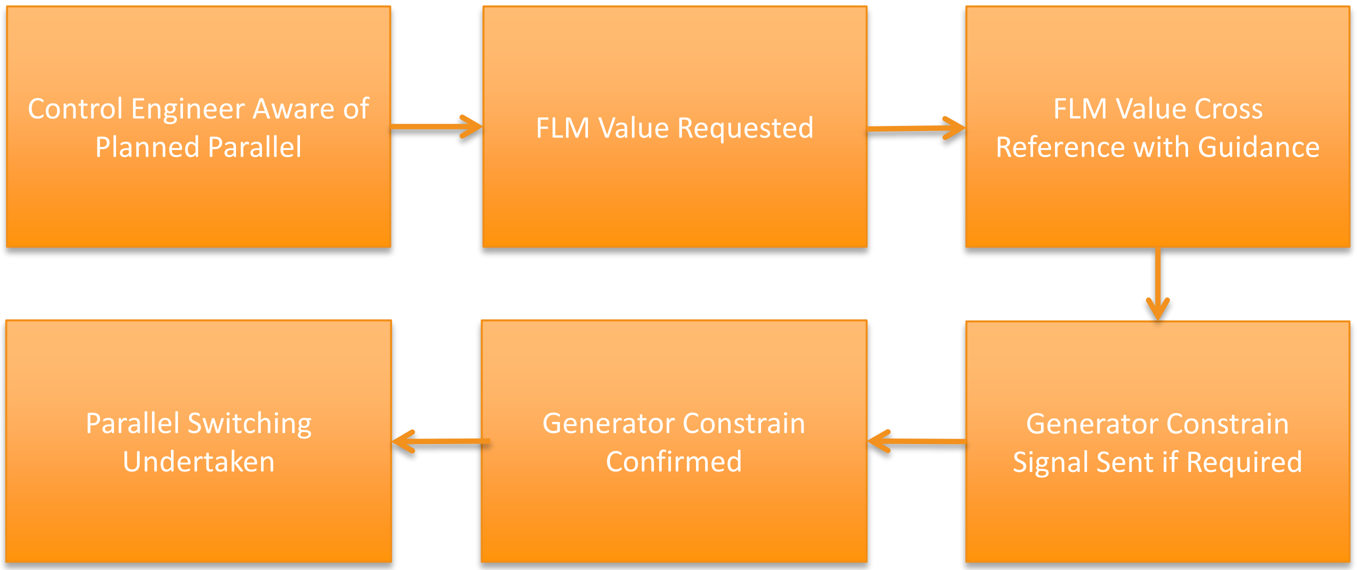
ANM

- Ideal scenario
- Lack of true '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 principals will need integrating in to ANM to cater for the possibility of both Fault Level and thermal constraints

Fault Level – Proposed Solution

Soft-Intertrip

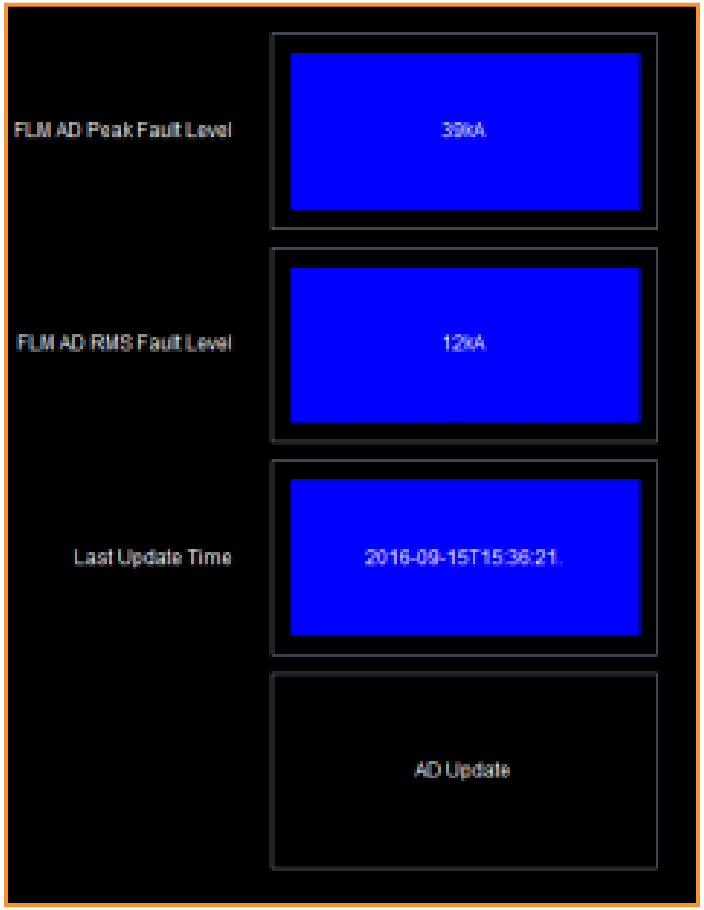
- Simpler & Cheaper installation
- Existing Soft-Intertrip coding can be altered internally to include an operator in the loop for the final decision



Fault Level Soft-Intertrip - Development

Power-on Integration

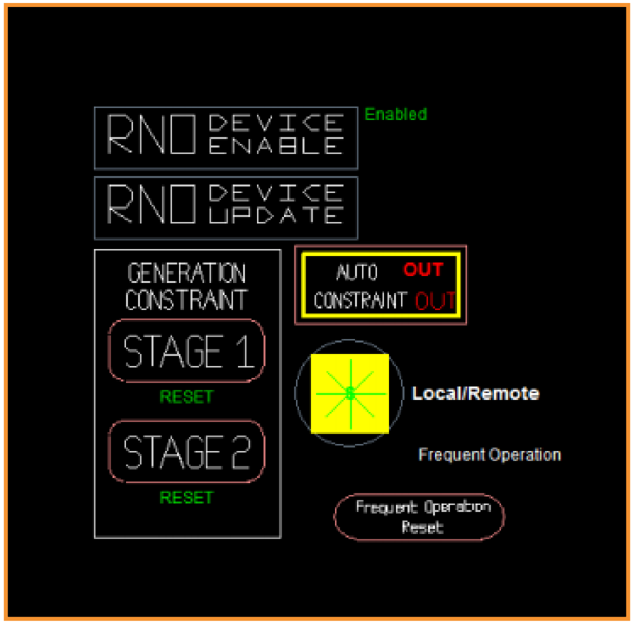
- Routed FLM data in to the WPD corporate network
- Created FLM PoF interface
- Developed ‘On-Demand’ Intellirupter control



Fault Level Soft-Intertrip – Trial Customer

Generator End RTU

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



Fault Level Soft-Intertrip – Trial Customer

Trial Customer

- Nechells West
- Existing on – site Fault Current Limiter at the end of its useful working life. Two large CHP & 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

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

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 & Three Years

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

Fault Level Soft-Intertrip – Final Key Points

- Two flavours 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.

Thank you for listening

Any questions?

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HEAT AND POWER FOR BIRMINGHAM

Closedown Dissemination Event
12th July 2017

Next Steps and Close

Roger Hey

Future Networks Manager

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

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Project Outputs

Learning from EFLA:

- Informed revised methodologies for increased FL modelling accuracy
- Updated WPD Modelling Policy for Fault Level at 11kV to 132kV
- Recommendations for future modelling and system operation practices

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Company Directive

STANDARD TECHNIQUE: SD7F/2

Determination of Short Circuit Duty for Switchgear on the WPD Distribution System

Policy Summary
This document provides guidance on calculation of fault levels so as to determine the short-circuit duty for switchgear installed on the WPD distribution networks.

Author: Jonathan Berry / Peter Aston

Implementation Date: May 2017

Approved by:

Policy Manager

Date: 12 May 2017

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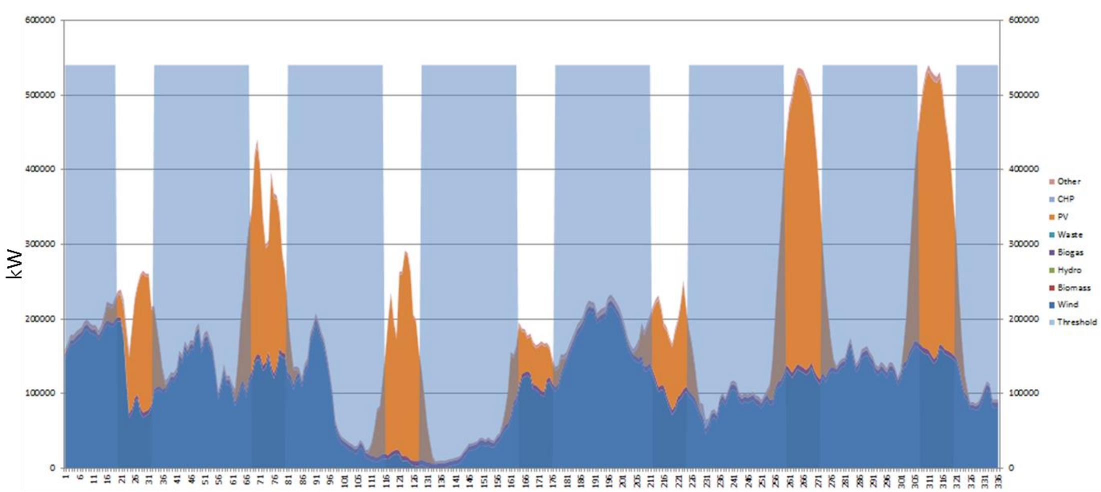
ST:SD7F/2 May 2017 - 1 of 14 -

Project Outputs

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



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

Learning from Management:

- Developed real-time fault level values for the first time
- Created a proposed template of revised general load infeed values to inform the industry
- Added to our existing suite of alternative connections to include Fault Level soft-intertrip schemes, where available

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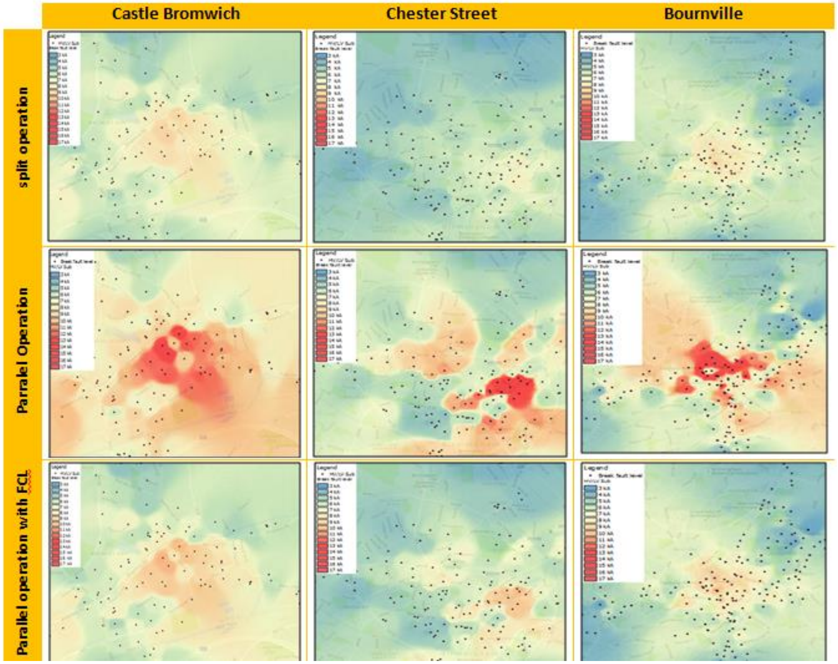
Project Outputs

Learning from Mitigation:

- Experience of three FCL installations
- Created over 50MVA of DG connection availability in Birmingham
- Significantly increased the security of supply to all customers through network paralleling



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

Next Steps

- Policies have been created for all technologies enabling a fast transition to suitable technologies being transferred to Business as Usual
- Studies are being carried out on new connection schemes to assess FCLs against traditional solutions
- Further research and development of FLMs and FCLs to facilitate refined solutions
- Wider study of revised general load infeeds to look at informing ENA standards (G74)

THANKS FOR LISTENING

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