Paper 0200 - Sensitivity analysis of fault level assessments in HV networks

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Introduction

Growing connections of low-carbon generation to urban distribution networks can increase the fault level of the network, requiring upgrades to electricity network assets. Birmingham Central Business District, in the UK, has been identified as an area where a high level of integration of combined heat and power plants is expected in 11kV networks by 2026. As a result of the anticipated level of CHP integration, the fault levels in HV networks could exceed the short circuit ratings of the switchgear. Smart solutions are being demonstrated, as an alternative to traditional network upgrade solutions, in a £17.1m Low Carbon Networks Fund project in the UK, FlexDGrid.

What is FlexDGrid?

Enhanced Assessment
- **Enhanced network models**
- **Detailed understanding of network fault level**

Management
- **Monitoring fault level (Steady-state)**
- **Measuring fault level (Faulted-state)**
- **Verifying/Updating network models**

Mitigation
- **Reduction of system fault level**
- **Utilised from output of Management**

Fault level sensitivity analysis aims and objectives

- Recommend network modeling approaches to enhance the accuracy of calculated fault level;
- Determine the effect of assumptions in engineering recommendations e.g. ER G74 recommendation for general load fault infeed;
- Propose commercial frameworks for embedded generators operating under an active fault level management scheme;
- Improve the accuracy of desktop analysis for validation of monitored fault level values.

Results

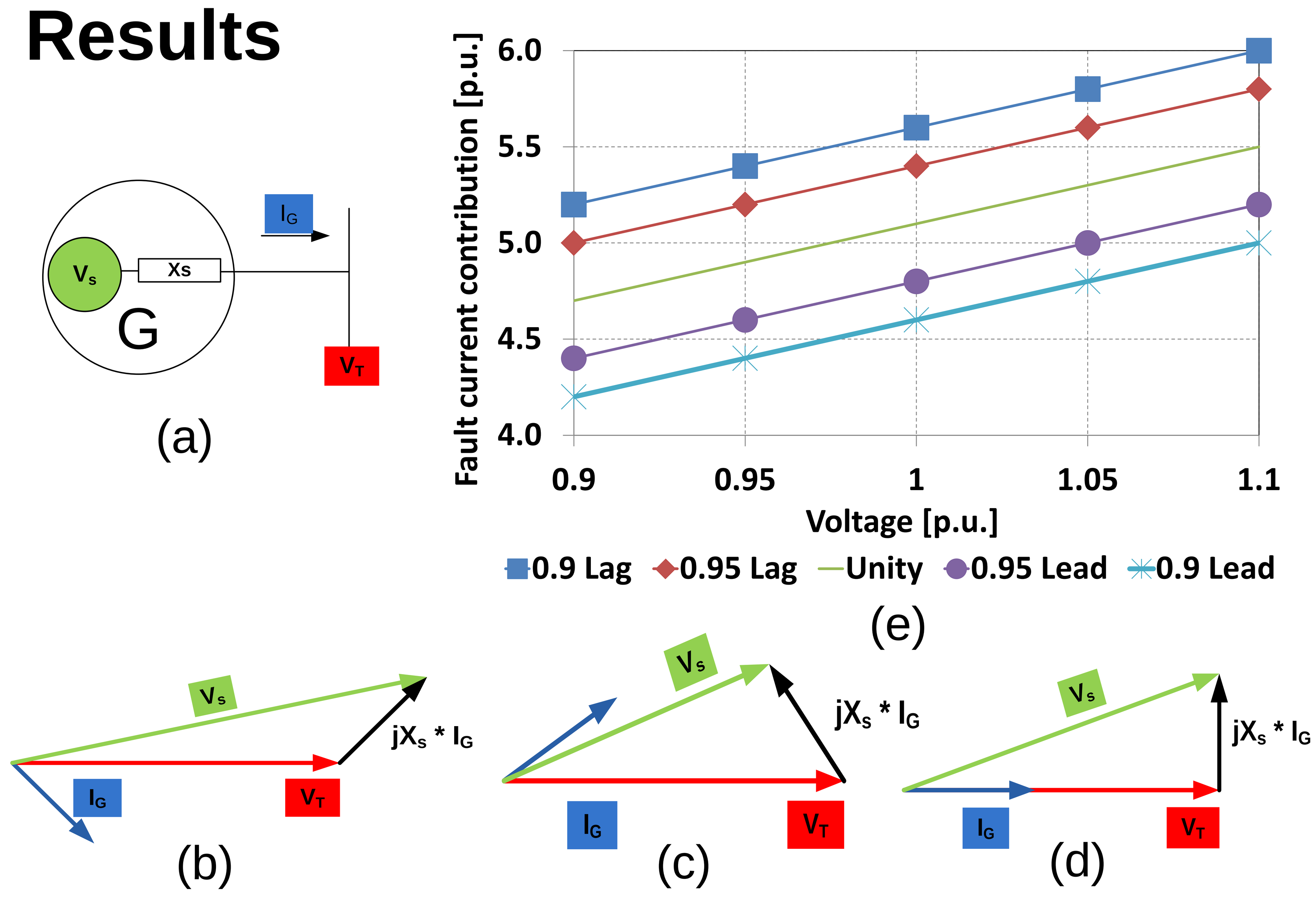


Figure 1: (a) Generator Thevenin model (b) Operation in Lagging power factor (c) Leading power factor (d) Unity power factor (e) Breaking fault current contribution

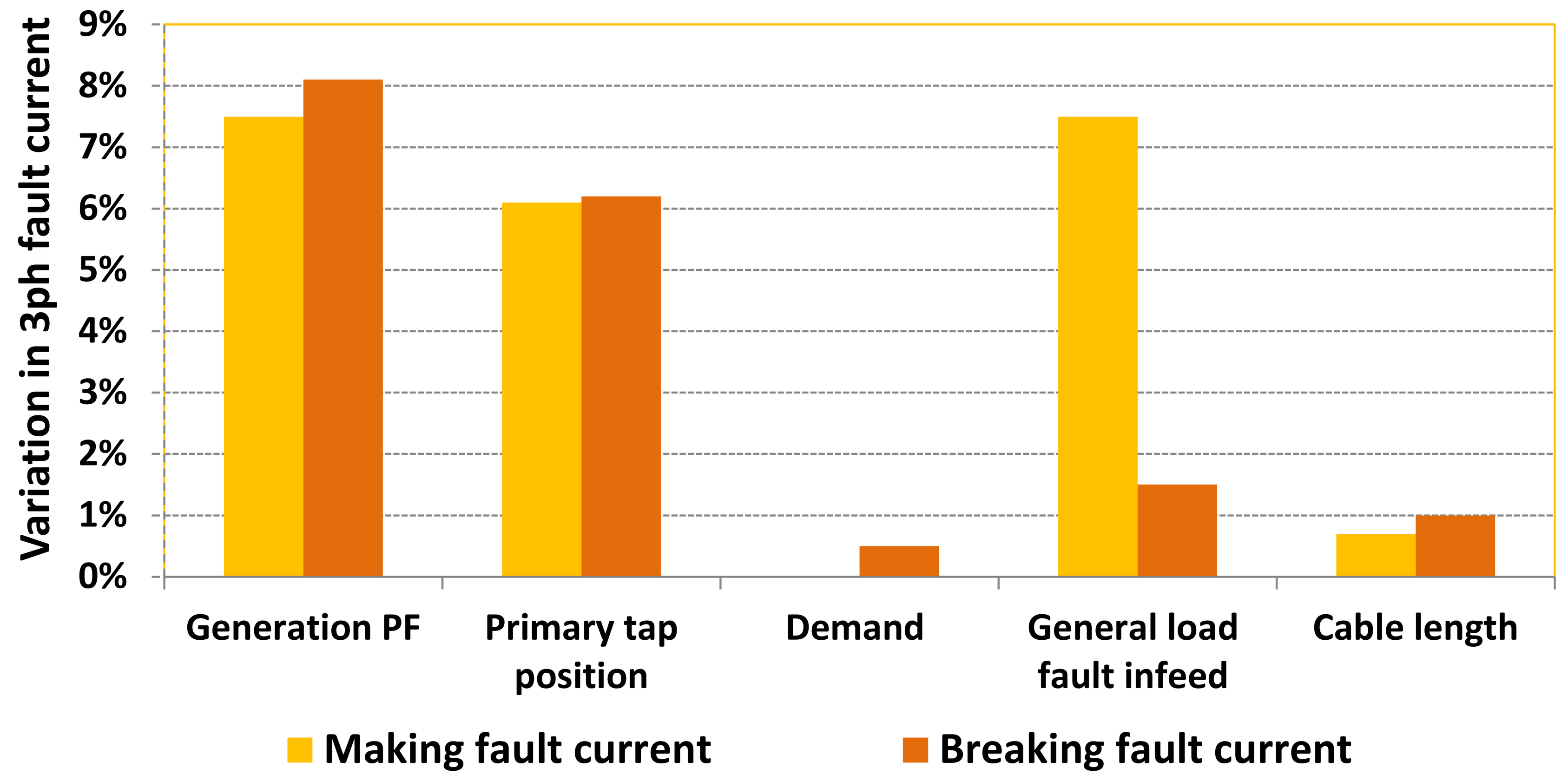


Figure 2: Summary of fault level sensitivity analysis results

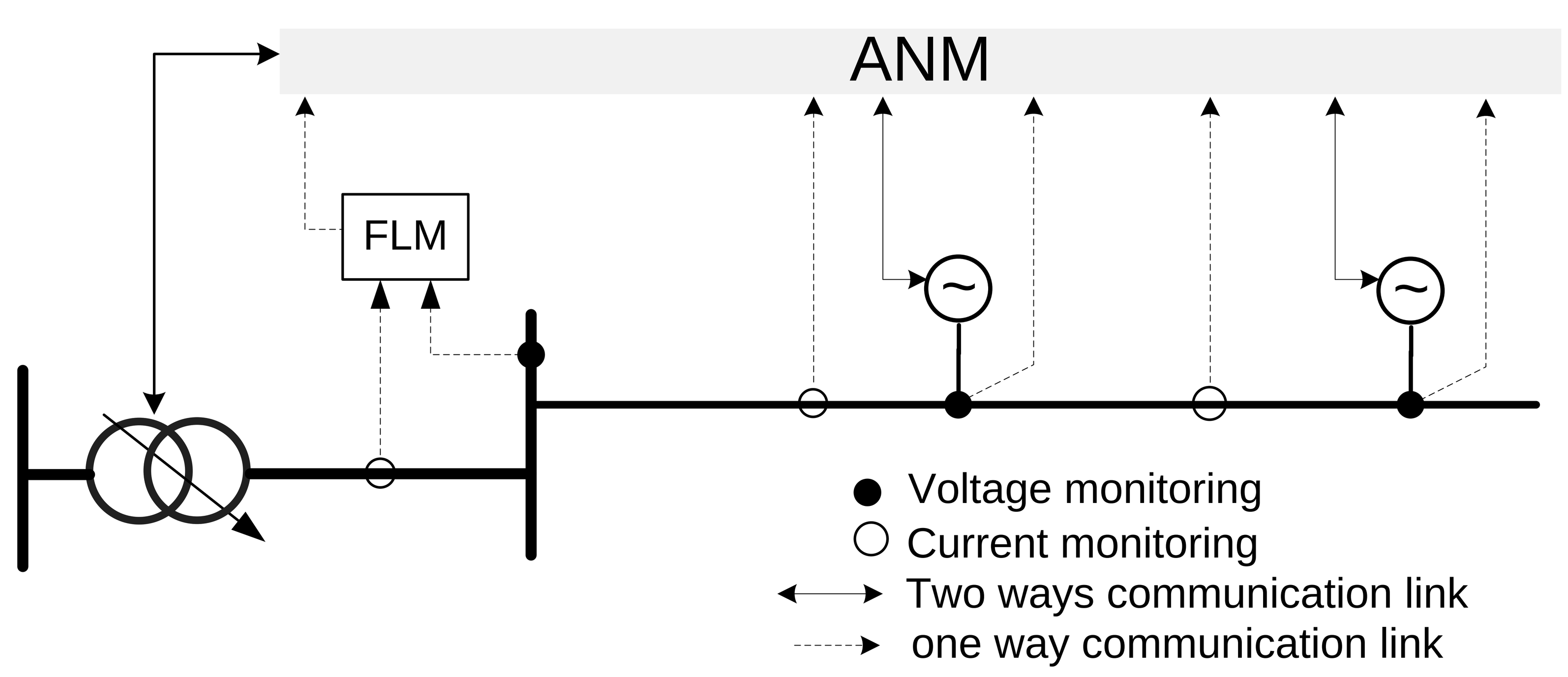


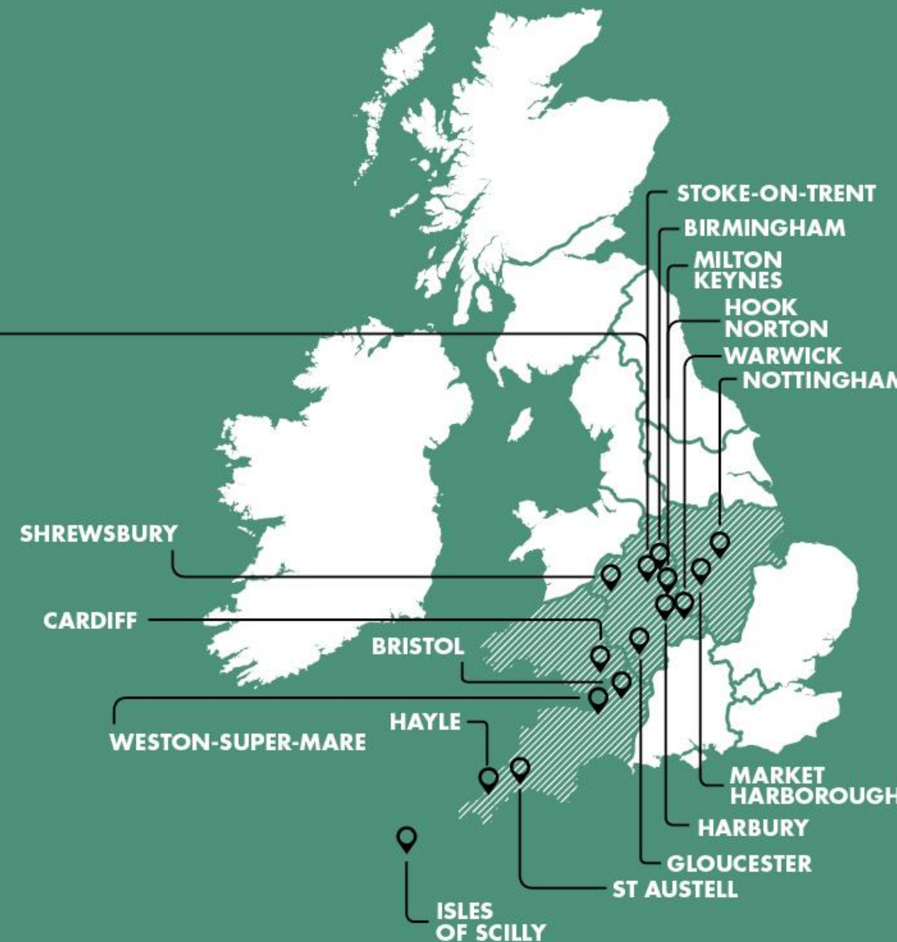
Figure 3: Active fault level management system

Project partners

Western Power Distribution — Serving the Midlands, South West and Wales
Parsons Brinckerhoff
The University of Warwick

WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS



Fault Current Limiters
ENA SHE Conference

Integration of 3 FCL Technologies

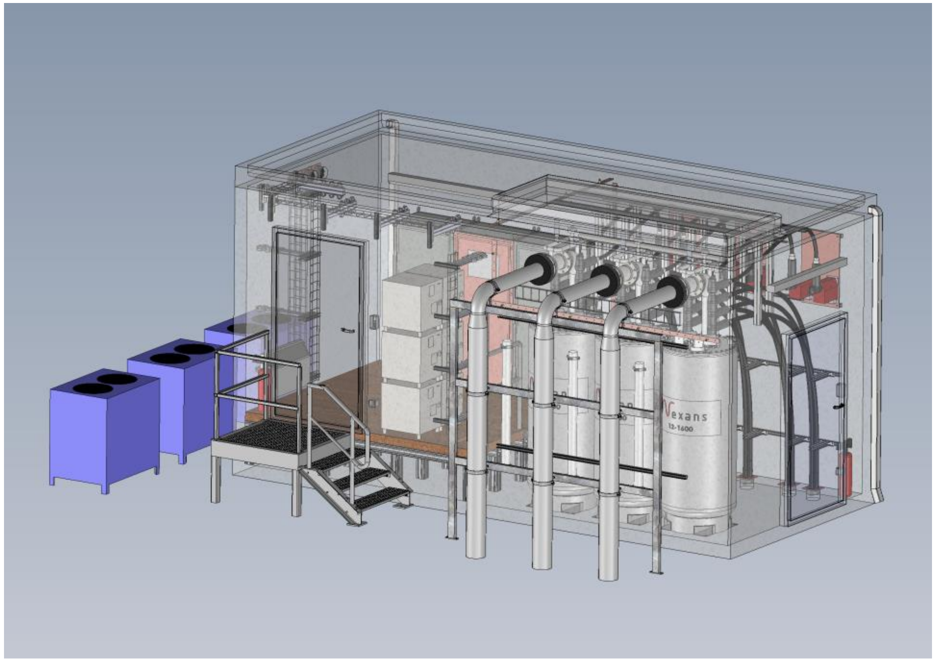
- Pre-Saturated Core
- Resistive Superconducting
- Active Fault De-Coupler (Power Electronics)

The technologies' primary purpose is to limit the flow of short circuit current, during a fault, to ensure that all existing equipment on the network is not exposed to currents greater than their withstand capacity

Pre-Saturated Core FCL

- Key technology differences to existing technology on the network:
    - Has DC and AC connections; and
    - Strong Magnetic Field.

Resistive Superconducting FCL



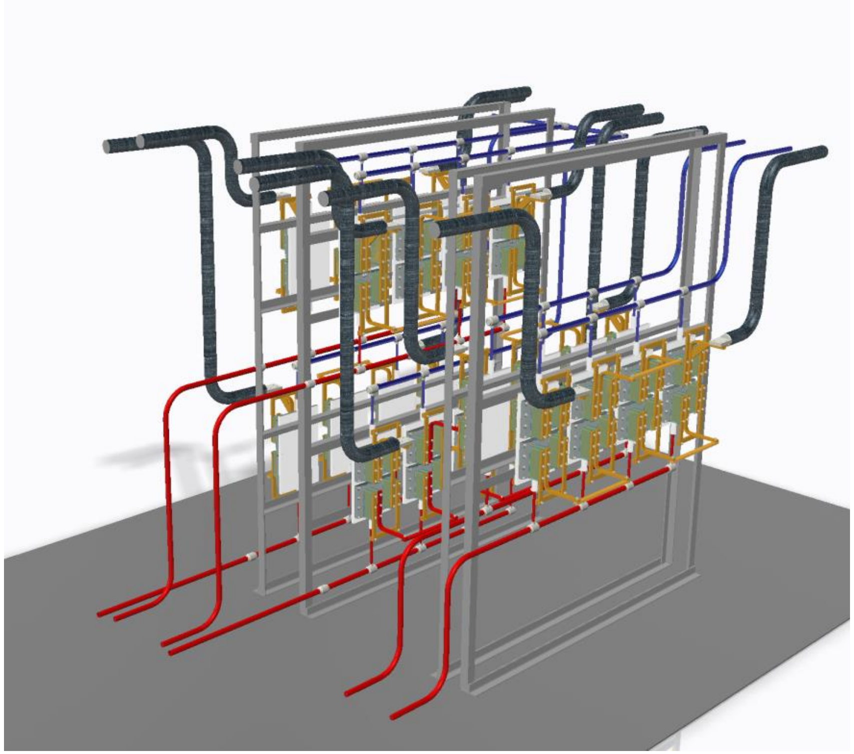
Key technology differences to existing technology on the network:

- Device operates at 77k (-196.15C)
- Uses a cryogenic cooling system

Active Fault De-Coupler FCL

Key technology differences to existing technology on the network:

- Power Electronics being used in series
- Water cooling system

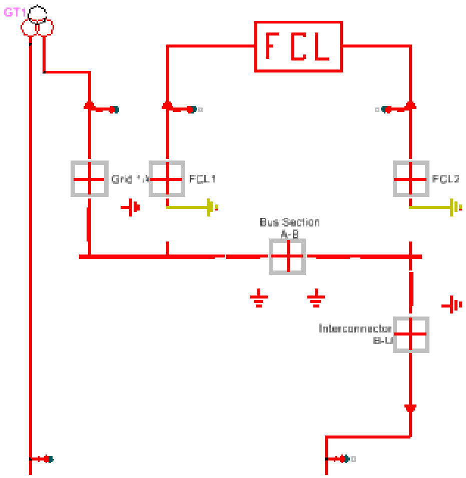


Control Measures for the FCLS

As each device is a new installation on to WPD's network additional control measures have been implemented:

- Each FCL can be bypassed on the network
- As a minimum an alarm / signal is provided to the Network Management System to determine if the device is safe to connect to the network – based on the device's state and condition
- Protection is in place to identify any internal faults with the devices and disconnect it from the system in that instance

Policies and Training



Policies produced to date:

- Application and Connection of FCLs
- Engineering Specification of FCLs
- Operation and Control
- Inspection and Maintenance

Training:

- A minimum of two operational staff witness the cold commissioning of each device and carry out the energisation

THE 23rd INTERNATIONAL CONFERENCE AND EXHIBITION ON **ELECTRICITY DISTRIBUTION**

Paper 1129 - Standardised Connections and the Economic Benefits of Fault Current Limiters on Distribution Networks

Jonathan Berry
Western Power Distribution, UK

Neil Murdoch
Parsons Brinckerhoff, UK

Introduction

In order to meet UK and global targets for carbon emission reductions associated with energy production, the installation and connection of distributed generation (DG) onto distribution networks has significantly increased. This DG generally contributes to the system fault level, where it can be so high that it is above the rating of switchgear and cables. Existing solutions to this problem, such as splitting the network, adding impedance into the network, or replacing the existing equipment with a higher rated equivalent can be expensive and complicated to implement. A new developing alternative to overcome excessive fault level is to install an FCL. These technologies are being demonstrated as part of a £17.1m Low Carbon Networks Fund Tier-2 Project, FlexDGrid.

What is FlexDGrid?

Enhanced Assessment
- **Enhanced network models**
- **Detailed understanding of network fault level**

Management
- **Monitoring fault level (Steady-state)**
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Mitigation
- **Reduction of system fault level**
- **Utilised from output of Management**

FlexDGrid FCL Technologies

- Pre-Saturated Core
- Resistive Superconducting
- Power Electronic

Average cost of purchasing and integrating an FCL in to the network is £1.41m.

Results

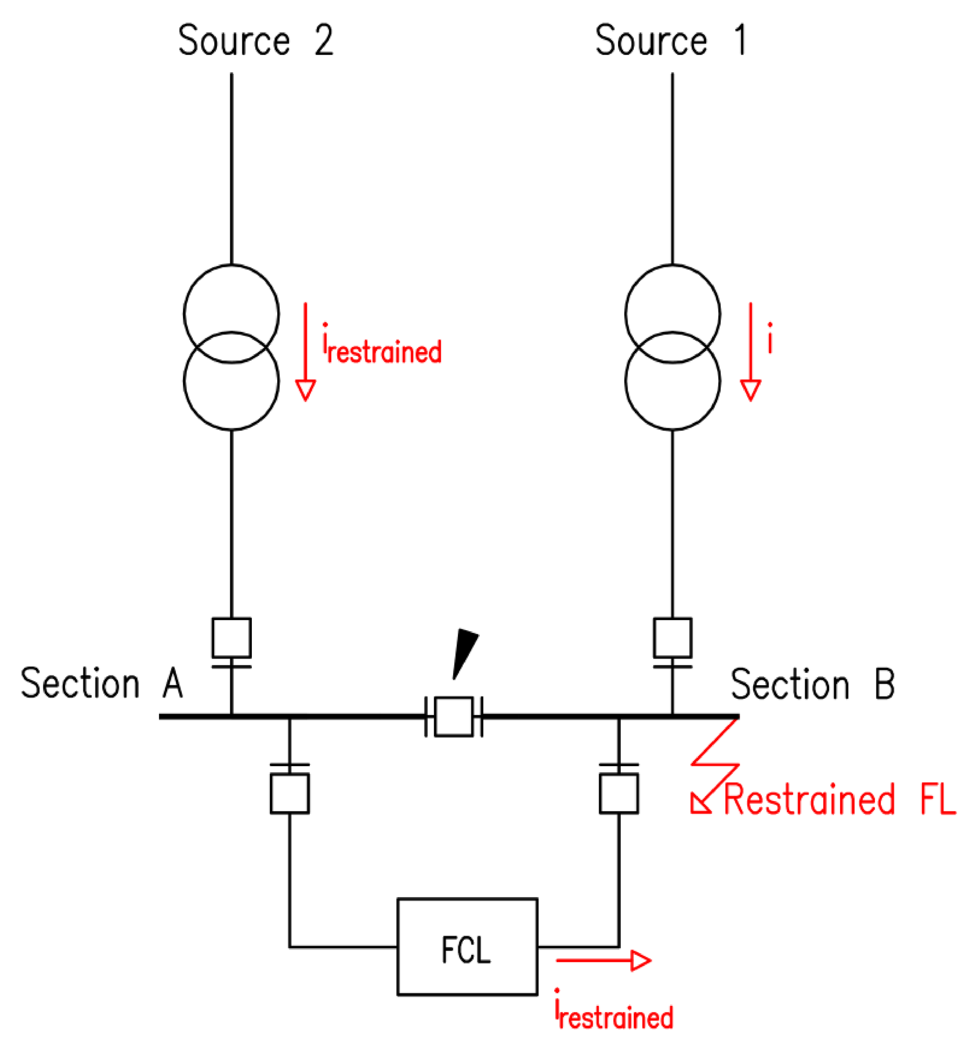


Figure 1 – Typical FCL Installation

Benefits of FCLs over Traditional Solutions

Splitting the network
- Increased reliability
- No SAIDI or SAIFI increase

Higher impedance transformers
- Greater fault level headroom created
- Financial savings

Switchgear upgrade
- System fault level reduction
- Significant financial savings

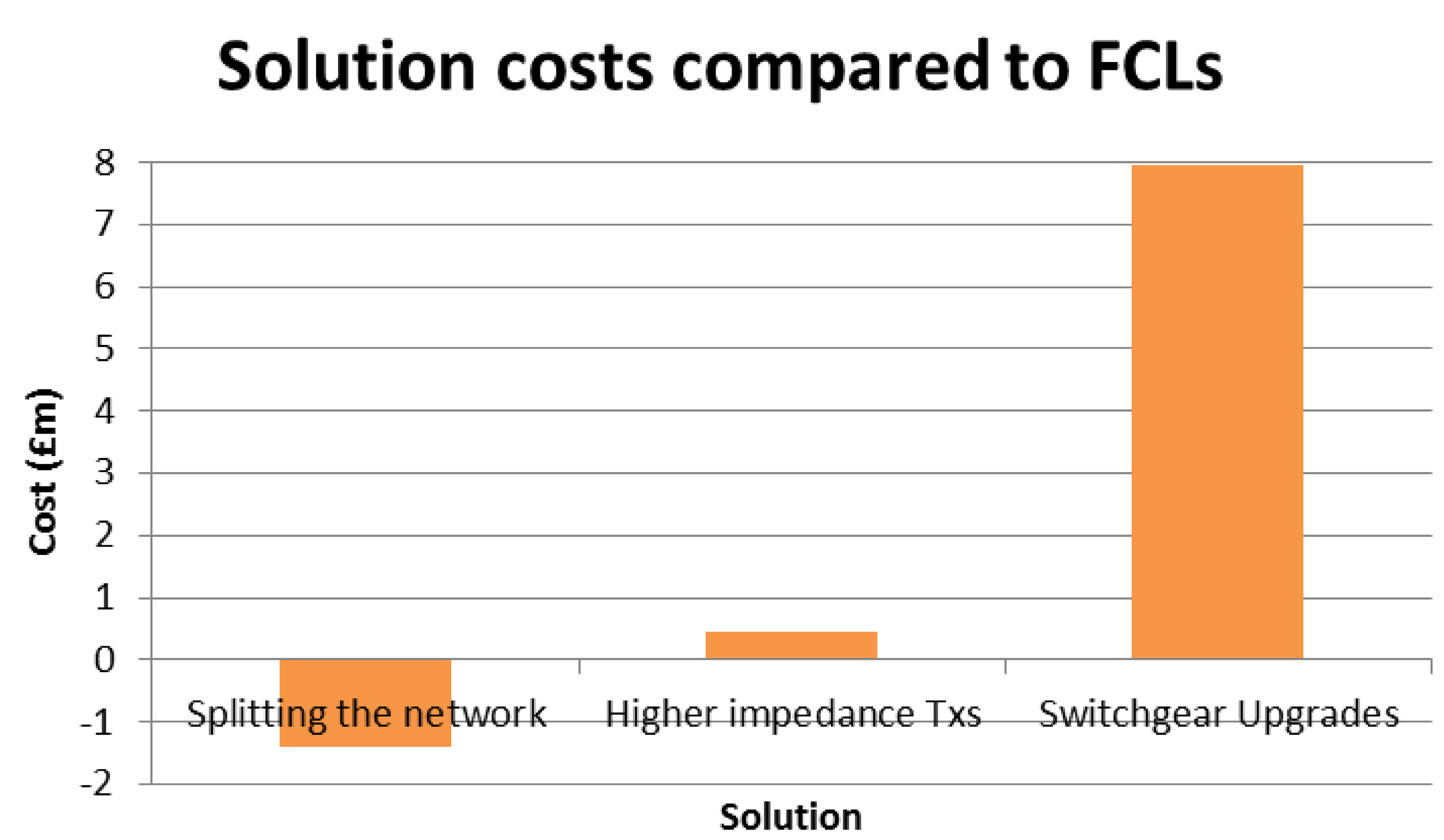


Figure 2 – FCL Cost Comparison

Lyon (France), 15-18 June 2015

Implementation and Roll-out of Innovative DER Grid Integration Solutions

Experiences and Learning of Innovative Projects and Connections

Jonathan Berry - Western Power Distribution - UK

Round Table 7

Implementation and Roll-out of Innovative DER Grid Integration Solutions

- Introduction
- Active Fault Level Monitor
  - Testing and Trials
  - Benefits
- Battery Storage
  - Installation and Trials
  - Benefits
- Alternative Connections
  - Options
  - Benefits
  - Experience

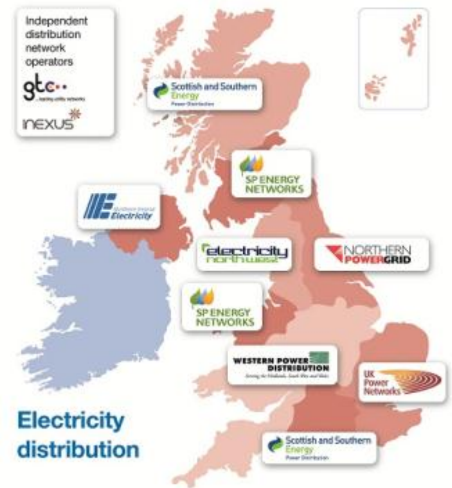
Jonathan Berry – UK – RT7

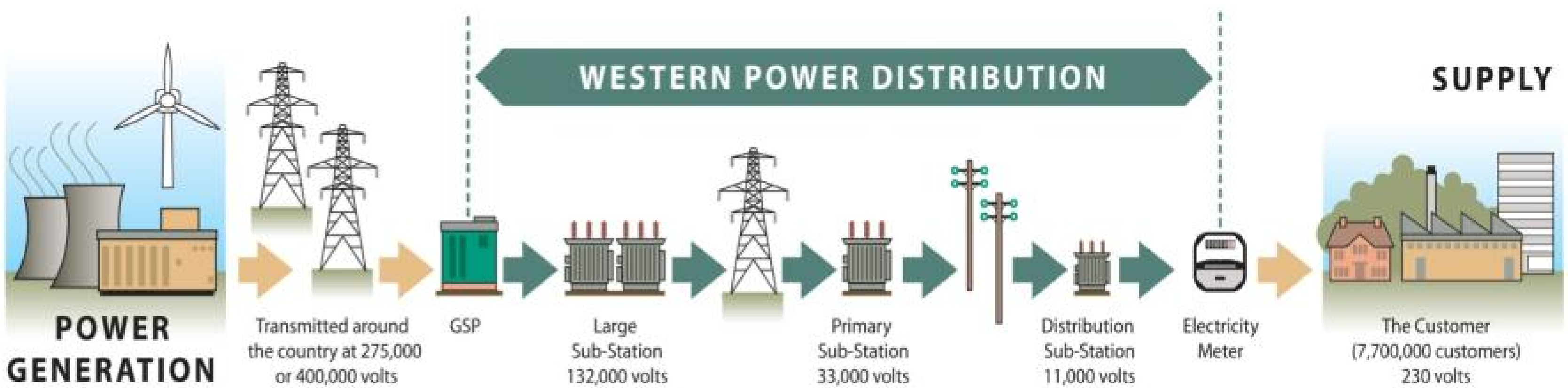
WESTERN POWER DISTRIBUTION

7.8 Million customers over a 55,500 sq kms service area

Our network consists of 221,000 kms of overhead lines and underground cables, and 185,000 substations

LV to 132kV Network ownership





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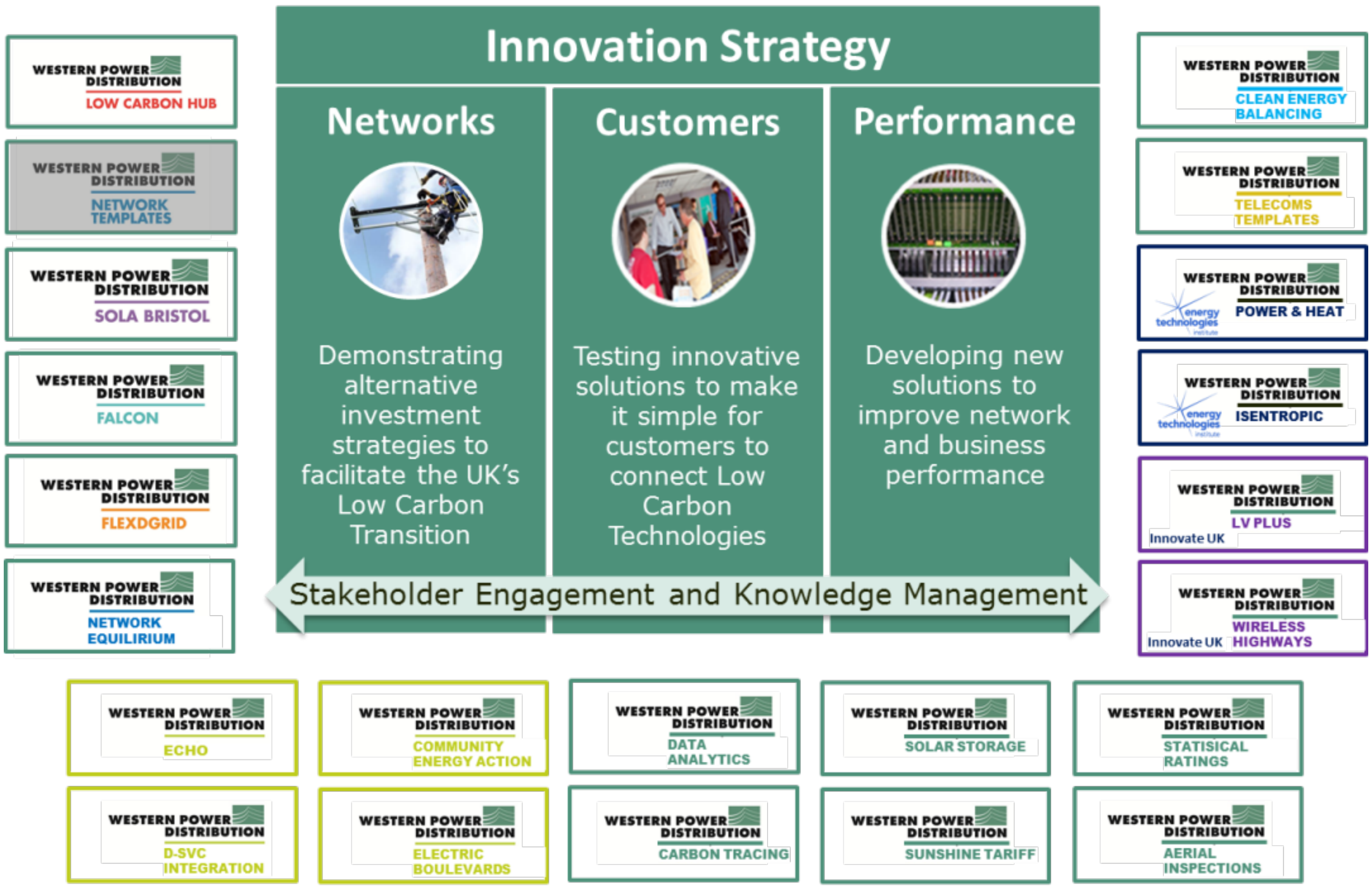
WESTERN POWER DISTRIBUTION



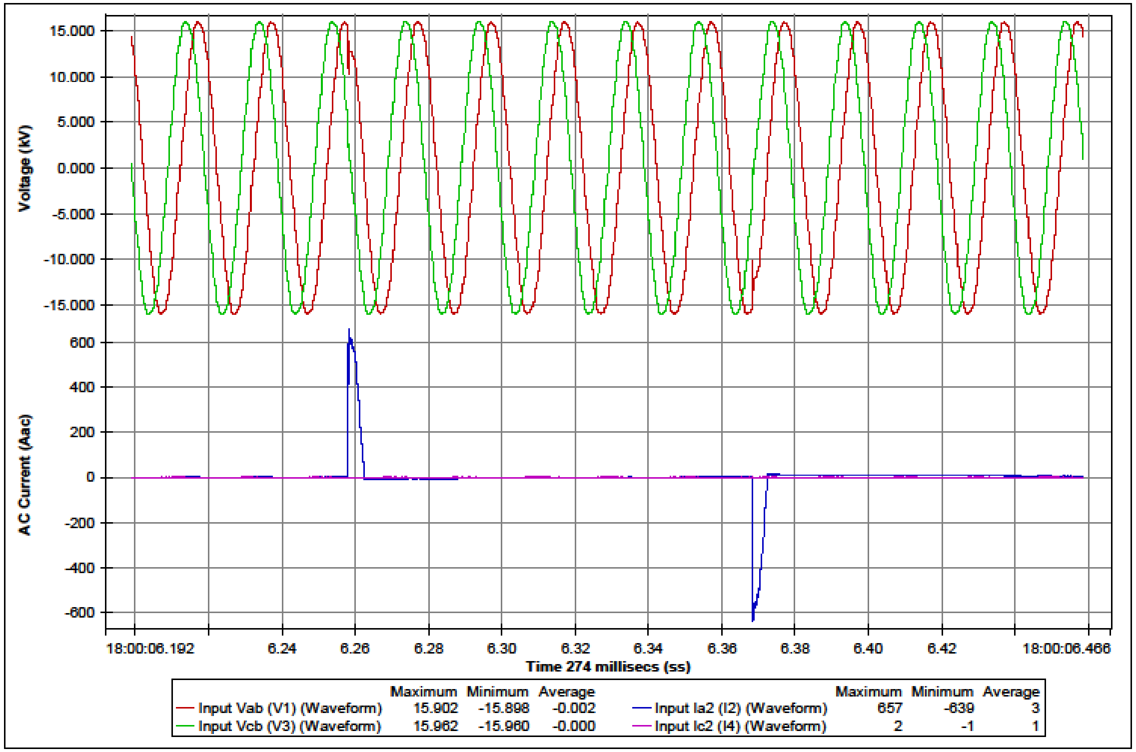
Active Fault Level Monitor

- Device to actively monitor fault level on the 11kV network
- Made up of three distinct components
    - S&C IntelliRupter
    - Resistor
    - PM7000-FLM
- Provides Make and Break Fault Levels
- Detects the network connection conditions

Active Fault Level Monitor

- Graph detailing the current and voltage disturbance on 11kV network

FLM Operation 20ohm Resistor



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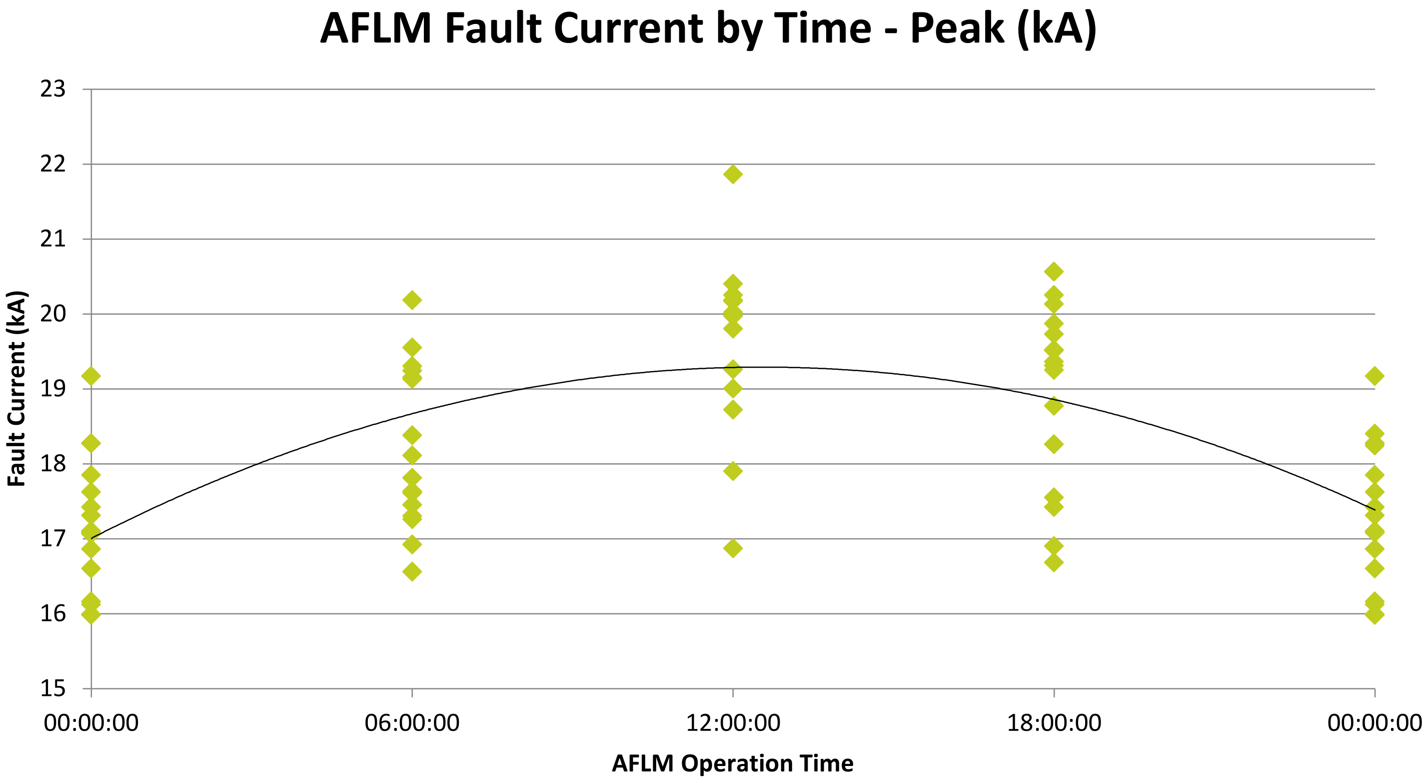
Active Fault Level Monitor

- Device results from laboratory testing

X/R Ratio	Switching Operation	Measured Fault Current		Predicted Fault Current		% Difference		Maximum Voltage	Minimum Voltage	Voltage fluctuation
(No Unit)	(No Unit)	Peak (kA)	RMS @ 10ms (kA)	Peak (kA)	RMS @ 10ms (kA)	Peak (kA)	RMS @ 10ms (kA)	(kV)	(kV)	(%)
30	With 200A load connected	13.83	5.10	13.37	4.87	3.33%	4.46%	6.417	6.353	1.00%
30	Without 200A load connected	13.83	5.10	13.50	5.24	2.37%	-2.70%	6.447	6.384	0.98%
13.3	With 200A load connected	12.88	5.09	13.27	4.95	-2.99%	2.79%	6.289	6.193	1.53%
13.3	Without 200A load connected	12.88	5.09	13.38	5.03	-3.88%	1.32%	6.453	6.298	2.40%
23	With 200A load connected	31.34	13.10	30.40	13.50	3.01%	-3.38%	6.298	6.150	2.35%
23	Without 200A load connected	31.34	13.10	31.02	12.87	1.01%	1.74%	6.451	6.273	2.76%

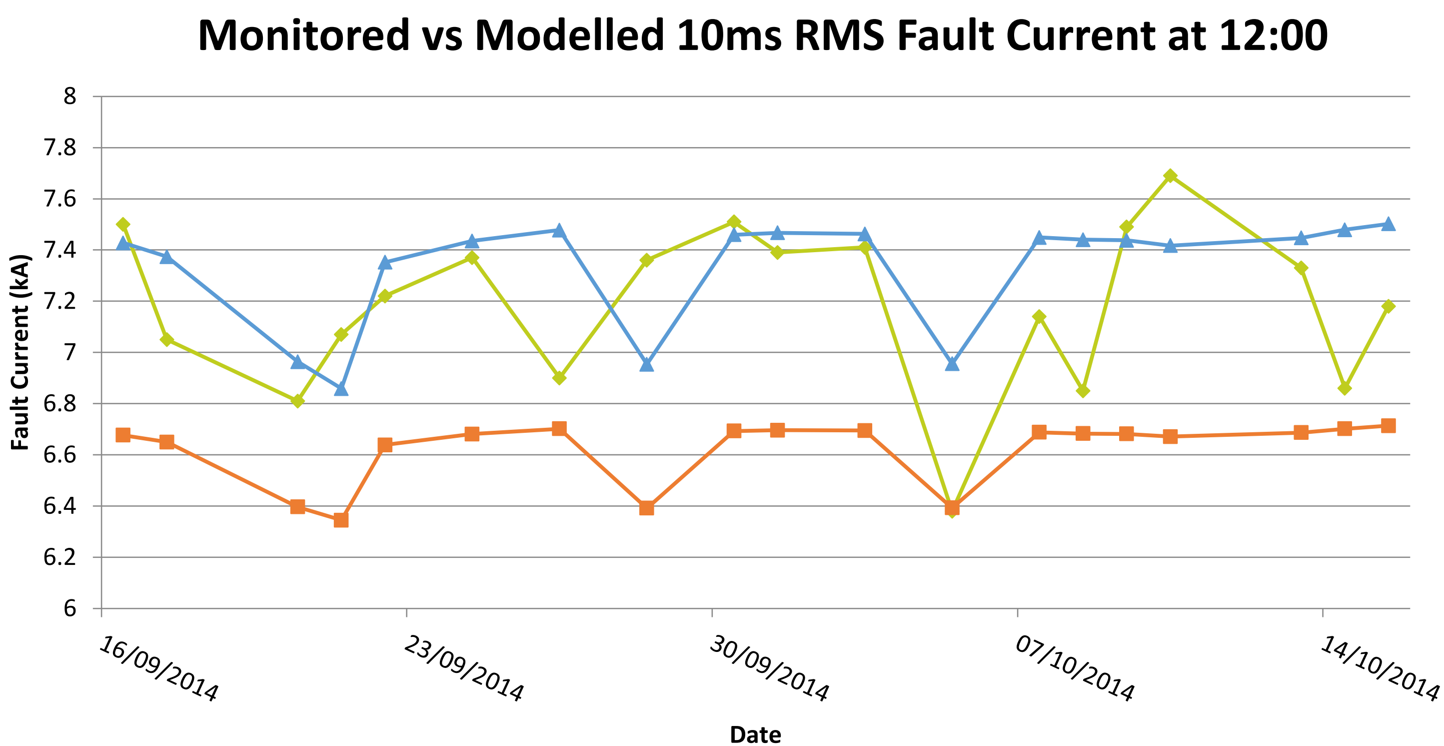
Active Fault Level Monitor

- Graph illustrating the varying fault levels at different times of day

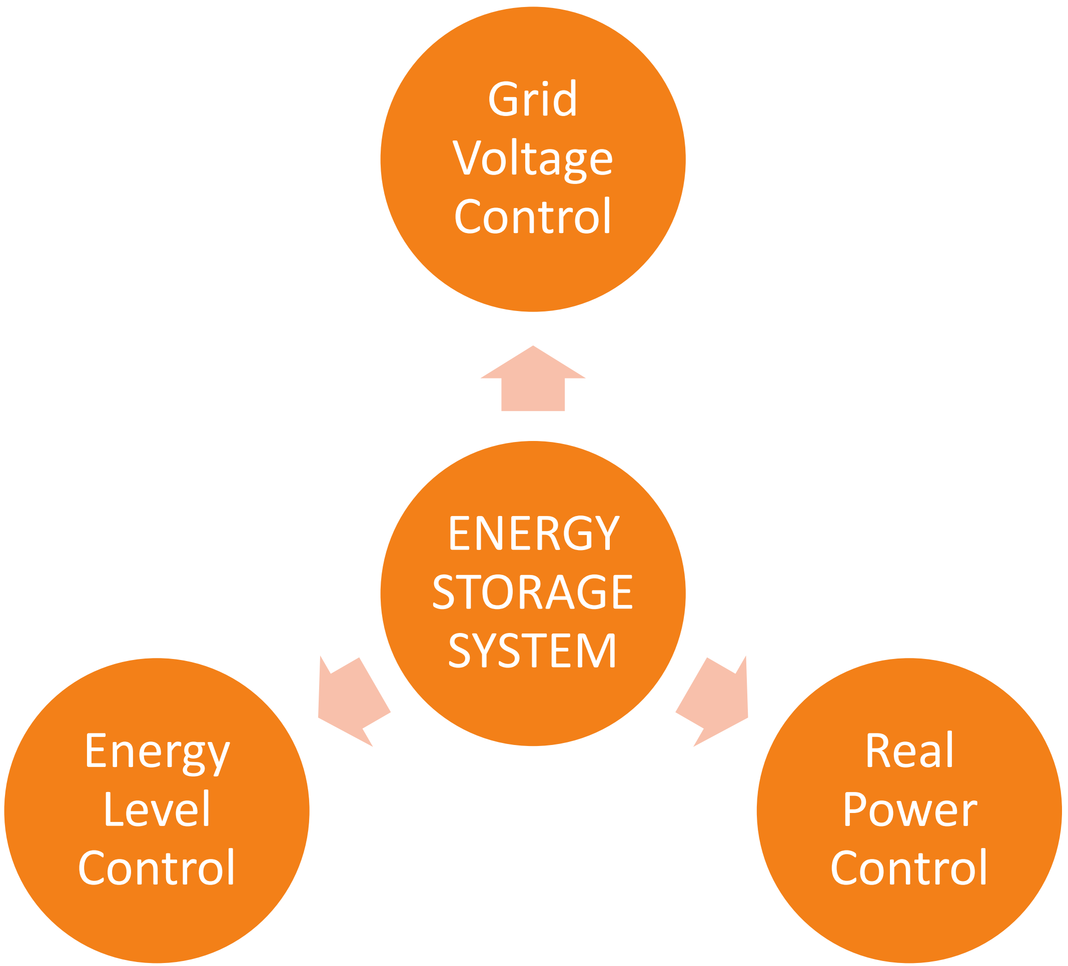


Active Fault Level Monitor

- Graph showing the AFLM results versus modelled results using G74

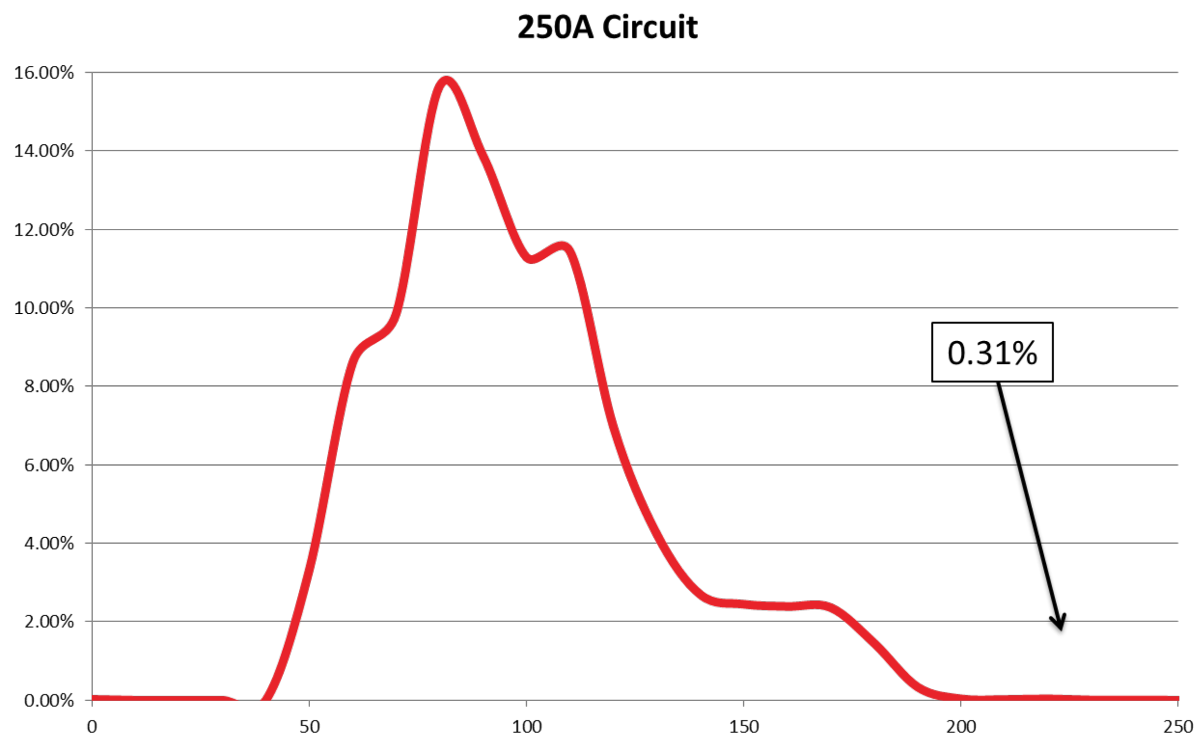


BATTERY STORAGE – FALCON PROJECT



BATTERY STORAGE – FALCON PROJECT

- Indication of average usage of an 11kV network feeder



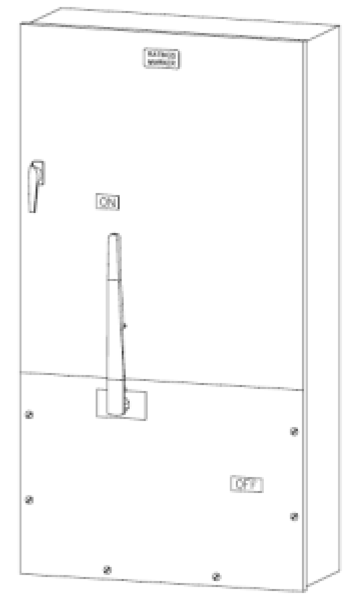
BATTERY STORAGE – FALCON PROJECT

100 kWh
Base Unit

50(100) kW
Inverter

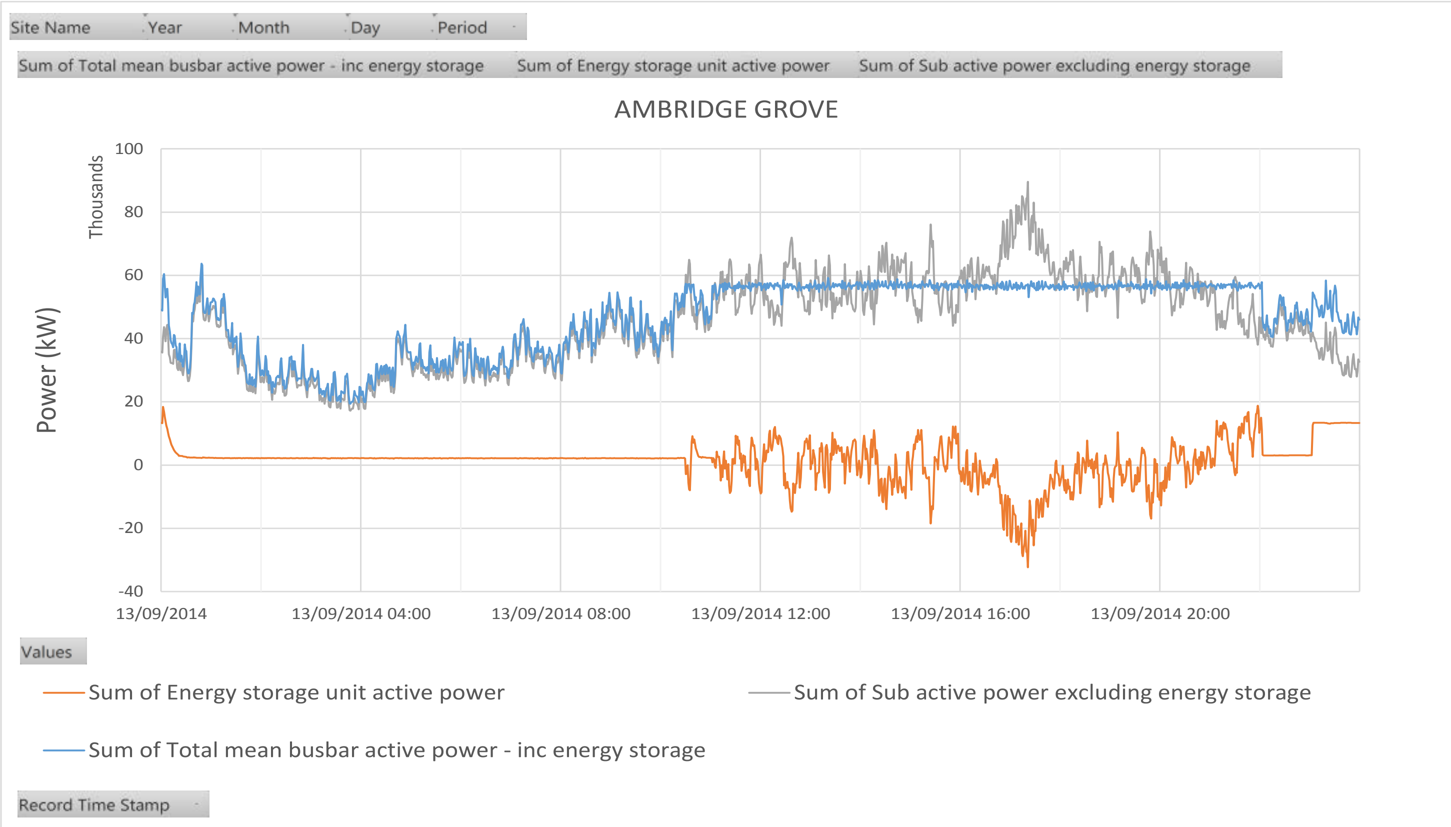
Site Controller

DC Switchgear



BATTERY STORAGE – FALCON PROJECT

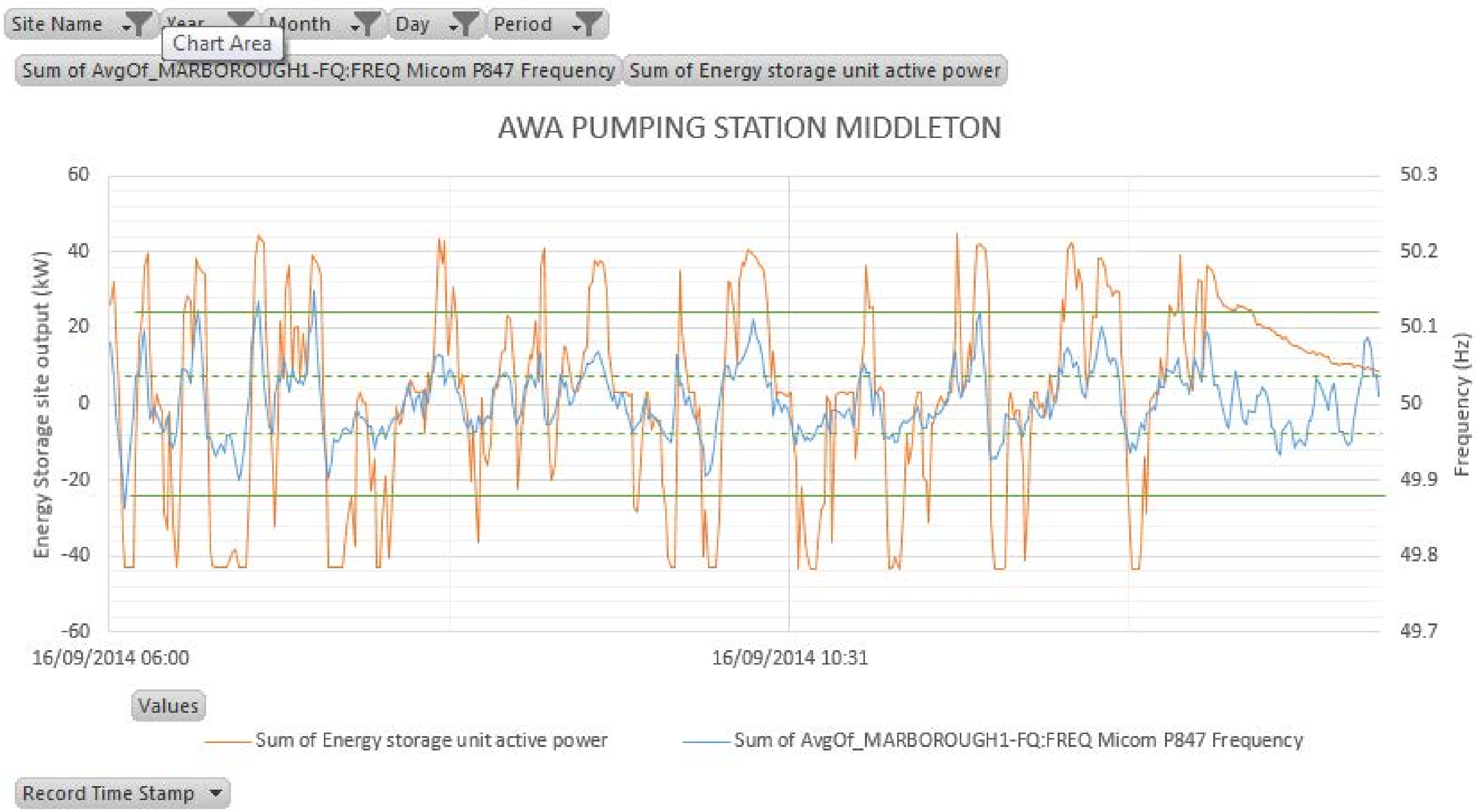
- Peak Shaving Operation provided by Batteries



Lyon (France), 15-18 June 2015

BATTERY STORAGE – FALCON PROJECT

- Frequency Regulation provided by Batteries



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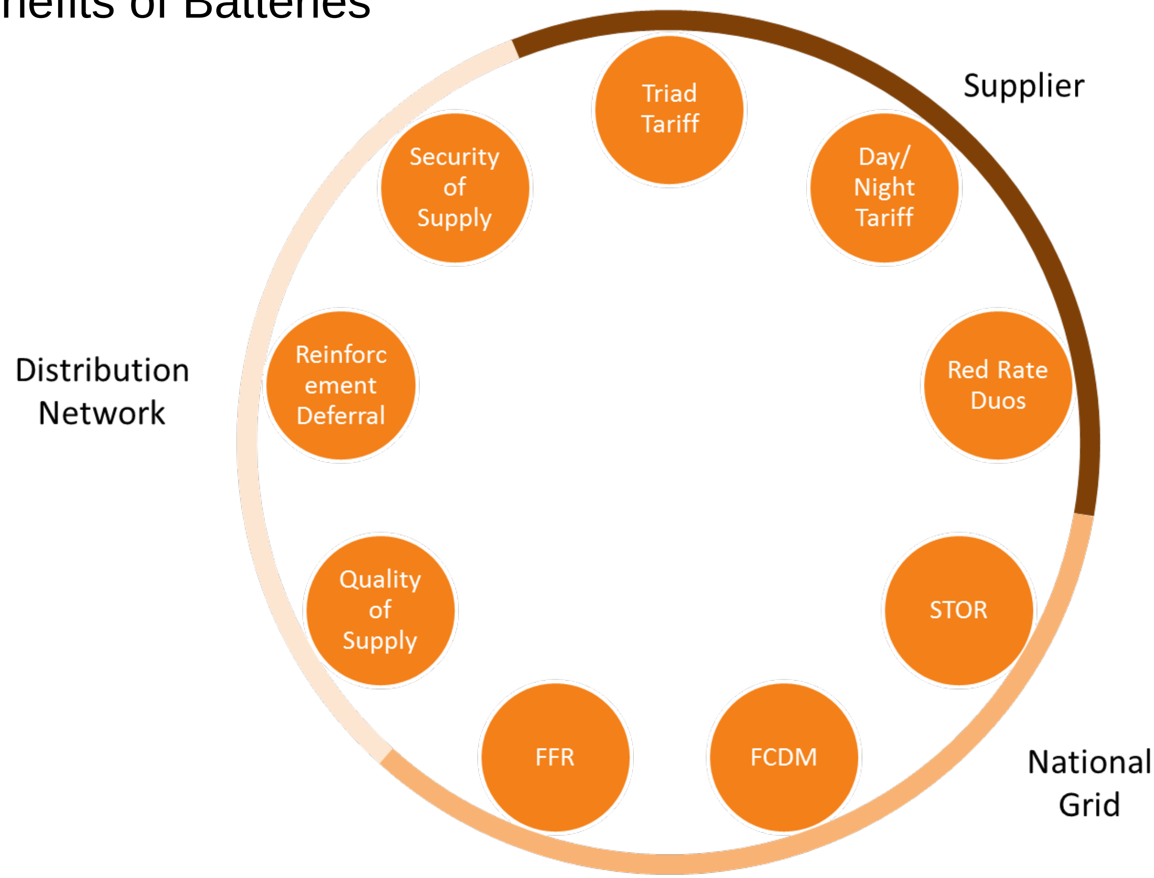
BATTERY STORAGE – FALCON PROJECT

- Varying benefits of Batteries



ALTERNATIVE CONNECTIONS

Generation connected under firm arrangements will have a resilient supply, however the majority of DG is connected under non-firm arrangements, so when the network is running abnormally, the generation may need to be switched off.

Typically this occurs due to:

- Unplanned faults (transient, short-term and long term)
- Planned maintenance
- Planned new construction works
- Planned asset replacement

The duration of the abnormal running depends on the criticality of the event and will range from milliseconds to months

ALTERNATIVE CONNECTIONS

TIMED

- **Generation curtailed within specific times**
- Sub 1MVA
- Modelled seasonal capacity variations
- Localised control only
- No comms
  - May have for voltage constraint
- Non-optimised

SOFT-INTERTRIP

- **Releases pre-fault capacity with trip facility**
- 11kV and 33kV
- Real-time monitored values
- Small clusters of generation or simple pinch points
- Existing monitoring with localised control

ACTIVE NETWORK MANAGEMENT

1010
1011
0100

- **Fully optimises capacity based on all constraints**
- Management of generation using LIFO principles
- Real-time granular control of output
- Requires new Active Network Management control and monitoring systems

Costs, Complexity & Network Optimisation →

ALTERNATIVE CONNECTIONS

- Trade-offs between Alternative Connections and Conventional Reinforcement

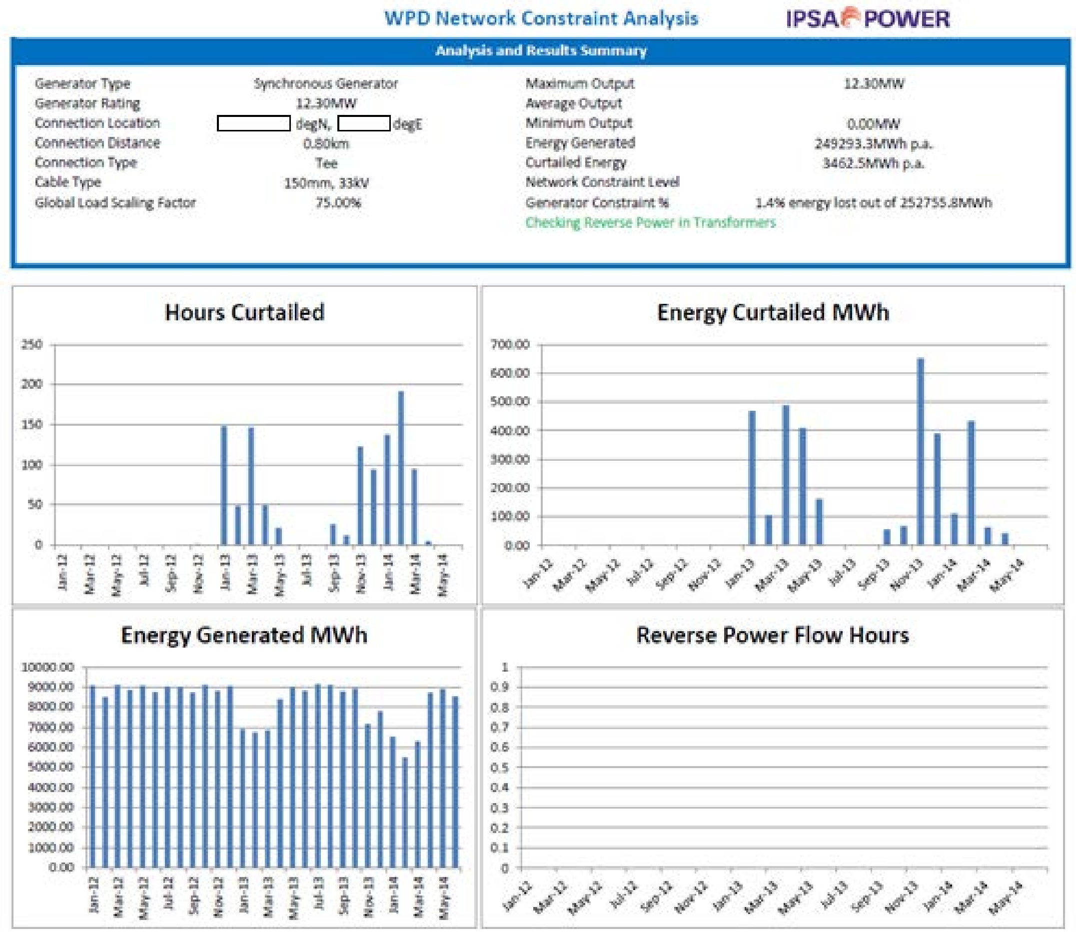
	Up Front Cost	Ongoing Cost
Timed connections	Low	Curtailment (fixed by timed restrictions, i.e. 11.3%)
Soft Intertrip	Medium	Curtailment (depending on network conditions, and "sub-optimal")
ANM	Medium	Curtailment (depending on network conditions, "optimal" curtailment) Capacity-based subscription fee
Conventional Reinforcement	High / Medium / Low	None

All connections designed as 'non-firm' will be switched off for abnormal running

ALTERNATIVE CONNECTIONS

- ❑Estimating Curtailment

WPD uses historical load data on its network models and superimposes idealised generation profiles to estimate the level of curtailment experienced by the connections



ALTERNATIVE CONNECTIONS

❑What Influences Curtailment

Increase	Decrease
• Outages for maintenance • Unplanned Faults • Load loss • Net demand transfers out • Net generation transfers in • Small scale generation • Communications loss	• New load connections • Load increases • Net demand transfers in • Net generation transfers out • Generation outages • Reinforcement • Accepted generation not materialising

Paper 0328 - USE OF REAL-TIME FAULT LEVEL VALUES TO GENERATE AN MVA PER MVA INFEED TEMPLATE FOR 11KV DISTRIBUTION NETWORKS

Jonathan BERRY
Western Power Distribution – UK

Paul EDWARDS
WSP|Parsons Brinckerhoff - UK

Introduction

This paper discusses the process of generating and the advantages of utilising real-time fault level values to produce MVA per MVA general load fault infeed templates for 11kV distribution network modelling. This paper is based on learning to date from Western Power Distribution's (WPD) Tier-2 Low Carbon Networks (LCN) Fund project, FlexDGrid.

Fault Level Monitoring

As part of FlexDGrid 10 Fault Level Monitors (FLM) have been installed on the 11kV network. This technology creates an artificial disturbance on the 11kV of 600A and a 1.5% voltage deviation to enable the network source impedance to be calculated and thus the make fault level (10ms) and the break fault level (90ms).

Data Analysis

Results from the 10 FLMs were used along with enhanced power system analysis models that included the network from the transmission infeed point to the remote end 11kV network, to accurately understand the general load fault level infeed values based on FLM data, whereby the model's infeed value was manipulated to derive modelled values matching that of the real-time FLM data.

Load profiles (Table 1) were used to develop a template of fault level MVA/MVA infeeds by characterising them against load types at the substations the FLMs were connected. This is shown in Figure 1.

Table 1: Load profiles of 10 FLM substations

Substation	% of Substation Load Domestic	Small Commercial /Industrial	Large Commercial /Industrial
ELMD	7%	7%	86%
CHES	20%	19%	61%
CASB	24%	10%	66%
BOVI	32%	14%	54%
NECW	35%	24%	41%
KITG	52%	14%	33%
HALG	57%	19%	23%
CHAV	60%	24%	16%
SHIR	61%	25%	13%
BARG	66%	12%	22%

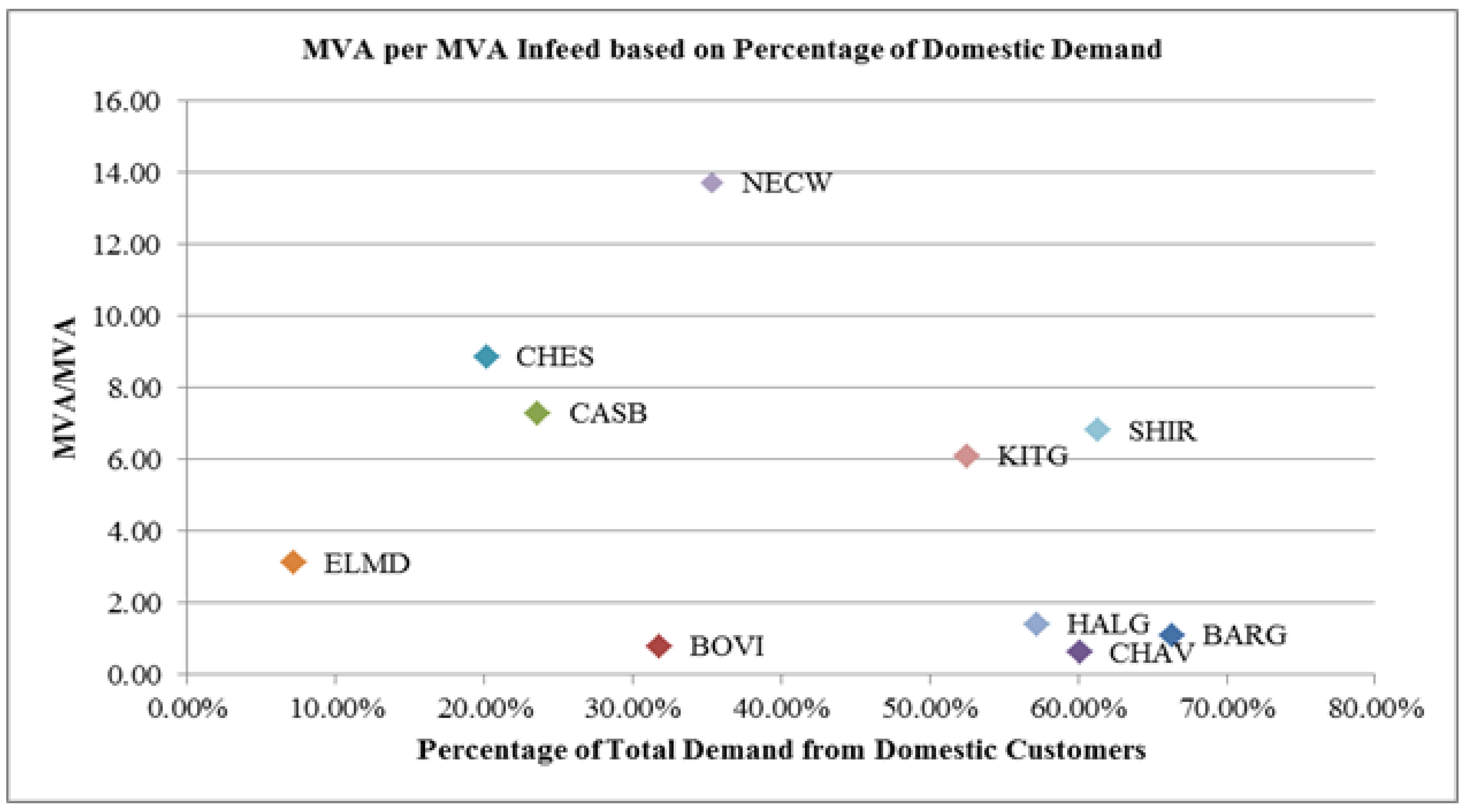


Figure 1: MVA/MVA Fault Level Infeed against percentage of Domestic Demand Connected

MVA per MVA Results

BARG, HALG and CHAV, generally follow the G74 recommendation of 1.0 MVA/MVA infeed for 11kV connected loads. These substations have a large domestic load with few large commercial or industrial customers connected. CHES and CASB substations by contrast have a relatively low domestic demand and a high percentage of large commercial and industrial customers connected. The combined average infeed calculated for these substations is 8.08 MVA/MVA. This is considerably above G74 recommended values. KITG substation has a high percentage of both domestic and large commercial and industrial loads, resulting in an infeed value of 6.09 MVA/MVA.

The four remaining substations are considered anomalous results at this stage. ELMD and BOVI, from the data provided in Table 1, indicate the fault level infeed for these substations should be similar to that of CHES and CASB, around 8.08MVA/MVA, however, both are significantly lower than this. NECW should, based on load type data, have a value between that of 6.09 and 8.08 MVA/MVA and SHIR should follow the G74 recommendation of around 1.0 MVA/MVA.

Next Steps

Anomalous results presented are a consequence of considering a substation's complete load profile, however, considering the load profile of the section of network the FLM is connected to should remove these issues. Therefore, further granular understanding of loads per substation section is required to finalise the MVA/MVA Fault Level infeed values of the 11kV system and suggest changes to G74 fault level infeed values.

WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS

Fault Level - FlexDGrid

8th September 2016

Jonathan Berry
Innovation and Low Carbon Networks Engineer

WESTERN POWER DISTRIBUTION INNOVATION

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

NETWORK TEMPLATES | SMART ENERGY ISLES | NETWORK TEMPLATES | FALCON

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

- Airborne Inspections
- AIRSTART[1]
- Telecoms Templates
- 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: Flexible Power
- Integrated Network Model
- Smart Meter Exploitation
- Distribution Operability Framework
- Data Analytics
- Voltage Level Assessment
- LV Connectivity
- Smart Systems and Heat[2]

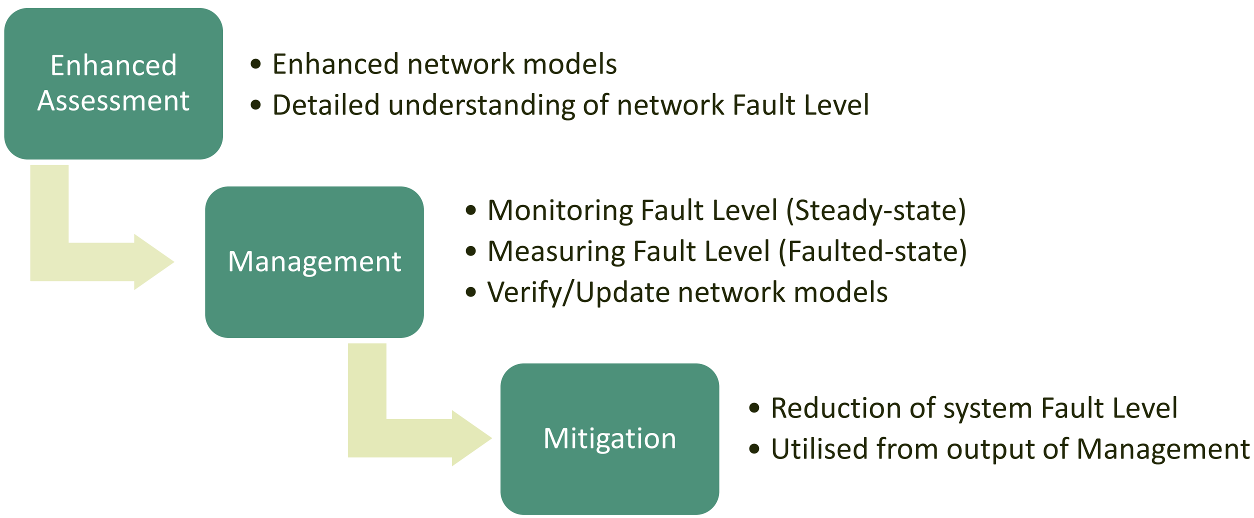
Note: 1 – Funded by Aerospace Technology Institution; Note 2 – Funded by the Energy Systems Catapult

Agenda

- What is FlexDGrid?
- What is Fault Level?
- What causes it to change?
- How is it going to (likely to) change?
- How does FlexDGrid benefit this?
- Next Step

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.

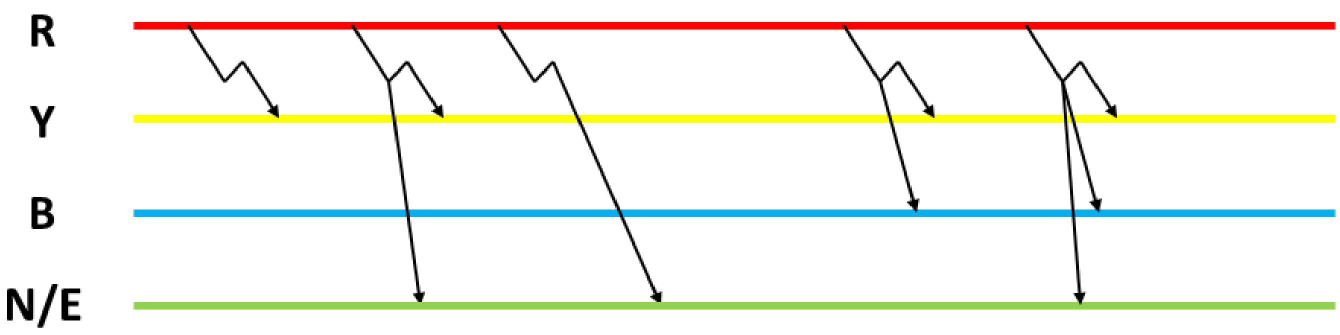


Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional Generation.

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.



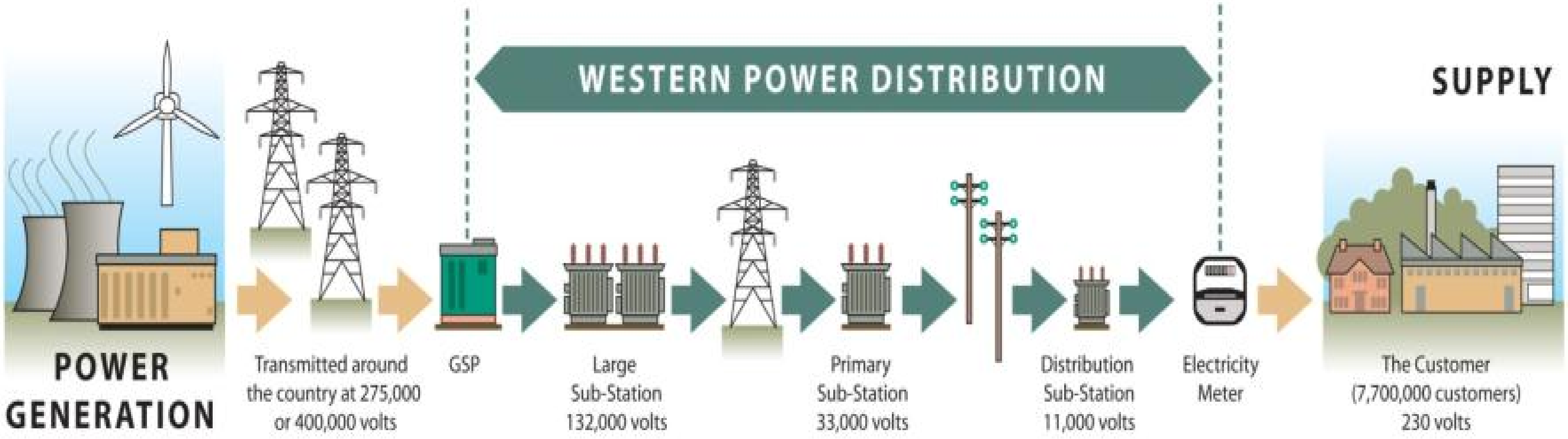
Examples of unintentional conducting paths in a 3-phase system (faults)

What is Fault Level?

What actually causes faults on the system?

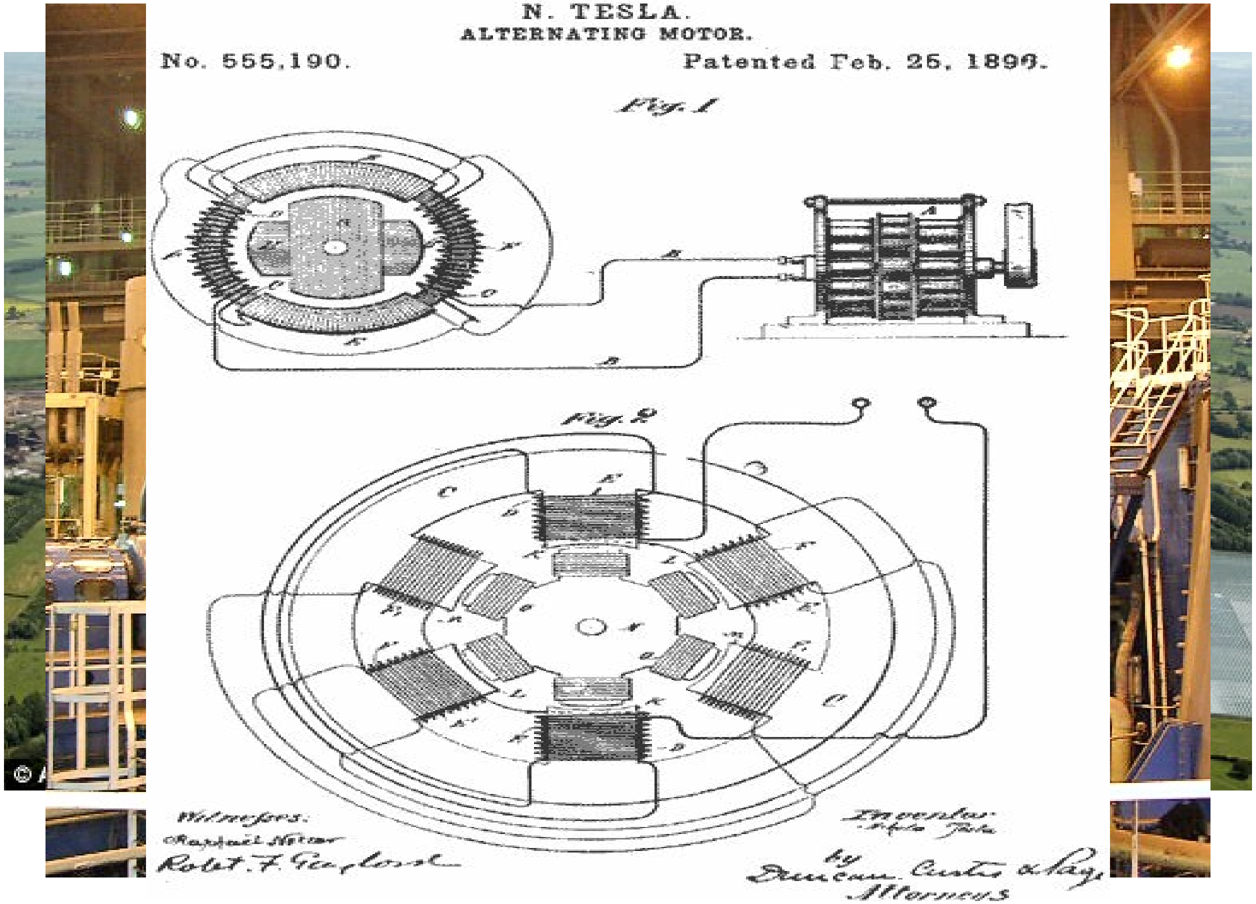
What is Fault Level?

What effects it and how does it change?



What is Fault Level?

What dominates the distribution fault level?



What is Fault Level?

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

$$V = IR$$

What is Fault Level?

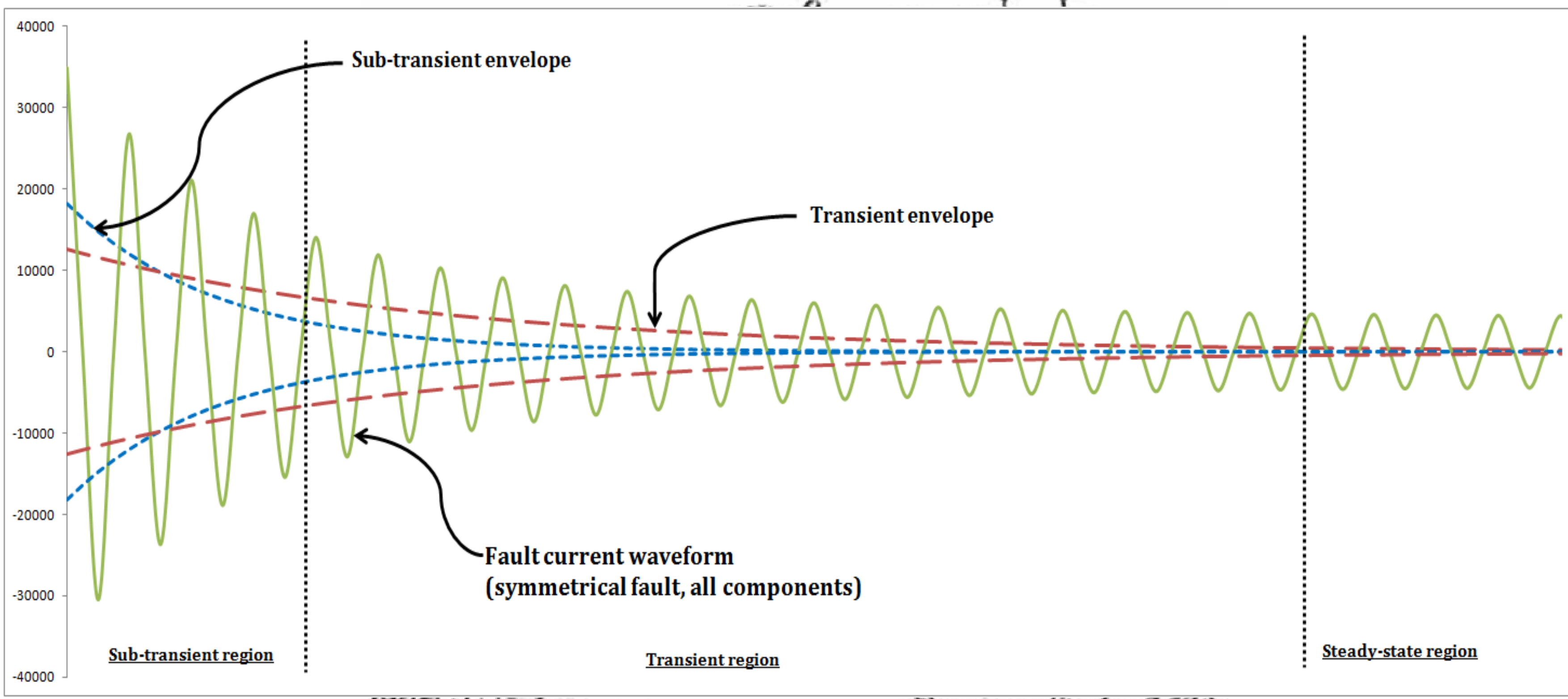
How is it generated and changed?

$$V = IZ$$

$$Z = R + X$$

What is Fault Level?

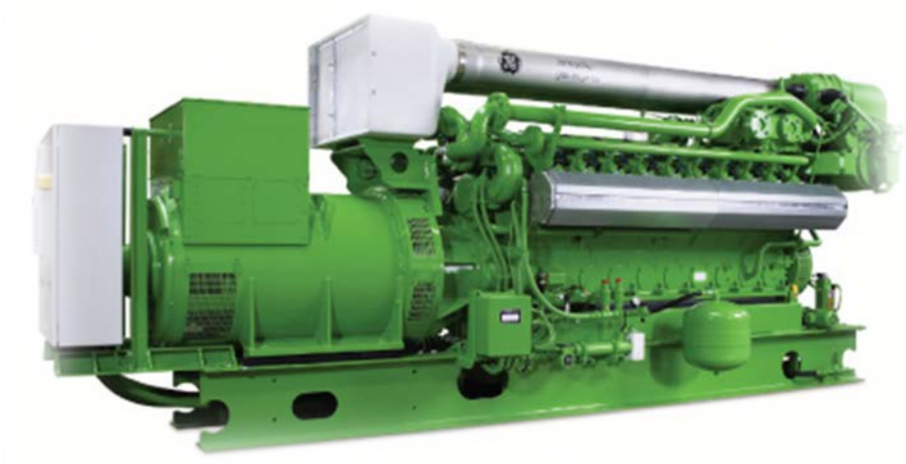
How is it generated and changed?

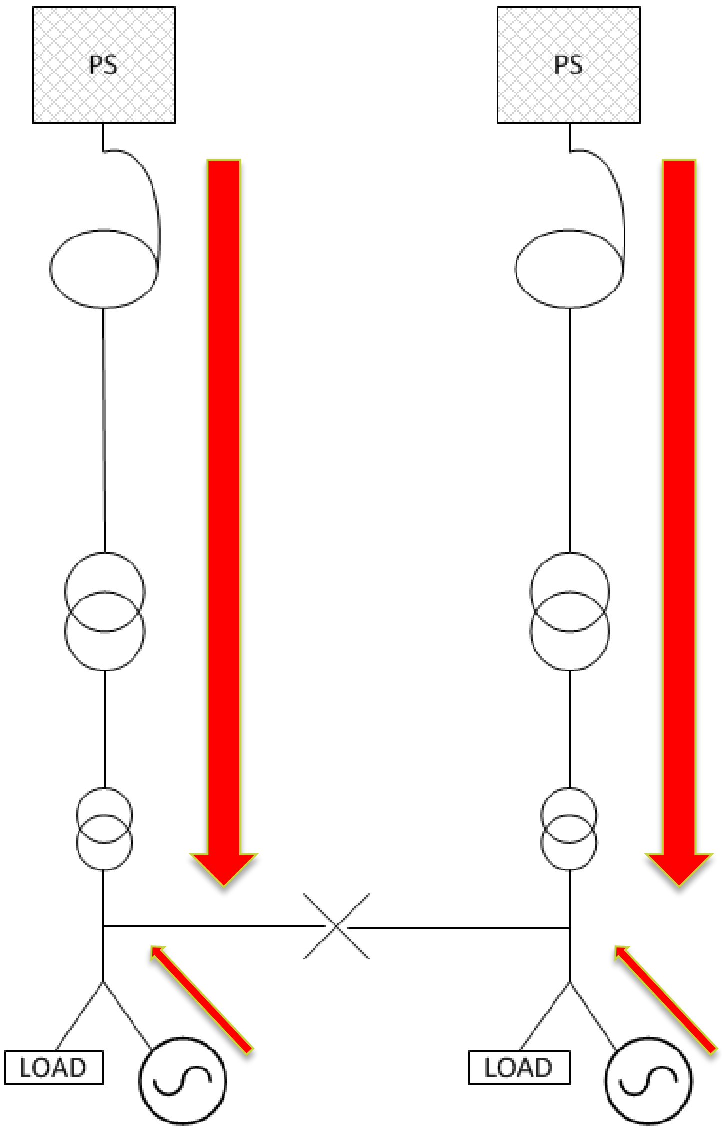


$$2I = \frac{V}{Z}$$

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**

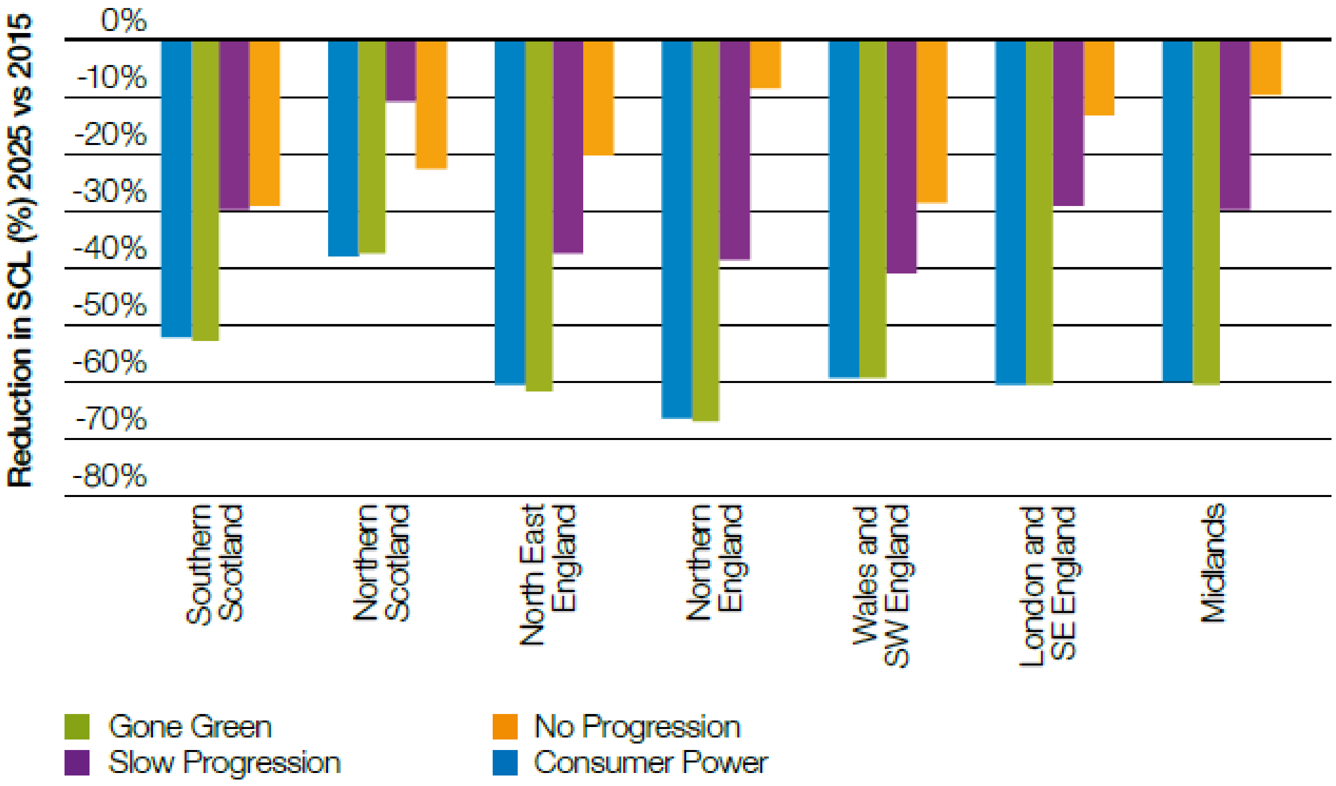
Average Inverter Fed Generator Infeed – **1.2MVA**

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?

Medium Term

Reduced Centralised Generation and Increased Distributed Generation

What does this mean?

Long Term

Minimal Centralised Generation and Dominated Distribution Generation

FlexDGrid Learning and Benefits

How to model and access the impact?

- Development of a model from National Grid infeed to the remote end of the 11kV network
  - More accurate assessment of the system and new connections
  - Refined load contribution analysis
  - Enables increased access to fault level data

- Supports FlexDGrid’s other two methods

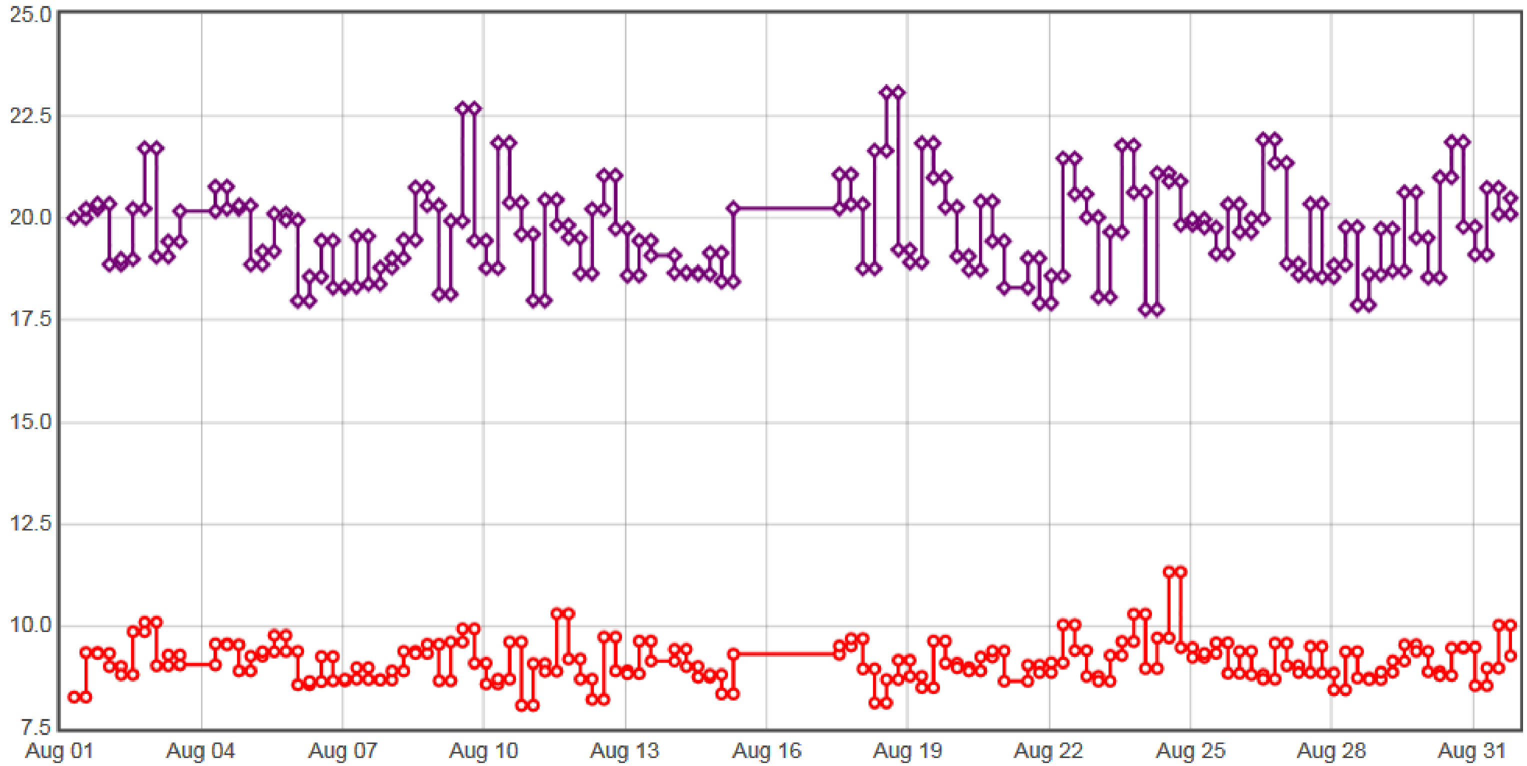
FlexDGrid Learning and Benefits

Greater visibility of the network?

- Installation of 10 Fault Level Monitors (FLM)
  - For the first time real-time make and break fault levels of the 11kV system can be generated

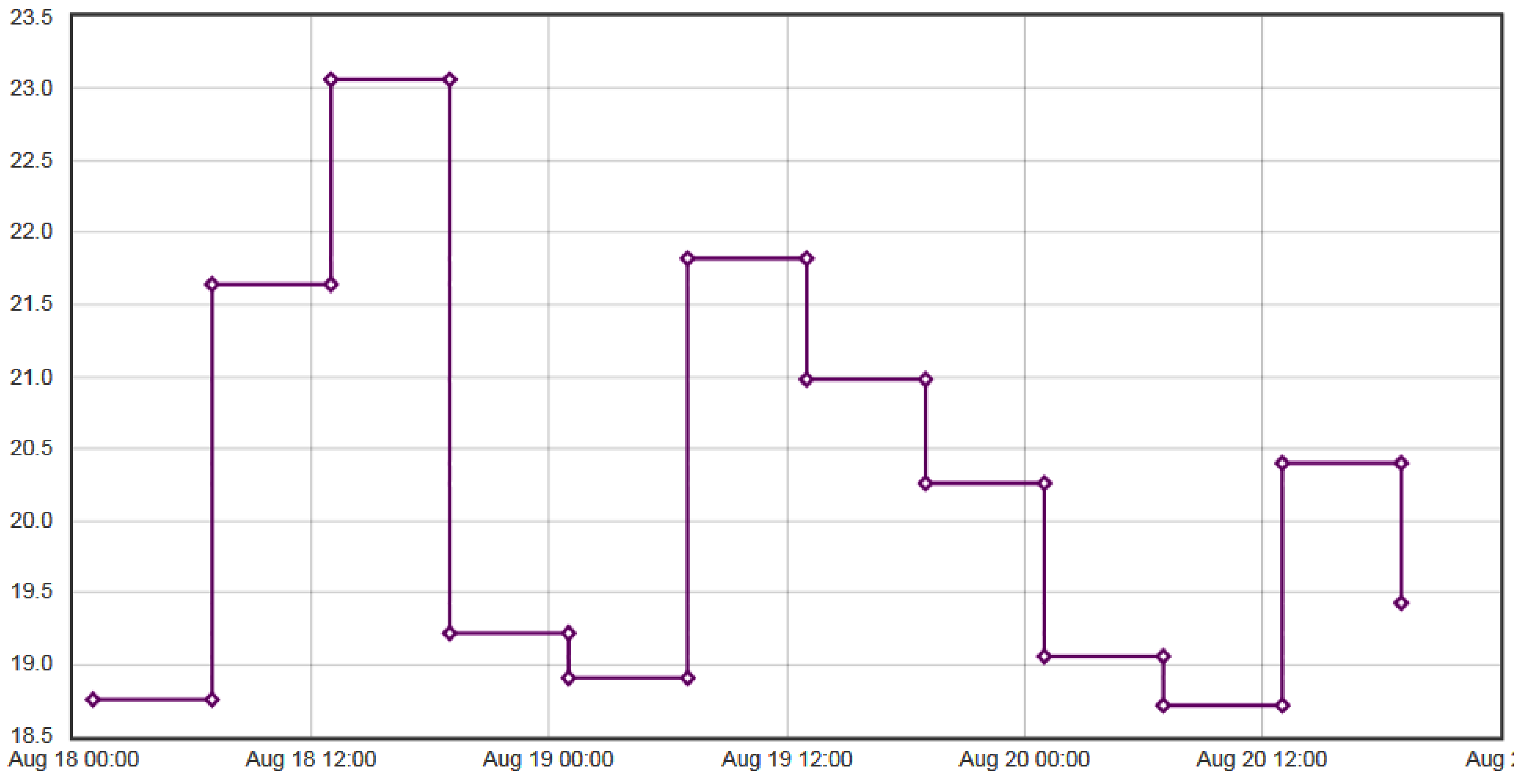
FlexDGrid Learning and Benefits

Make and Break fault level (MVA) for August 2016



FlexDGrid Learning and Benefits

Make Fault Level (MVA) for three days



FlexDGrid Learning and Benefits

Benefits of real-time Fault Level monitoring

- Enables design engineers to have greater information:
  - System fault level infeed by substation
  - Historic data to inform customers about the possibility of flexible connections
- Enables control engineers to have greater information to:
  - Increase network security of supply
  - Connect / Disconnect generation
- Future Use:
  - Inform requirements for network reconfiguration
  - Understand the requirements and purpose of dynamic protection settings
  - Enact the use of synthetic inertia

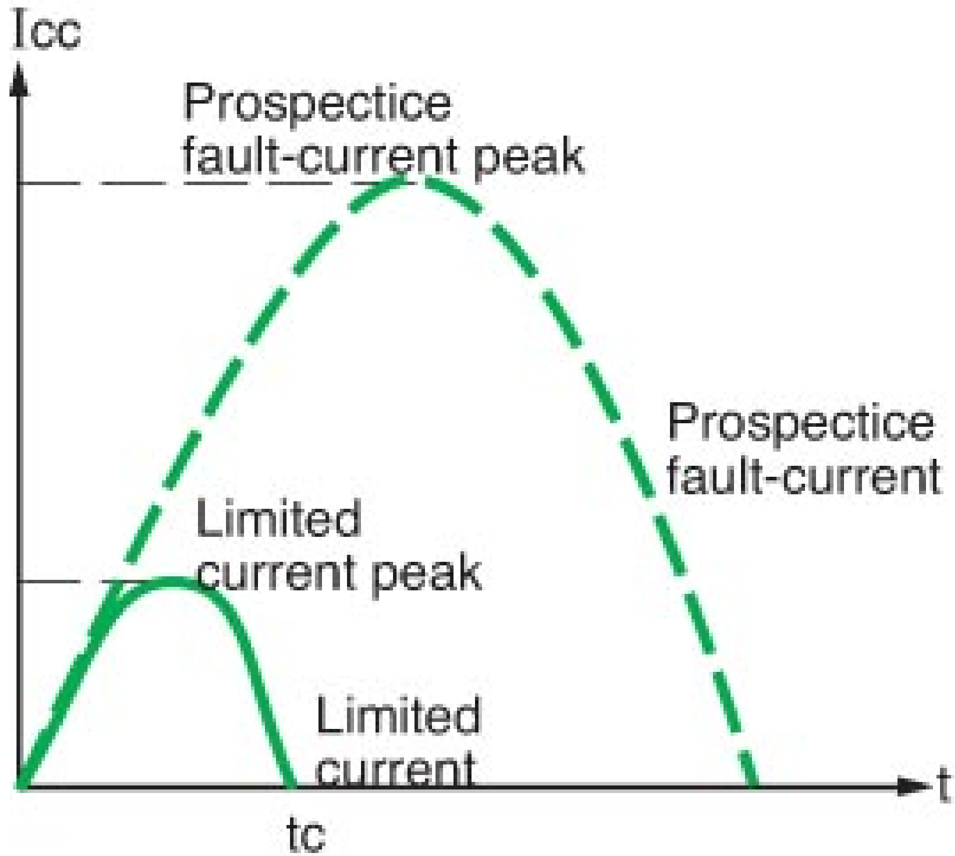
FlexDGrid Learning and Benefits

Fault Level Mitigation

- Technologies to increase the impedance (Z) of the system, on inception of a fault, to limit fault level flow through it

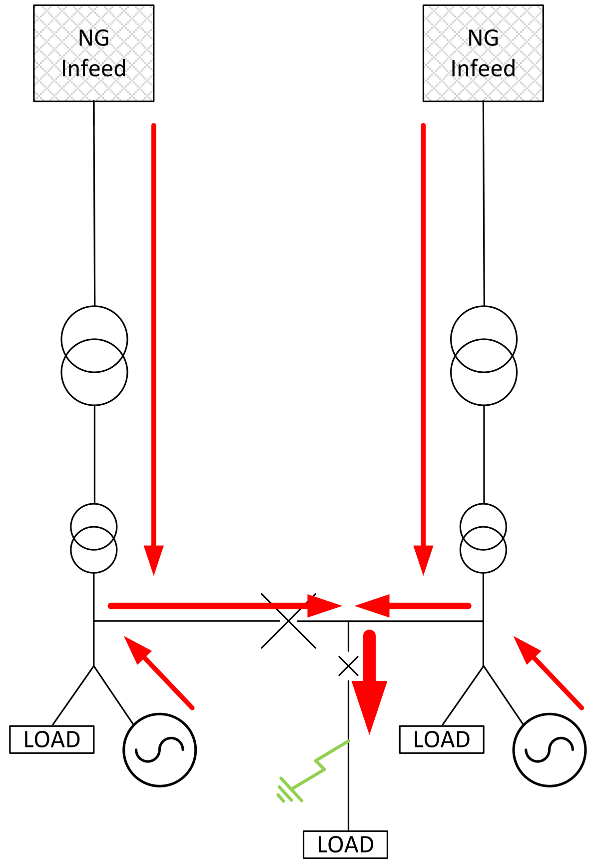
FlexDGrid Learning and Benefits

Fault Level Mitigation



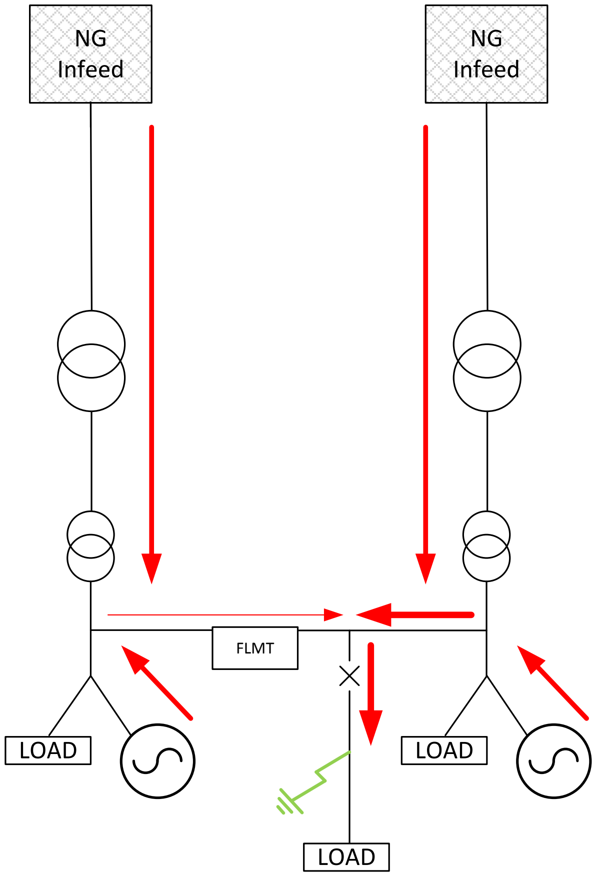
FlexDGrid Learning and Benefits

Fault Level Mitigation

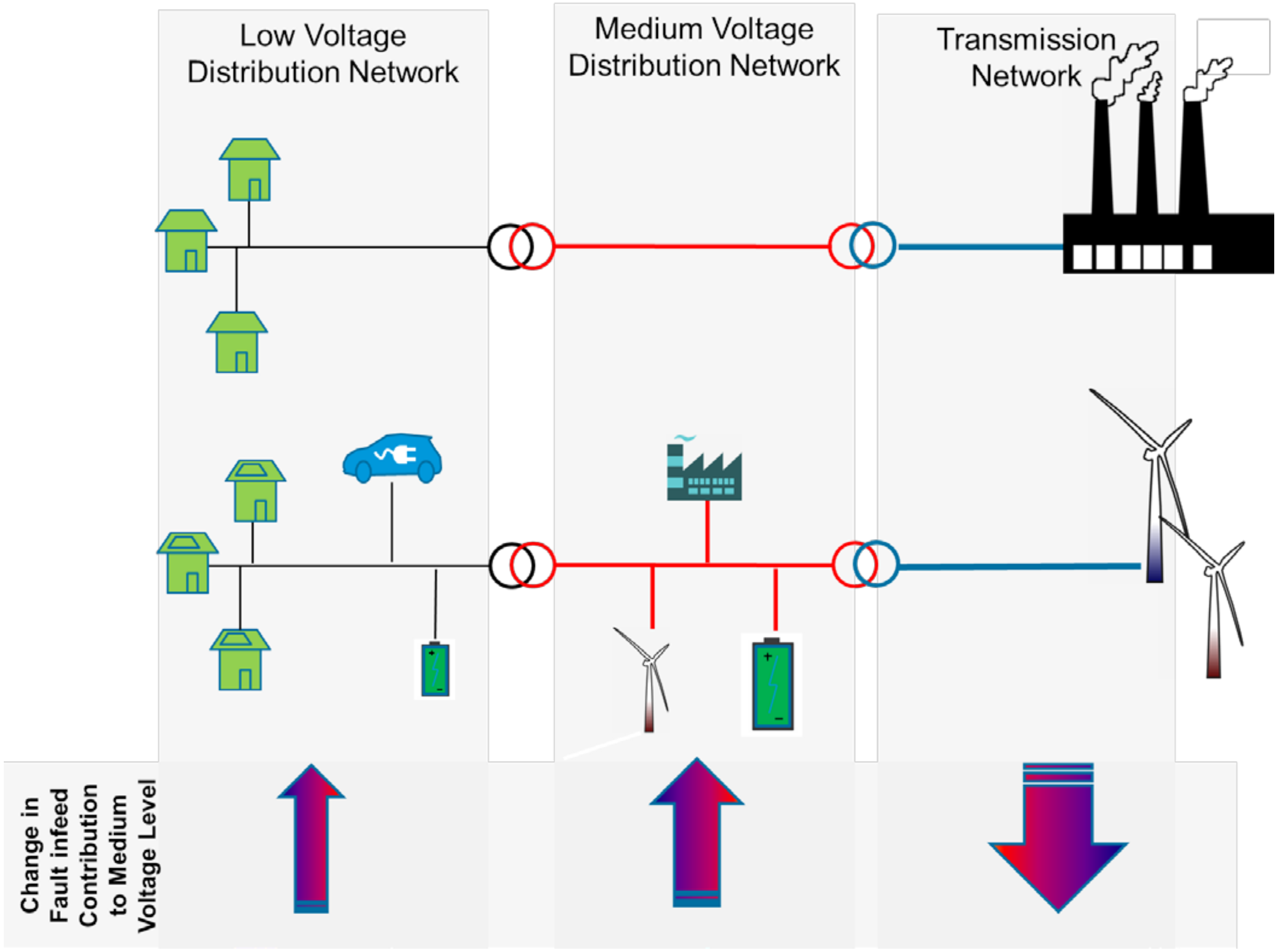


FlexDGrid Learning and Benefits

Fault Level Mitigation



Conclusion and Next Steps



THANKS FOR LISTENING

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Serving the Midlands, South West and Wales

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Innovation and Low Carbon Networks Engineer

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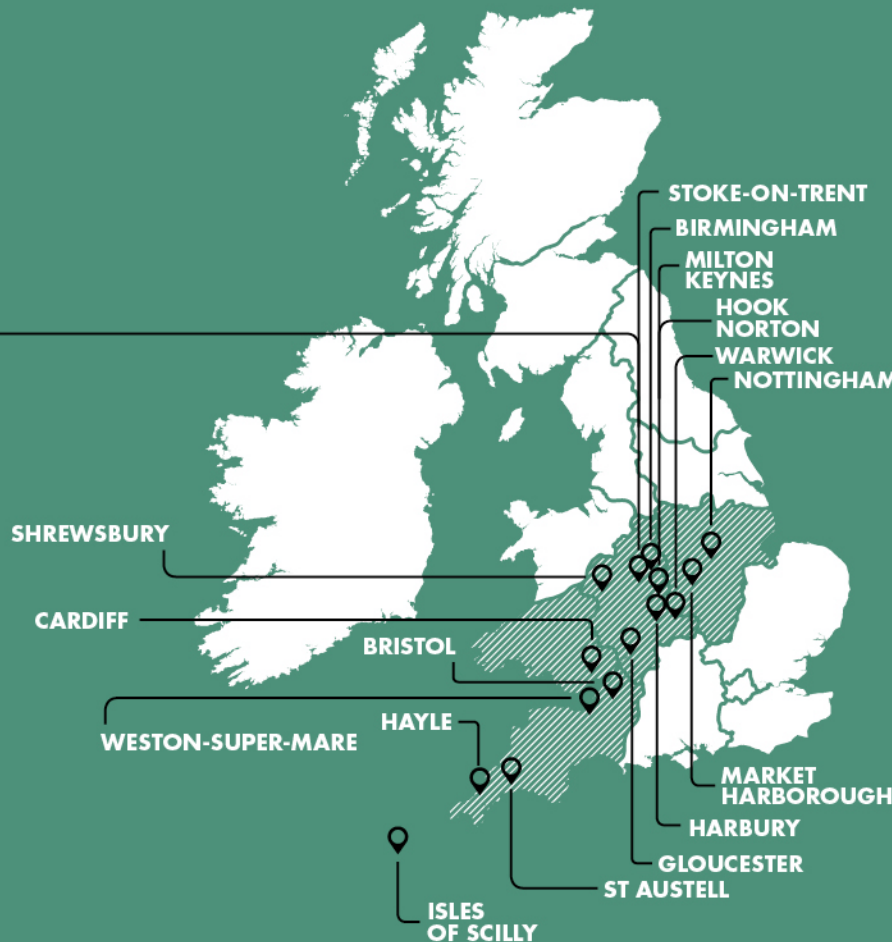
WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS



How will the Grid deal with Renewable Energy

Energy Saving Convention 2016

24th November 2016

Jonathan Berry

Innovation and Low Carbon Networks Engineer

Agenda

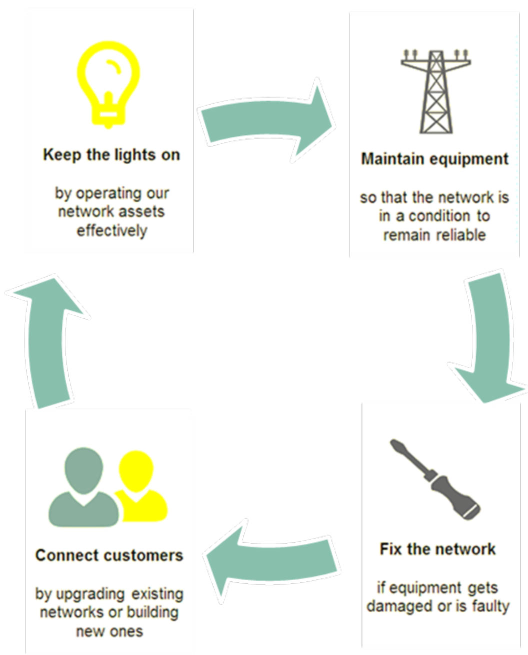
1. Western Power Distribution – Who Are We?
2. Traditional Role of the DNO
3. Distribution Network Transformations
4. Role of DSO
5. WPD Innovation

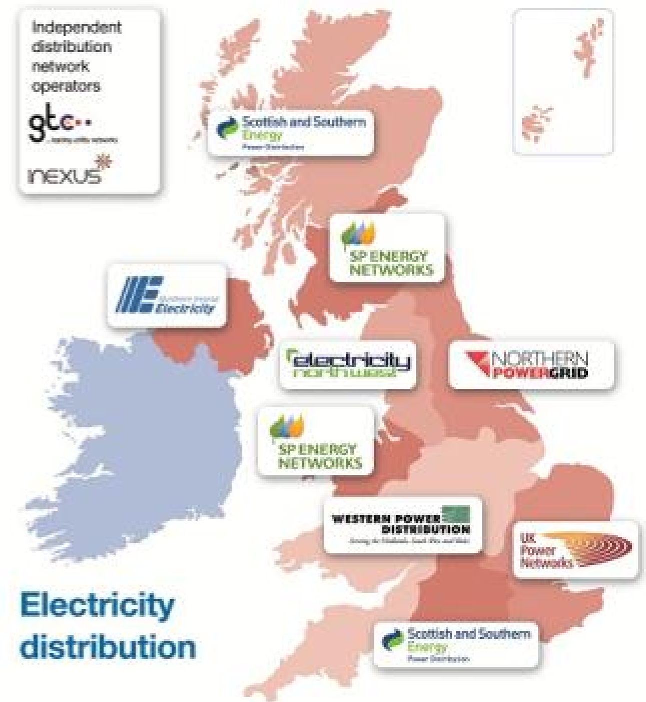
Who Are We?

•7.8 Million customers over a 55,300 sq kms service area

•Our network consists of 220,000 kms of overhead lines and underground cables, and 185,000 substations

•LV to 132kV Network ownership





WESTERN POWER DISTRIBUTION
INNOVATION

WESTERN POWER DISTRIBUTION PROTEUS — NEW

WESTERN POWER DISTRIBUTION FLEXDGRID

WESTERN POWER DISTRIBUTION PLUGS AND SOCKETS

WESTERN POWER DISTRIBUTION SOLA BRISTOL

WESTERN POWER DISTRIBUTION LOW CARBON HUB

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

WESTERN POWER DISTRIBUTION OPEN LV — NEW

WESTERN POWER DISTRIBUTION NETWORK EQUILIBRIUM

WESTERN POWER DISTRIBUTION SMART ENERGY ISLES

WESTERN POWER DISTRIBUTION NETWORK TEMPLATES

WESTERN POWER DISTRIBUTION FALCON

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

- **Hybrid Heat Pump Demonstration**
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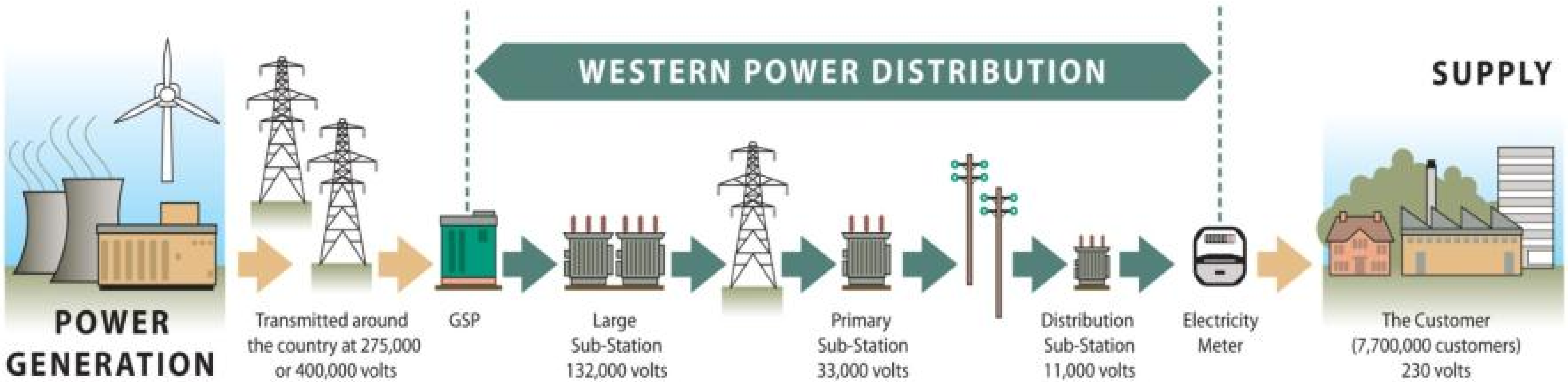
- **Solar Storage**
- **LV Connect and Manage**
- **Sunshine Tariff**
- **Car Connect: Electric Nation**
- **Virtual Private Wires**
- **Industrial and Commercial Storage**

- **DSO/SO Shared Services**
- **Project Sync**
- **Project Entire: Flexible Power**
- **Integrated Network Model**
- **Smart Meter Exploitation**
- **Distribution Operability Framework**
- **Data Analytics**
- **Voltage Level Assessment**
- **LV Connectivity**
- **Smart Systems and Heat[2]**

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

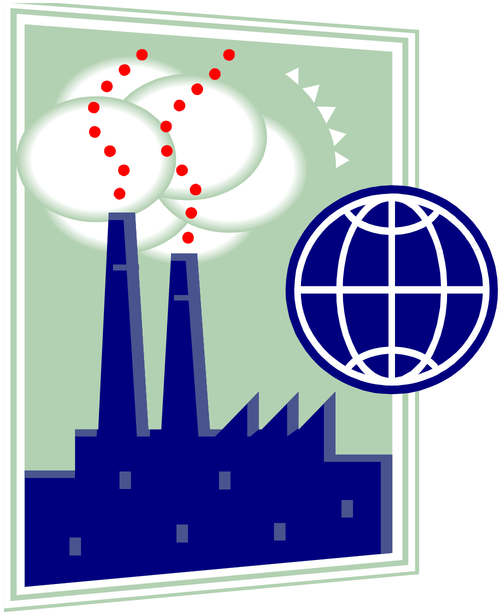
Traditional Role of the DNO



WESTERN POWER DISTRIBUTION INNOVATION

Network Changes - Drivers

- Climate change and international agreements on reducing carbon emissions
- EU and UK binding targets – delivered through renewable DG, EV, RHI
- Rapid changes in GB generation
  - Much more DG
  - Volatile market/incentives
  - Increased need for local and coincidental demand
- Consideration of whole system issues
  - Power
  - Energy
  - Also Gas, Heat and transport fuels
- Significant uncertainty over the pace of change
  - Risk of stranded assets
- Long lead time to build conventional capacity



Network Changes - Drivers

Intermittent renewable DG

- Summertime, daytime DG peaks
- Limited contribution to Winter demand peaks

Electrification of heat and transport

- Larger peaks
- Potentially volatile to external events

Storage – falling prices and mass production

- Potentially disruptive to existing customer profiles
- …but to also be used to help

Building a passive grid to cater for unmanaged peaks is cost prohibitive

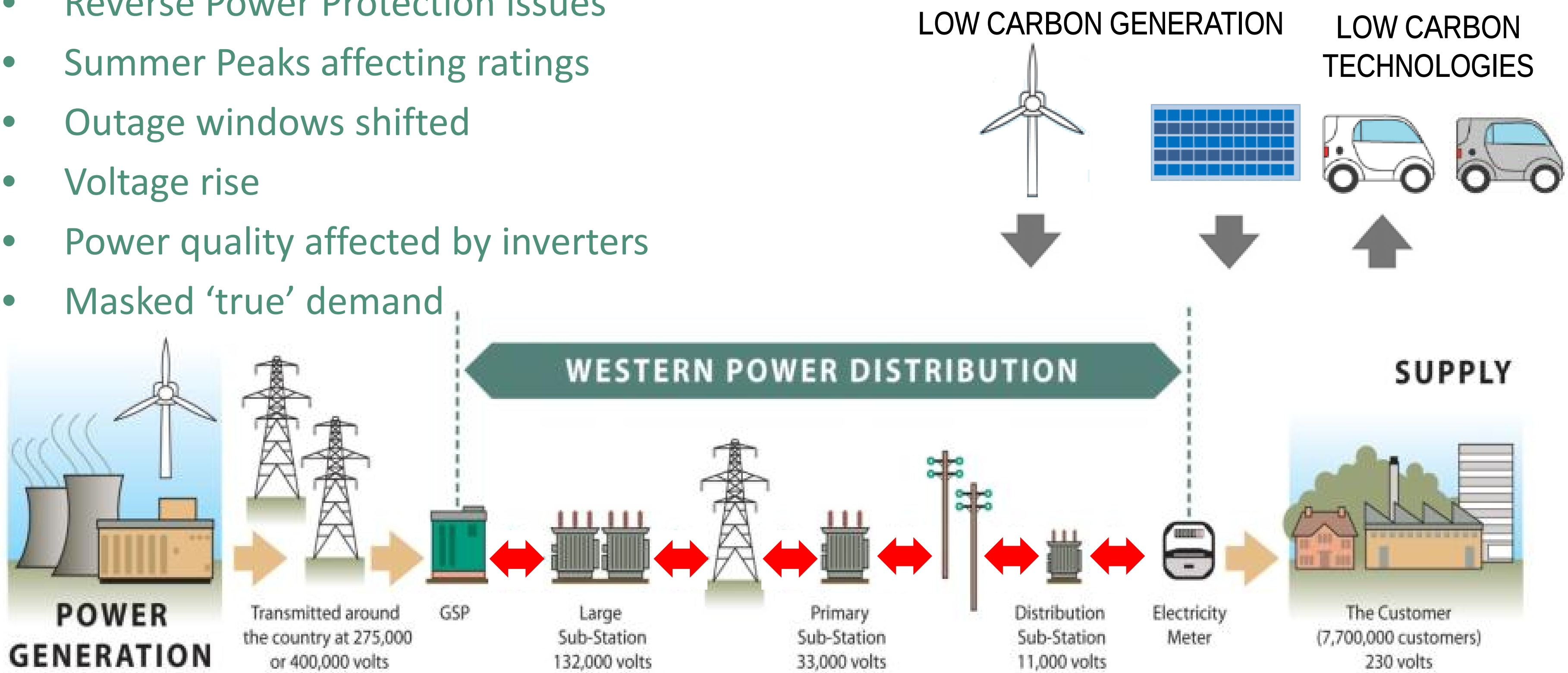
- Customer interest in managed connections (eg ANM)

Coordination with GBSO essential

- Avoid paying for conflicting services
- Distribution network compliance and customer service
- Facilitate residual balancing by the SO

Distribution Network Transformations

- Bi-directional power flow
- Exporting GSPs
- Potential increase in Fault Level
- Reverse Power Protection issues
- Summer Peaks affecting ratings
- Outage windows shifted
- Voltage rise
- Power quality affected by inverters
- Masked 'true' demand



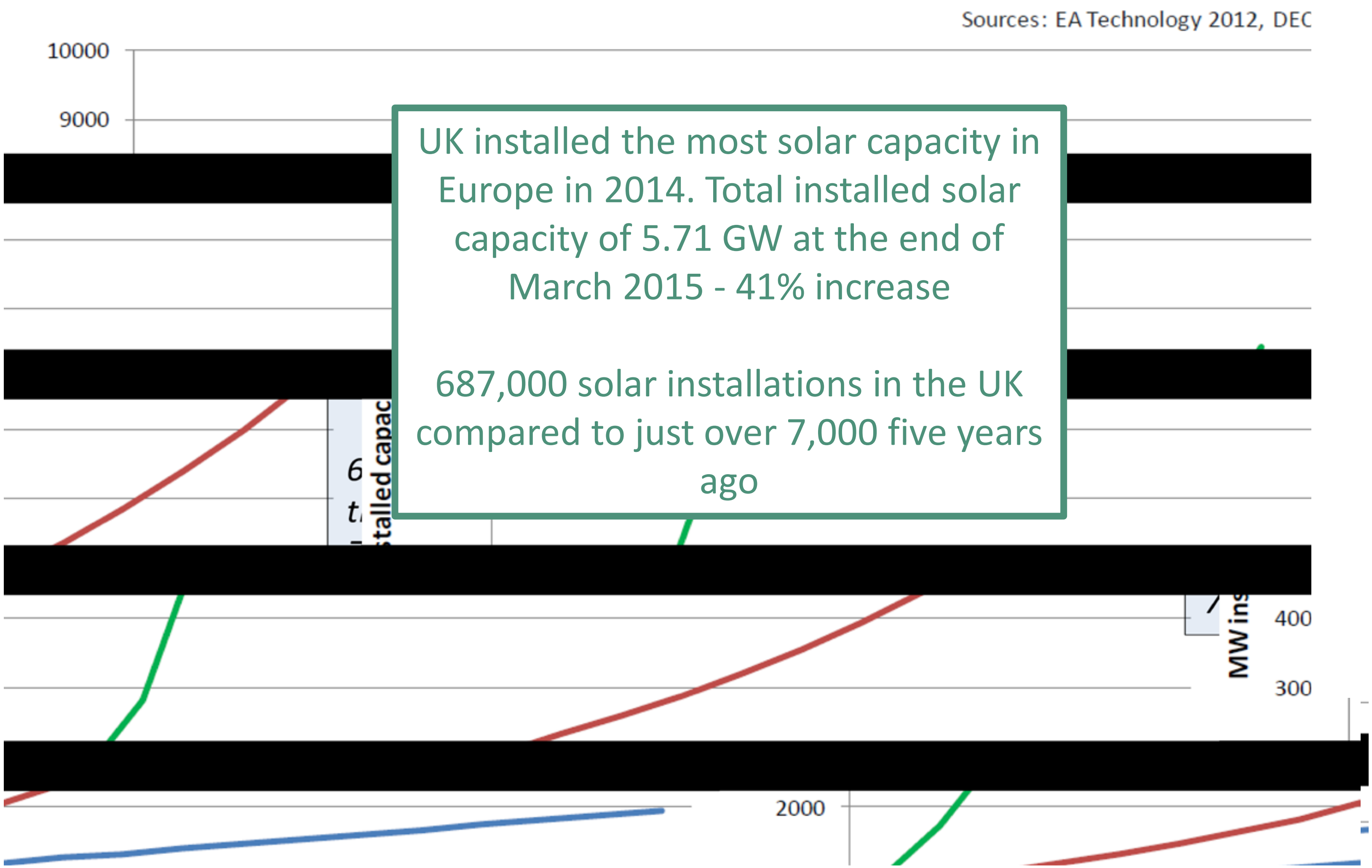
Role of the DSO – WPD's view

- Understanding historic and real time energy flows
- Forecasting future energy volumes across the network (under different scenarios),
- Actively reconfiguring the system dependent on need (ranging from seasonal adjustments through to fine adjustments pre gate closure)
- Contracting/despatching DER through commercial arrangements
- Operation of storage and DG where no commercial provider exists, where technically needed or when more cost effective
- Coordinating DSO operations with the GBSO (and potentially providing some services to the SO)
- Maintaining a platform for energy suppliers, communities and other market participants to have visibility of network congestion (and to offer the DSO flexible demand or DG solutions)

Not the Role of the DSO – WPD's view

- Will not replace the Transmission System Operator (TSO)
  - Will not manage frequency
  - Or national balancing
- Will not be operating an additional Energy Market
- Will not operate on other DNO networks
- Will not loose site of prime objectives of operating an affordable, resilient and safe network

Connecting Renewables



[redacted]

UK installed the most solar capacity in Europe in 2014. Total installed solar capacity of 5.71 GW at the end of March 2015 - 41% increase

687,000 solar installations in the UK compared to just over 7,000 five years ago

Renewables in Numbers (WPD)

50,00
connection enquirie

6,000

.7GW
tal DG connected

14.1G
maximum de

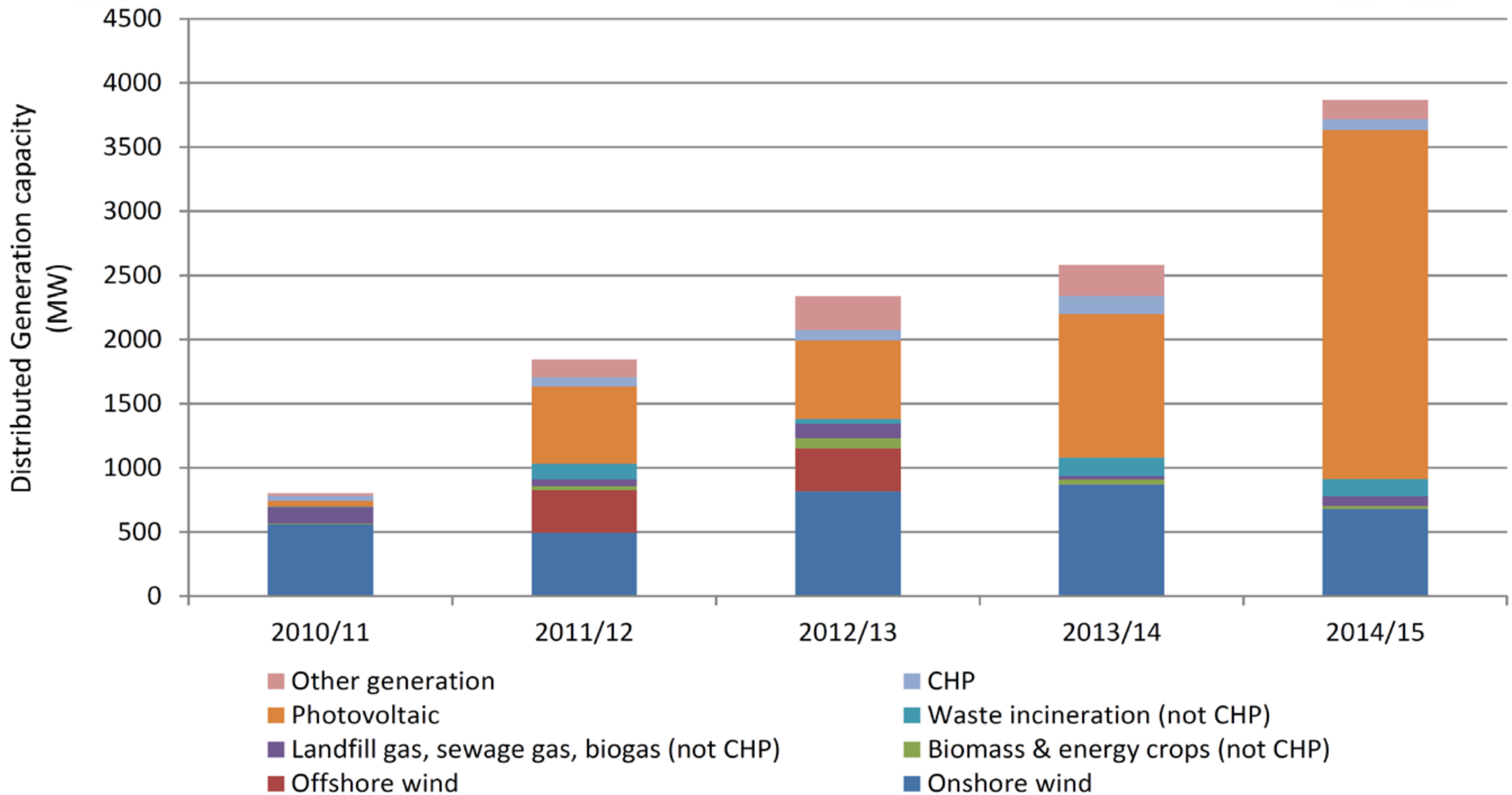
>8GW
accepted and preparing to connect

5.1G
minimum de

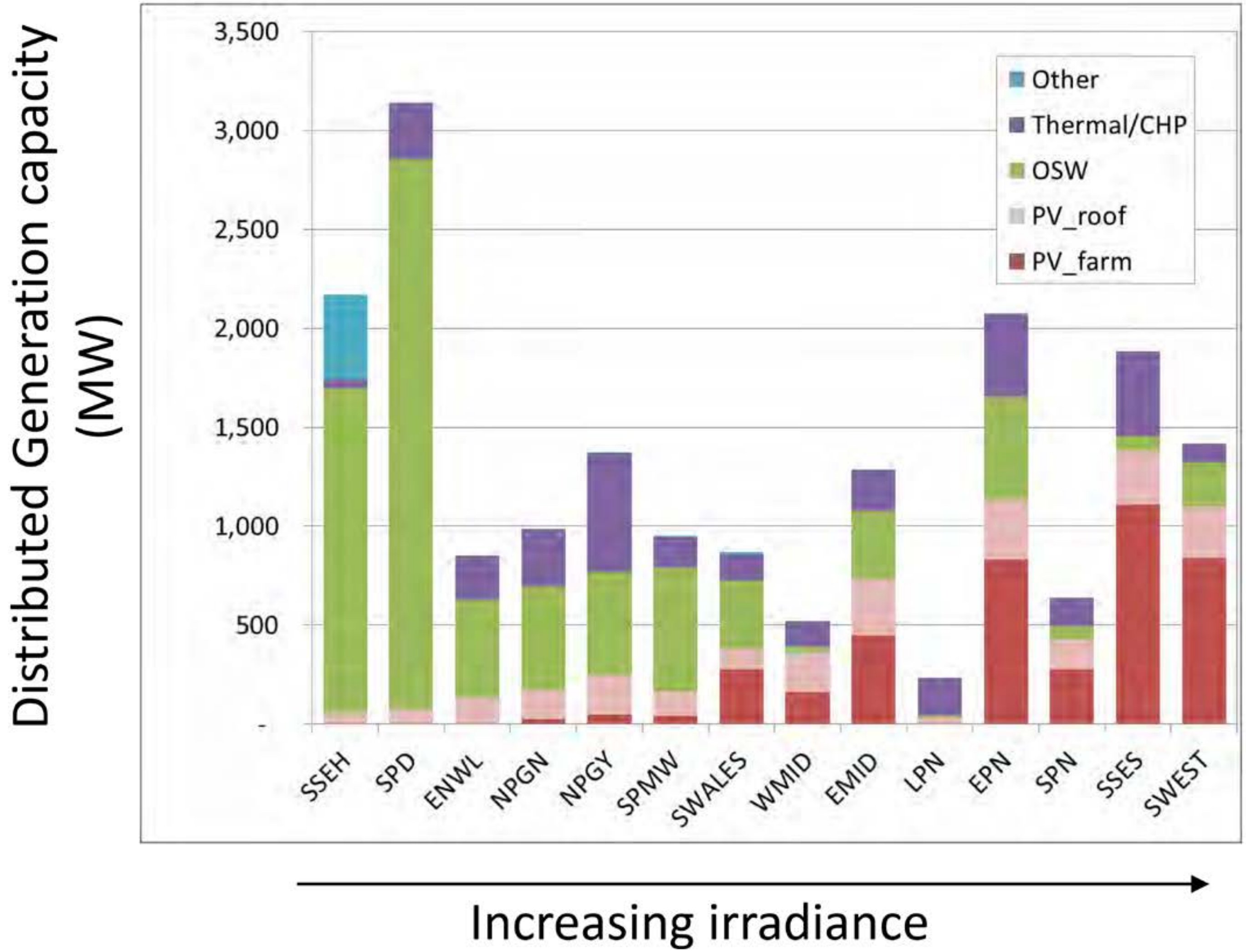
.1GW
G connected in 2014

EHV

Renewables in Numbers (UK)

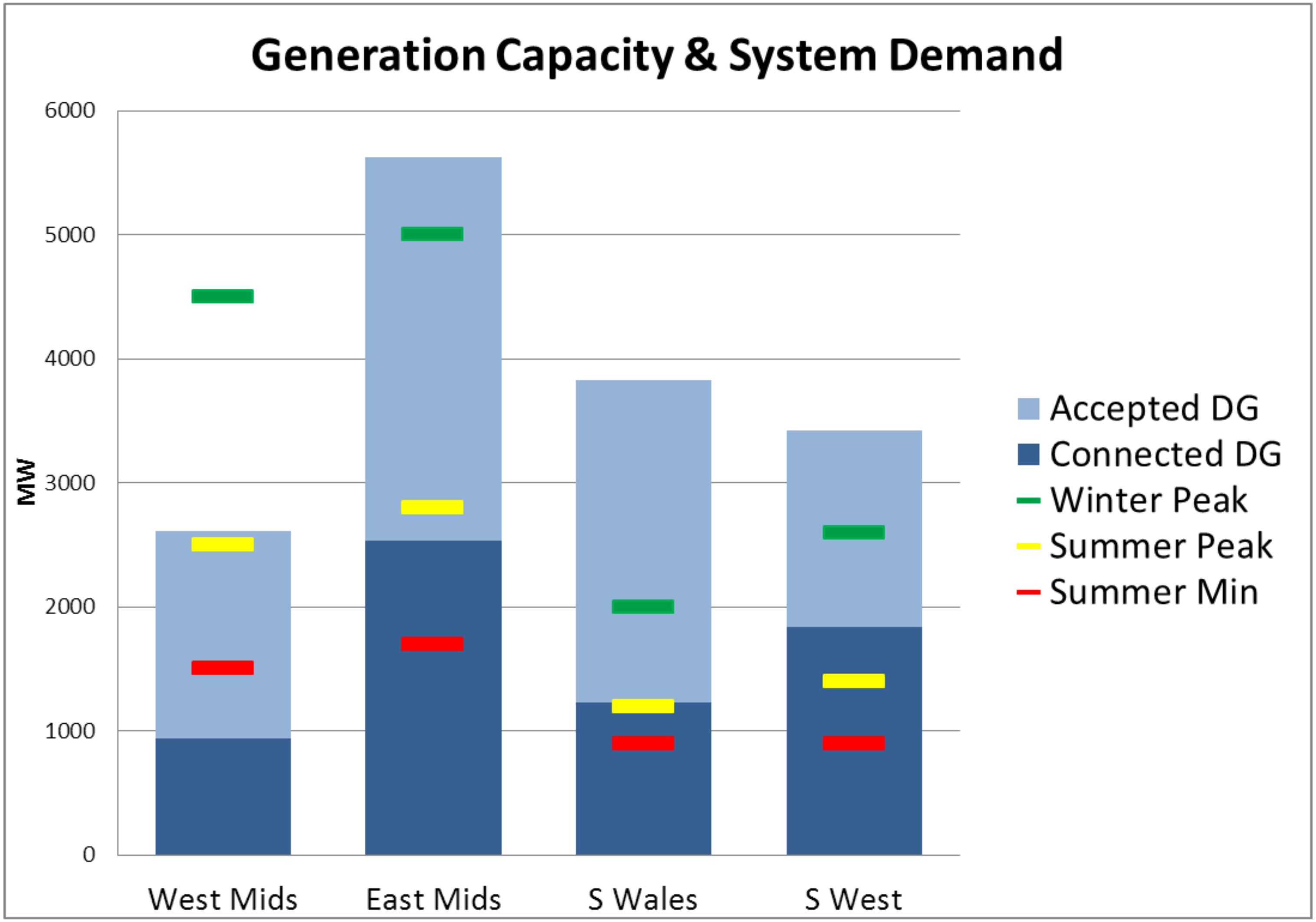


Renewables in Numbers (UK)



WESTERN POWER DISTRIBUTION INNOVATION

Distribution Network Transformations



WESTERN POWER DISTRIBUTION INNOVATION

FlexDGrid

What are we doing?

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

Why are we doing it?

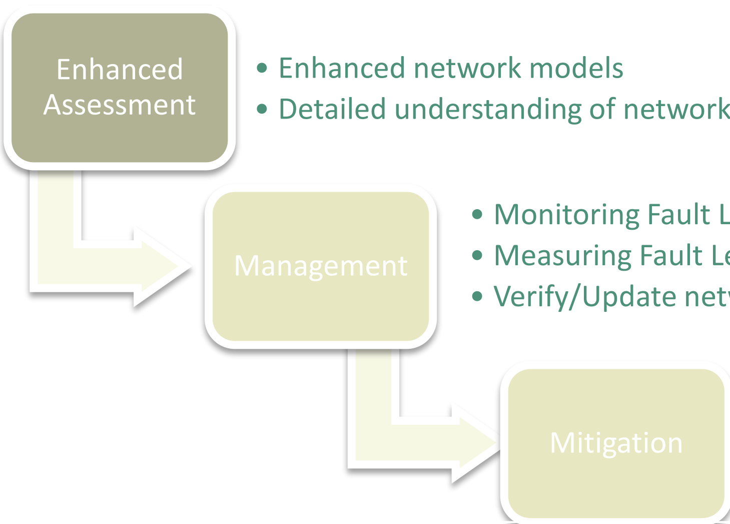
Facilitating the early and cost effective integration of Low Carbon generation

Why are we doing it now?

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

What is FlexDGrid?

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



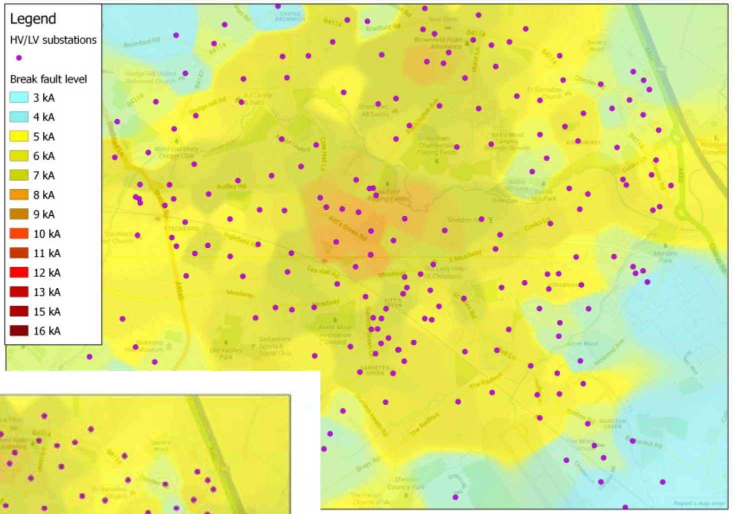
- Enhanced network models
- Detailed understanding of network Fault Level

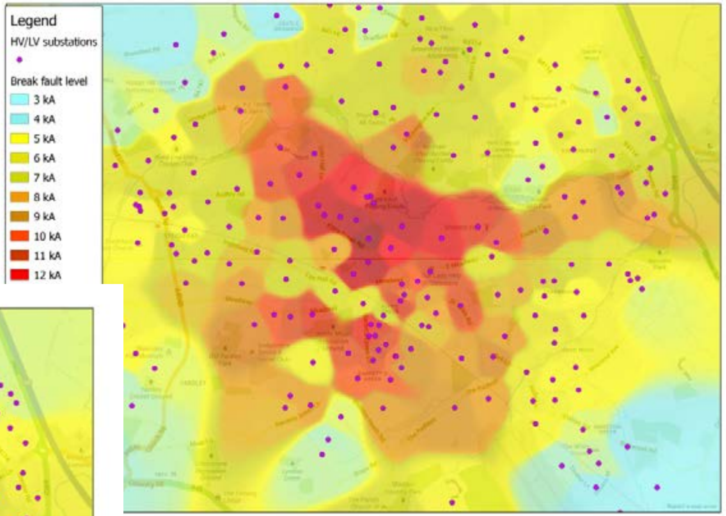
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

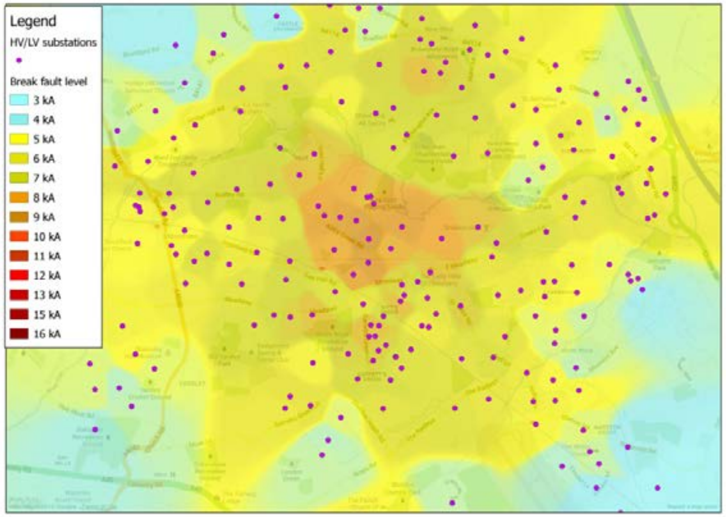
- Reduction of system Fault Level
- Utilised from output of Management

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





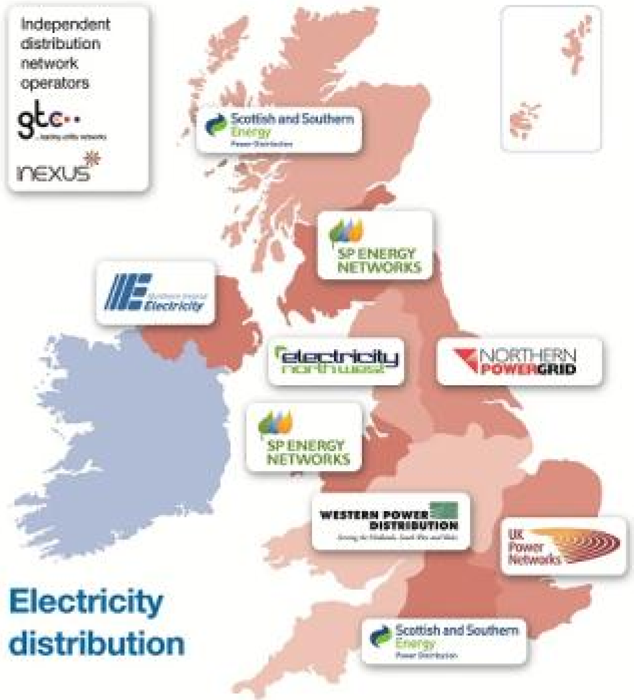


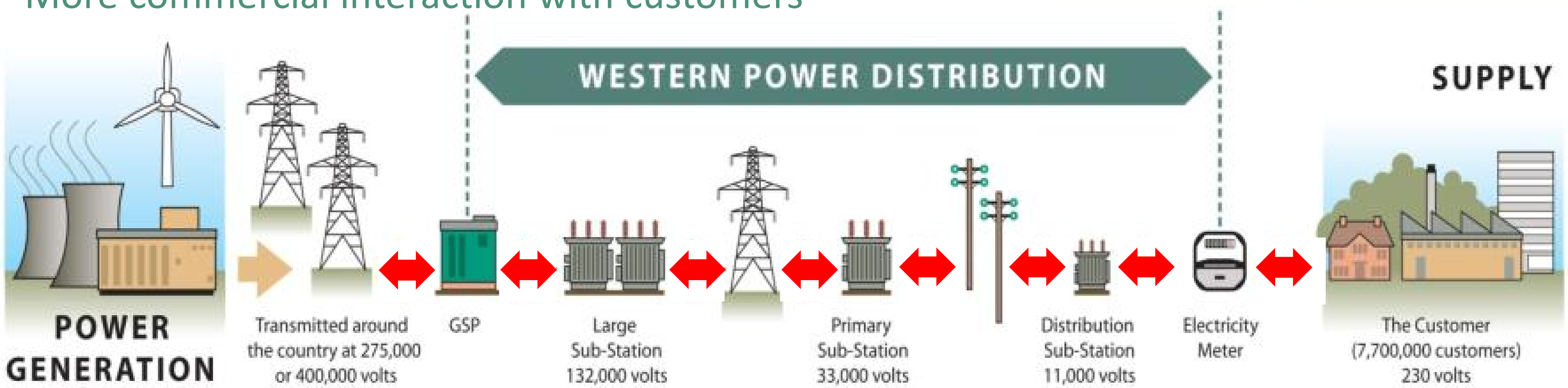
Fault Level Heat Maps

Who Are We? (Future)

•7.8 Million customers over a 55,300 sq kms service area
•Our network consists of 220,000 kms of overhead lines and underground cables, and 185,000 substations
•LV to 132kV Network ownership

•Managing Energy not Power
•Demand response contracts
•Balancing & Settlement
•Enhanced connections
•More commercial interaction with customers





Ideas for Projects

- Focussed issues and problems identified
- Scope of project and solution
- Timescales and Implementation

THANKS FOR LISTENING

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WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Active Fault Decoupler Development

Power Electronics in Distribution Networks

30th November 2016

Jonathan Berry

Innovation & Low Carbon Networks Engineer

LCN Fund Low Carbon Networks THE UNIVERSITY OF WARWICK PARSONS BRINCKERHOFF

Introduction

- Who We Are
- WPD Innovation Portfolio
- FlexDGrid Overview
- AFD Requirements
- Developments and Issues
- Key Learning

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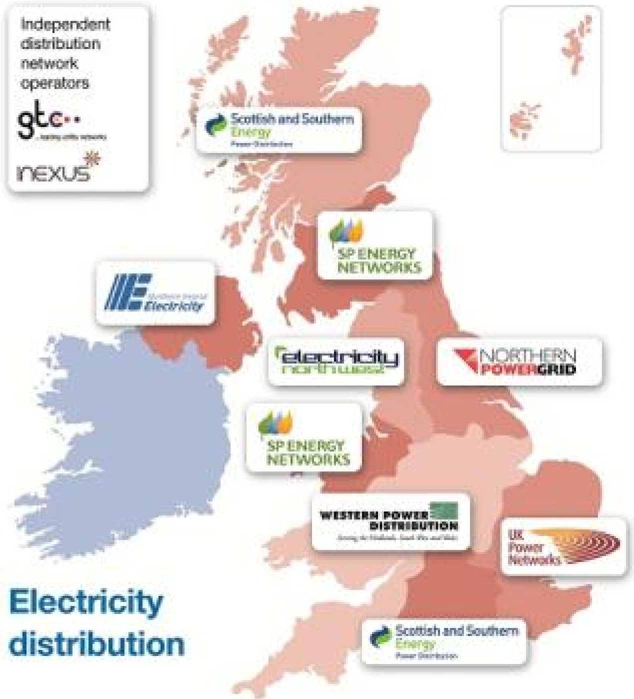

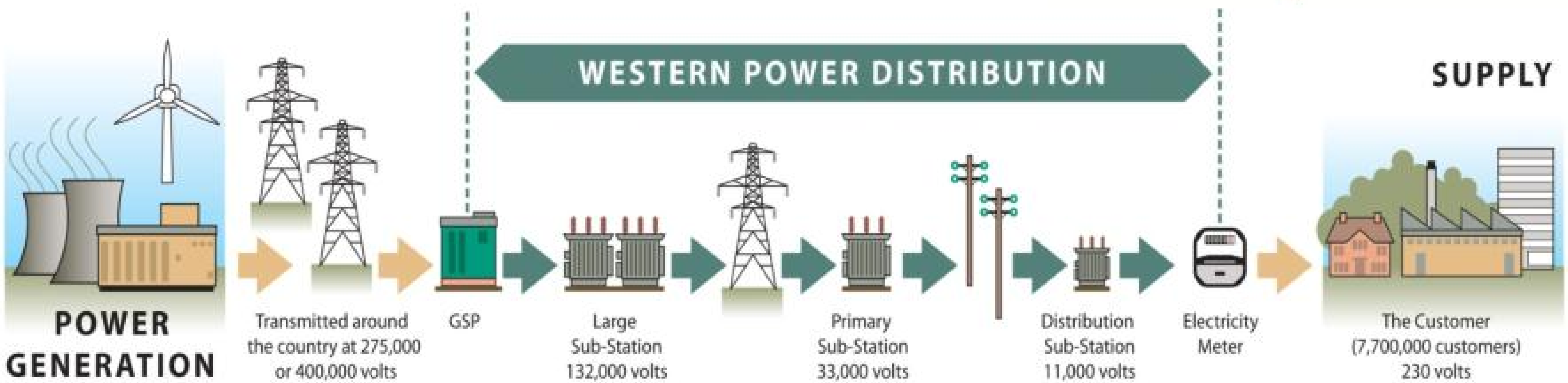

WESTERN POWER DISTRIBUTION FLEXDGRID

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

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

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

Enhanced Assessment

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- Detailed understanding of network Fault Level

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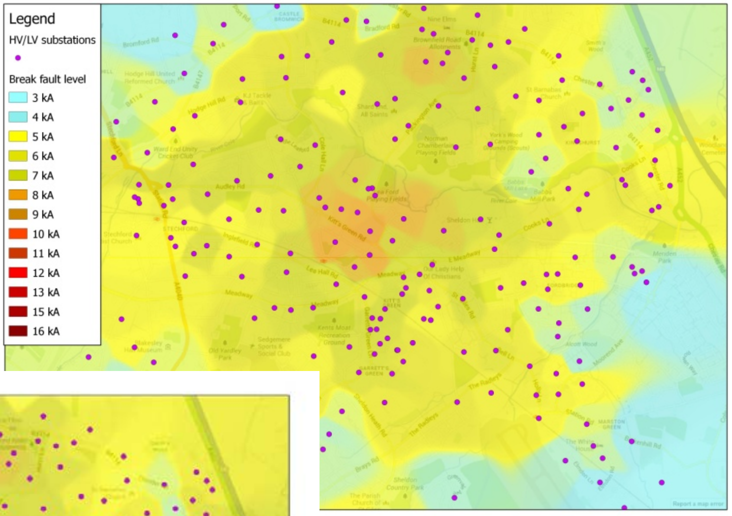
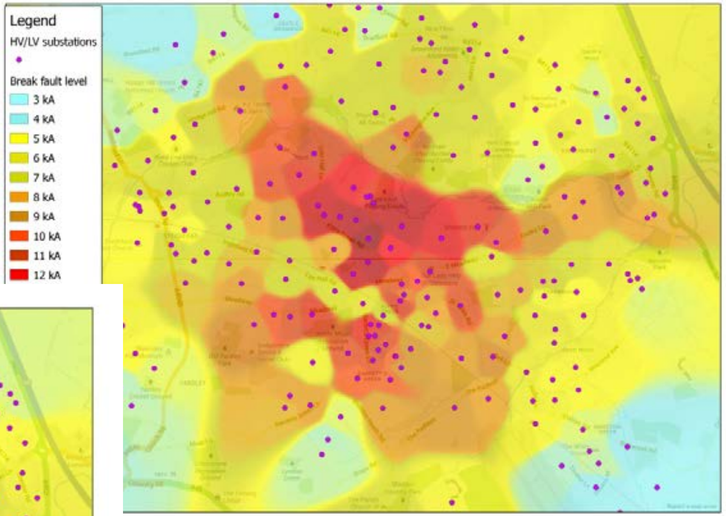
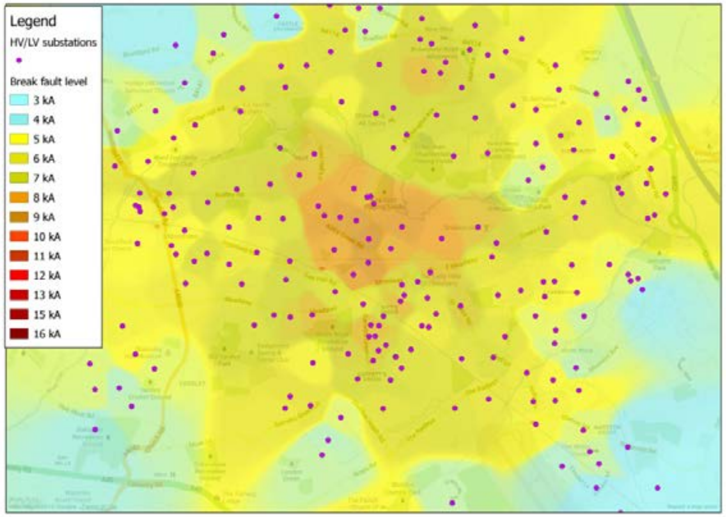
WESTERN POWER DISTRIBUTION
FLEXDGRID

Effect on Fault Level







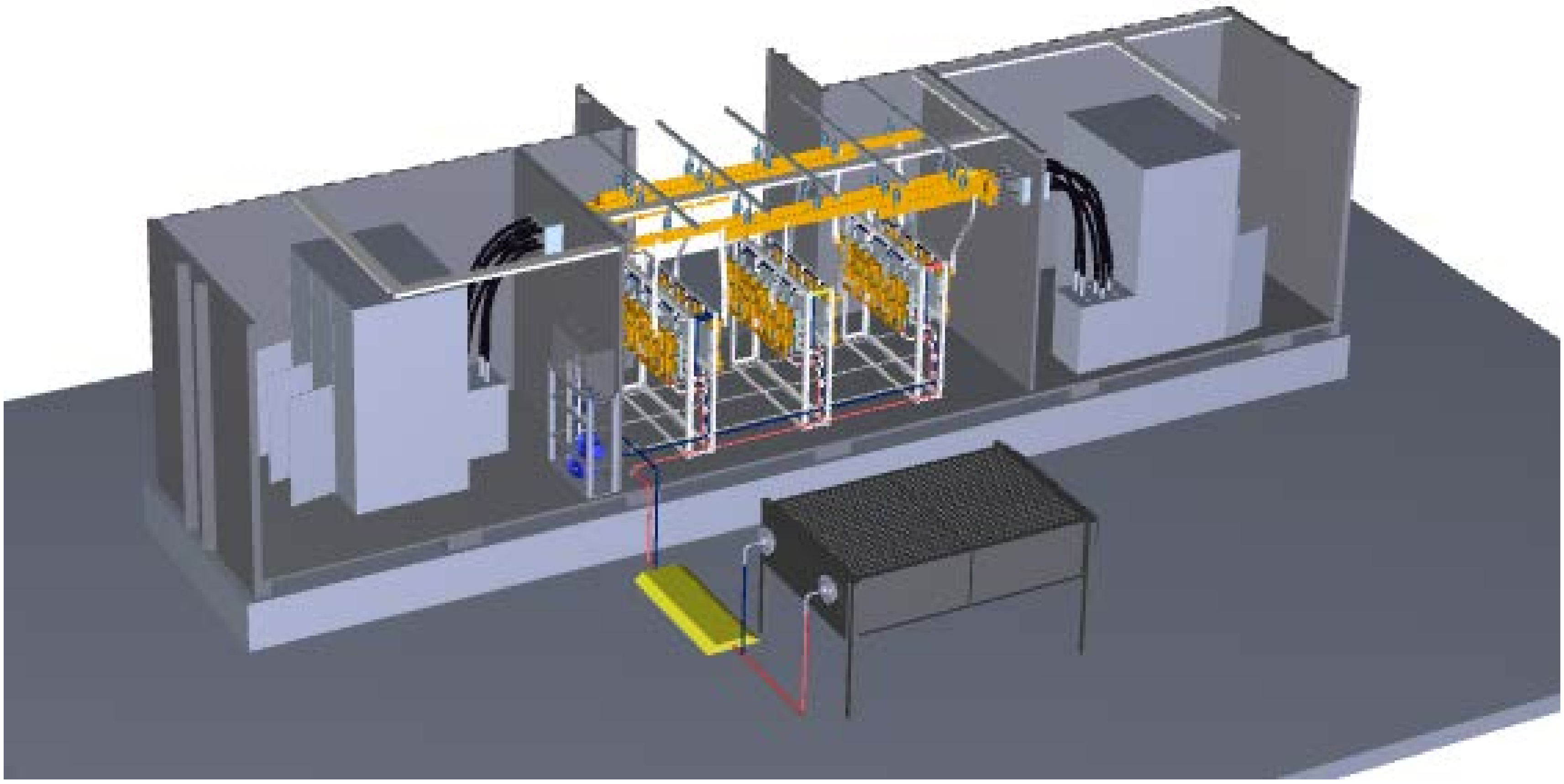
Fault Level Heat Maps

AFD Requirements

- Ability to disconnect two distinct networks from each other, for the instant a fault is seen on either network, within 10ms;
- Continuously carry 2000A at 11kV;
- Compact design; and
- Repeatable solution.

Power Electronic 11kV Circuit Breaker

AFD Requirements



Development and Issues

- Current Interruption
  - Significant transient overvoltage that could not be absorbed
- IGBT Voltage Sharing
  - Design did not ensure that IGBTs would equally share, subjecting some to undue stress
- Insulation Level
  - Clearances and materials selected were not adequate

Remedial Actions

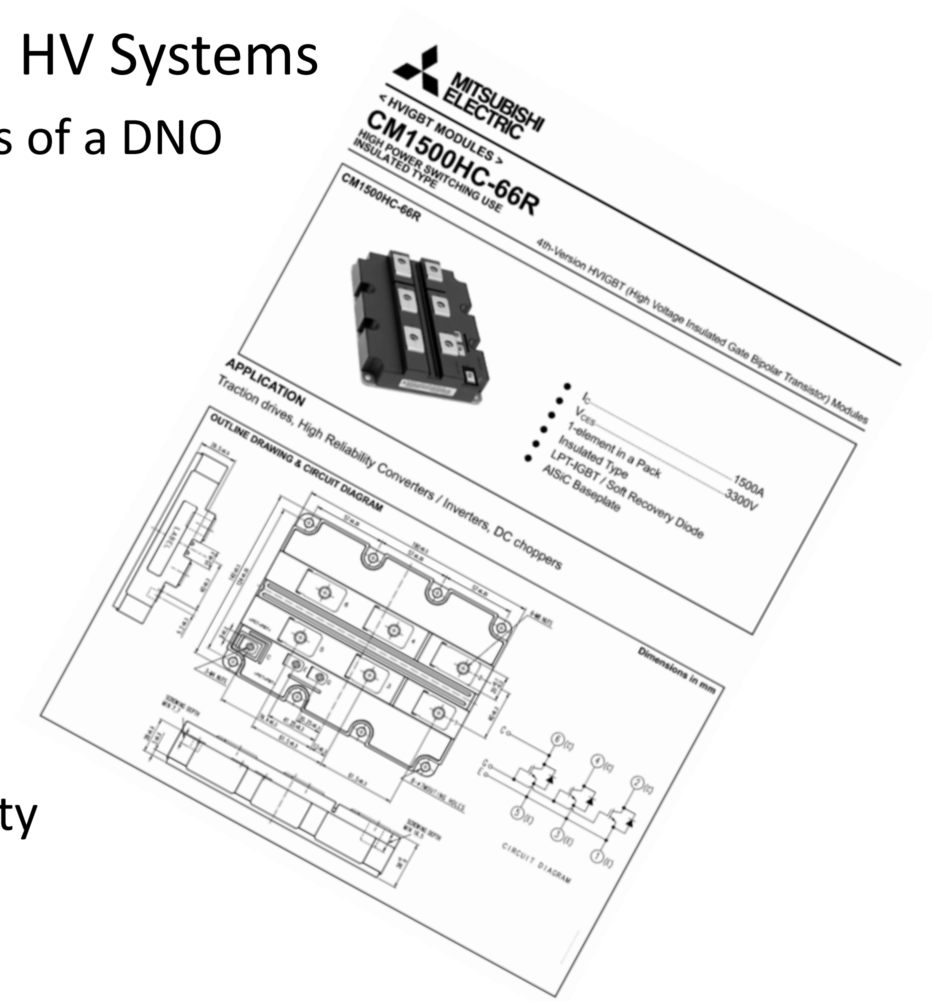
- Current Interruption
  - Larger surge arrestors installed
- IGBT Voltage Sharing
  - Implementation of a resistor-capacitor snubber circuit
- Insulation Level
  - Complete re-design of the IGBT enclosure, cooling system and power supplies

Potential Benefits

- Design Requirements
  - One design is suitable for all (most!) site installations
  - Ease of inclusion in to existing network
- Cost
  - Favourable compared to competing technologies
- Performance
  - Complete removal of additional fault current contribution

Key Learning

- Skills - Power Electronics and HV Systems
  - Manufacturers – Requirements of a DNO
  - DNOs - Technology
- Operation and Control
  - Fault detection
  - On-going performance
- Critical Testing Criteria
  - Demonstrate network suitability



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WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

Fault Current Limiters Utilisation and Operation

Jonathan Berry

1st December 2016

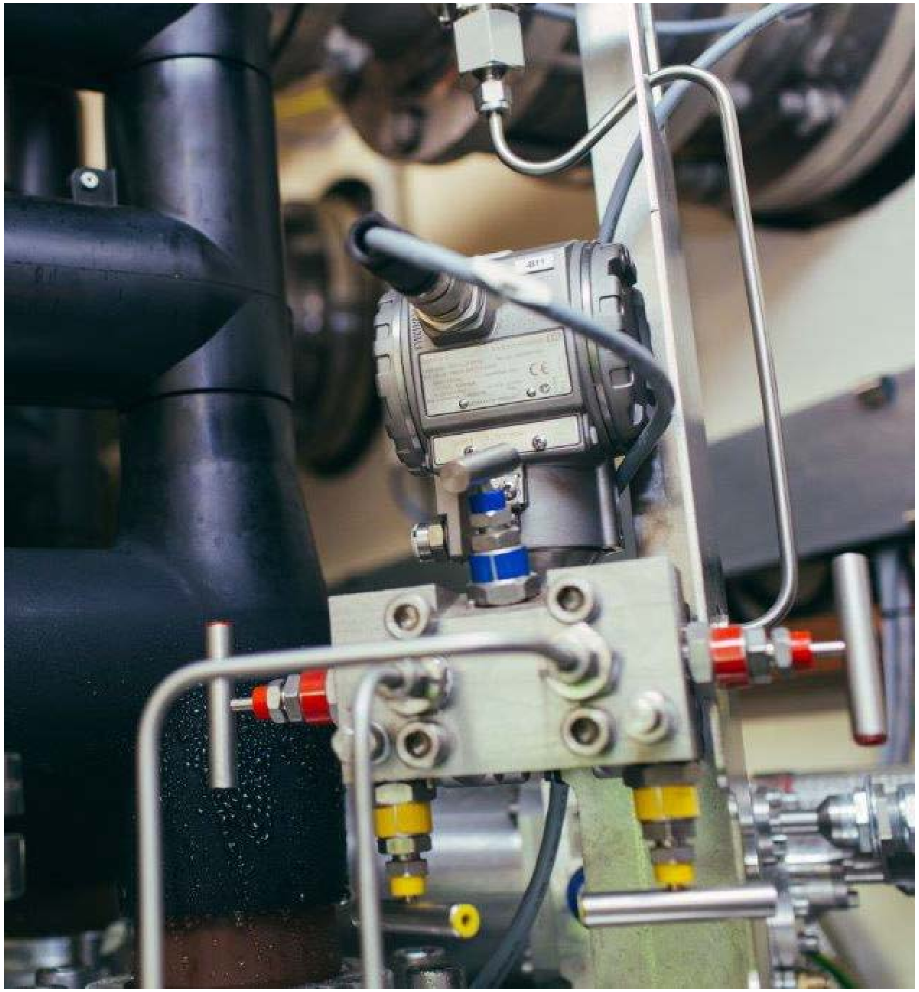
EuroTech Conference

LCN Fund Low Carbon Networks THE UNIVERSITY OF WARWICK PARSONS BRINCKERHOFF

WESTERN POWER DISTRIBUTION
FLEXDGRID

Introduction

- Who we are
- Projects Portfolio
- Fault Level Solutions
  - Traditional
  - New Technologies
- FlexDGrid Overview
- Technology Overview
  - Performance Characteristics
  - Testing
  - Operation



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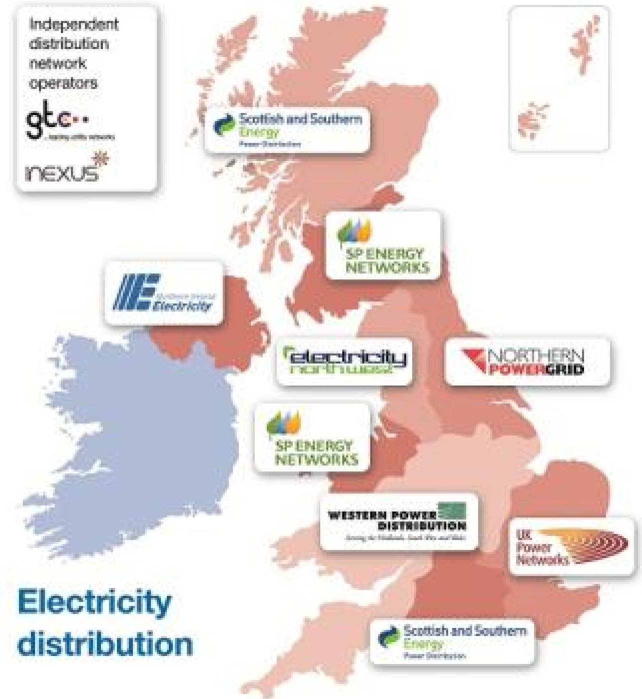

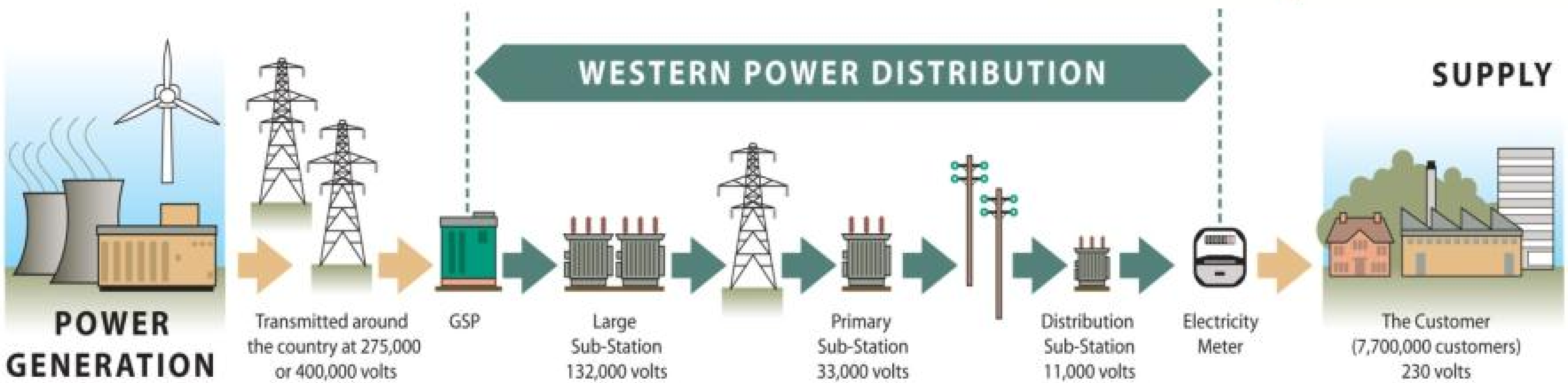

WESTERN POWER DISTRIBUTION FLEXDGRID

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- FLEXDGRID
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WESTERN POWER DISTRIBUTION
FLEXDGRID

Traditional Fault Level Solutions

- Replacement of Switchgear
  - Higher Fault Level Rating

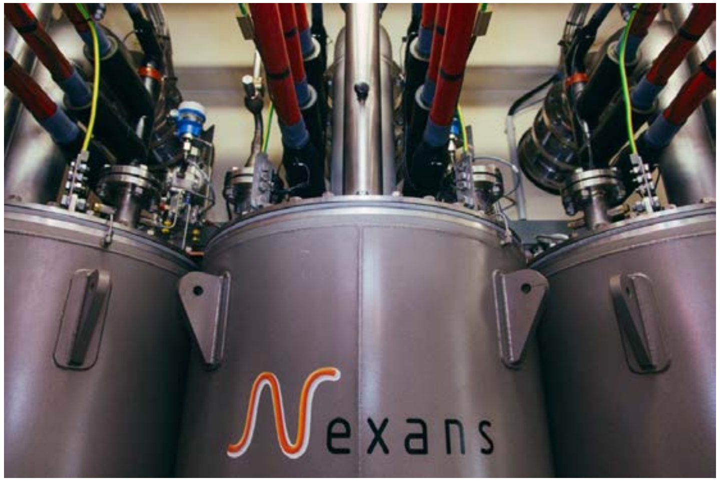
- Issues
  - Replacement of otherwise fit for purpose assets
  - H&S implications
  - Cost and Timescales

Traditional Fault Level Solutions

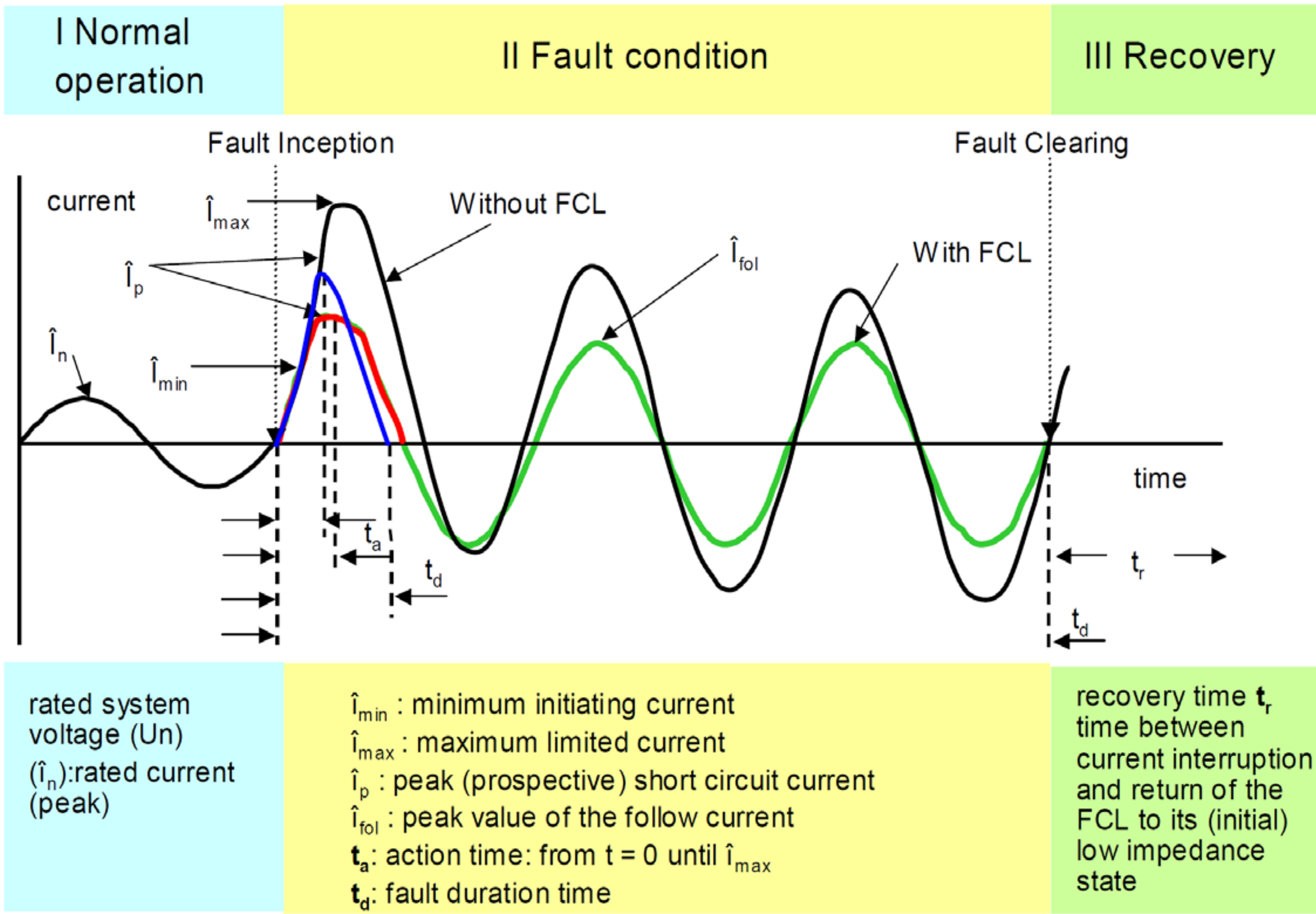
- Replacement of Transformers
  - Reduction in Fault Level
- Issues
  - Replacement of otherwise fit for purpose assets
  - Higher Losses
  - Cost and Timescales

New Fault Level Solutions

- Fault Current Limiters
- No requirement to replace existing (for for purpose) assets
- Greater reduction in fault level
- Faster implementation
- Smaller capex investment(?)
- Additional benefits
  - Loss reduction
  - Increased security

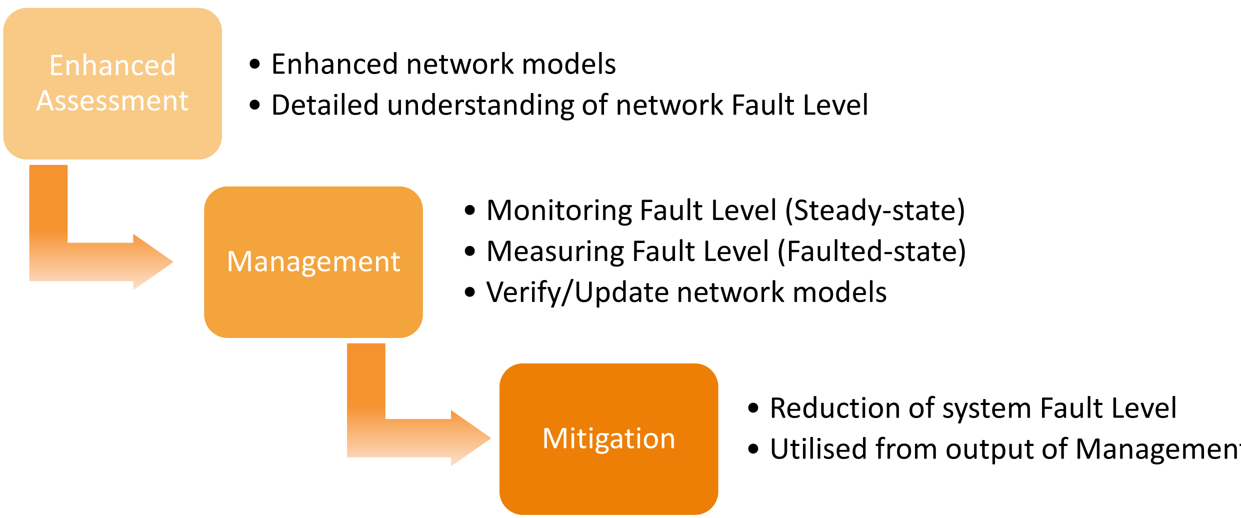


New Fault Level Solutions



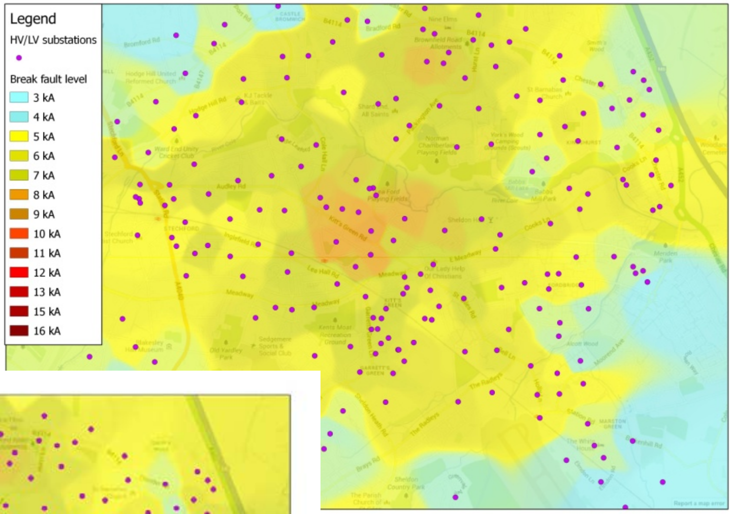
What is FlexDGrid?

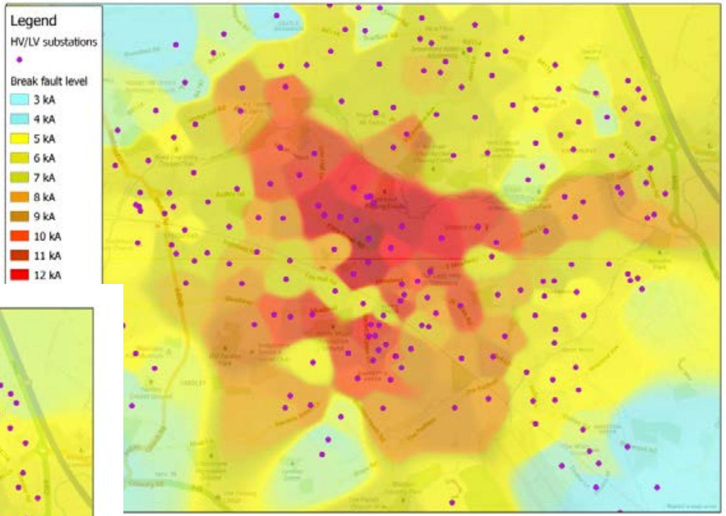
Three integrated Methods leading to quicker and cost effective customer connections through a timely step change in the enhanced understanding, management and mitigation of distribution network Fault Level.

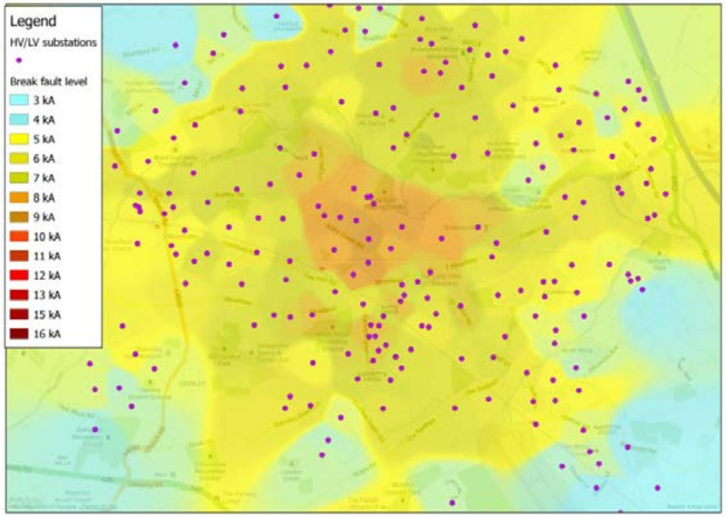


Each Method can be applied on its own whilst the integration of the three Methods combined will provide a system level solution to facilitate the connection of additional Generation.

Effect on Fault Level

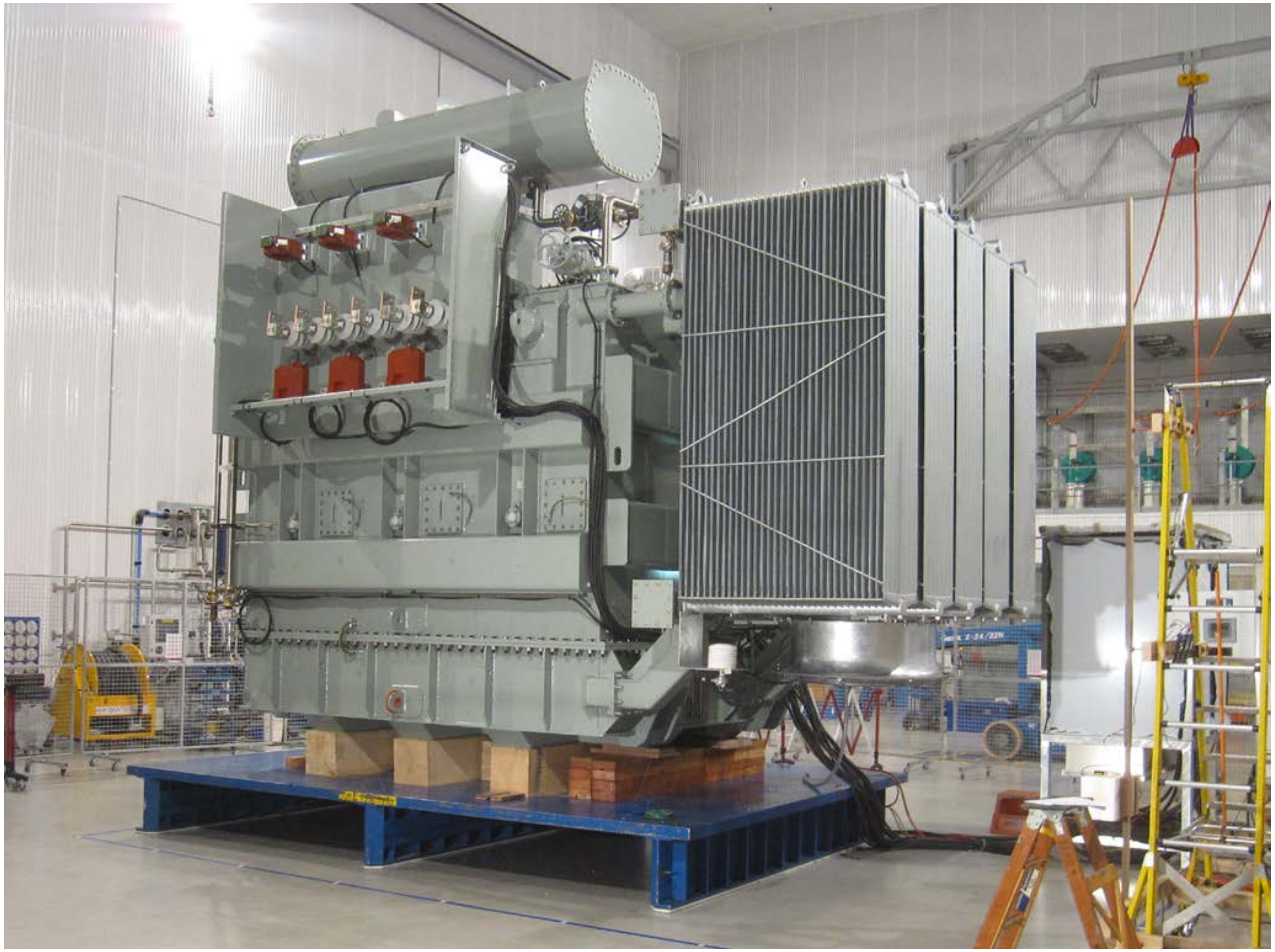






Fault Level Heat Maps

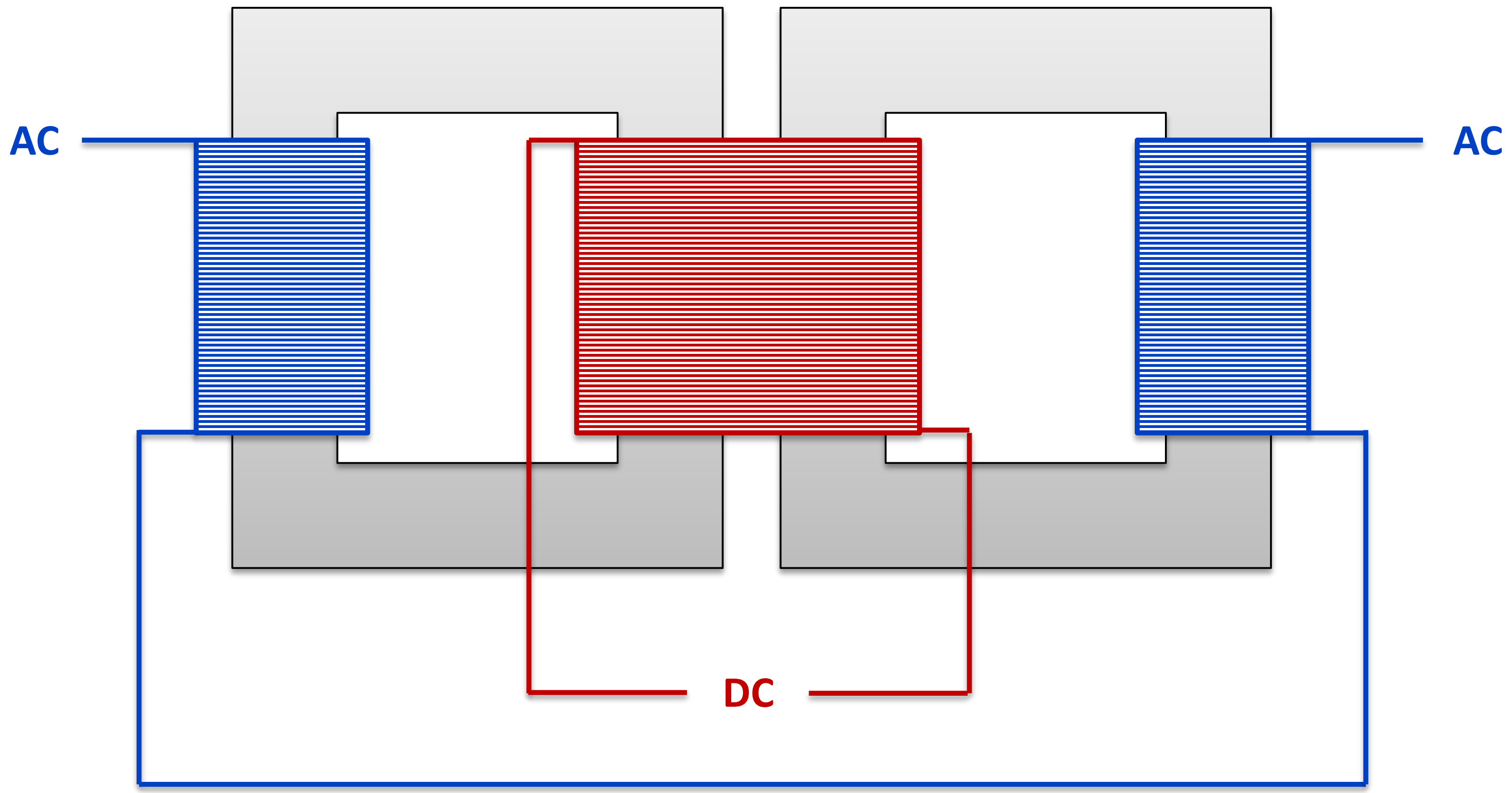
Pre-Saturated Core Fault Current Limiter



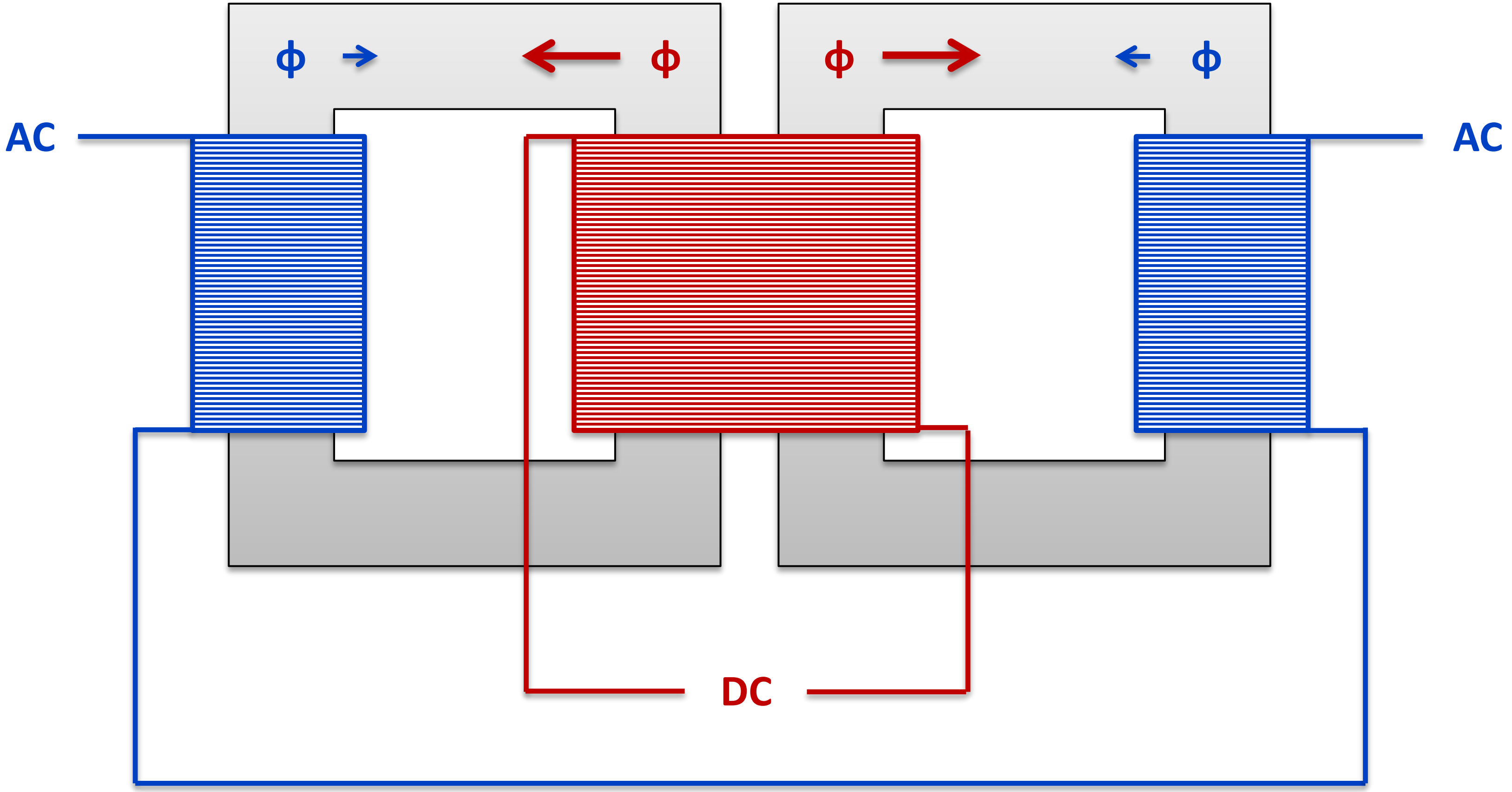
Pre-Saturated Core Fault Current Limiter

- 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)

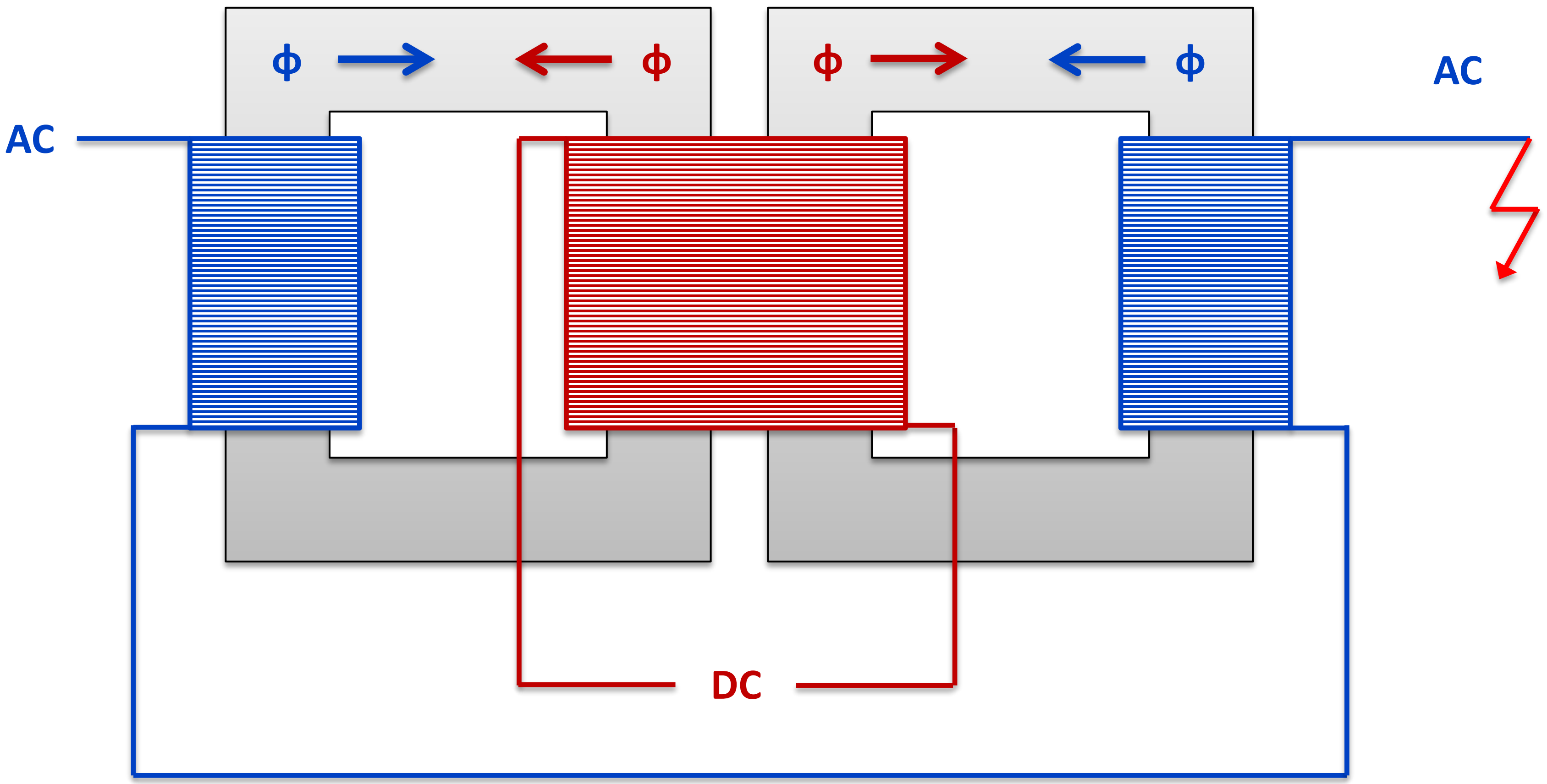
Diagram of PSCFCL



Normal Operation of PSCFCL

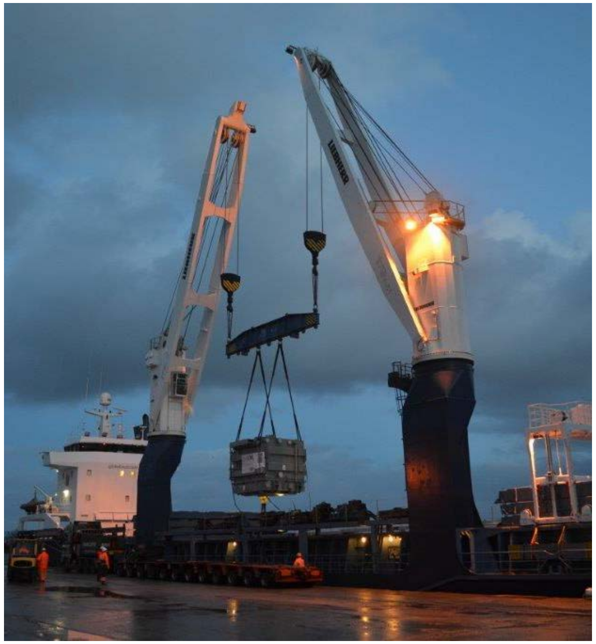


Operation of PSCFCL during a fault



PSCFCL - Details

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



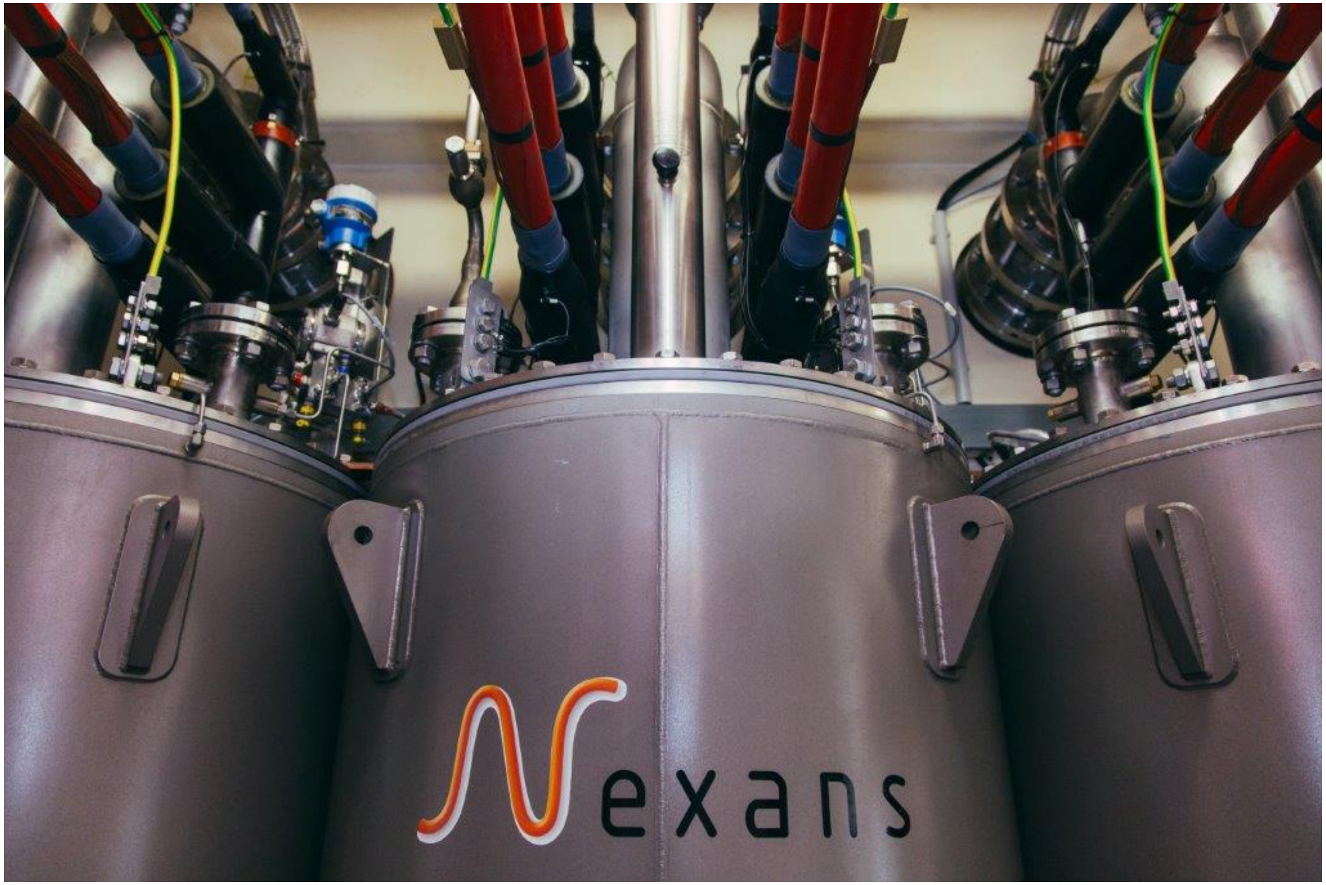
Milestone	Date
Short Circuit Tests	15th August 2014
Factory Tests Complete	6th September 2014
Device Energised	8th April 2015

PSCFCL - Testing

- Summary of short circuit tests

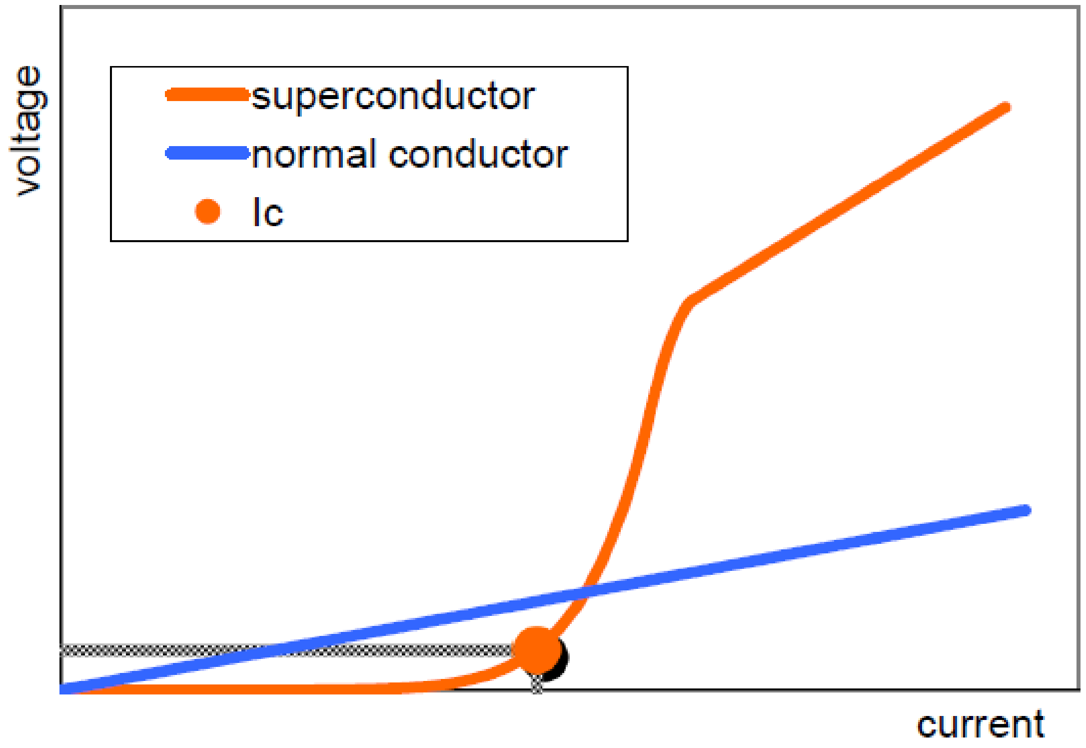
Scenario	Prospective Current	Required Limitation	Actual Limitation
RMS Break (nom. DC Bias)	6.85kA	4.06kA	3.71kA
RMS Break (min. DC Bias)	6.85kA	4.06kA	3.75kA
Peak Make (nom. DC Bias)	20.2kA	10.16kA	10.13kA

Resistive Superconducting Fault Current Limiter



Resistive Superconducting Fault Current Limiter

- Exploits the properties of High Temperature Superconducting (HTS) material (Yttrium barium copper oxide)



RSFCL - Details

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

RSFCL - Testing

- 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

WESTERN POWER DISTRIBUTION
FLEXDGRID

RSFCL - Testing

Chester Street

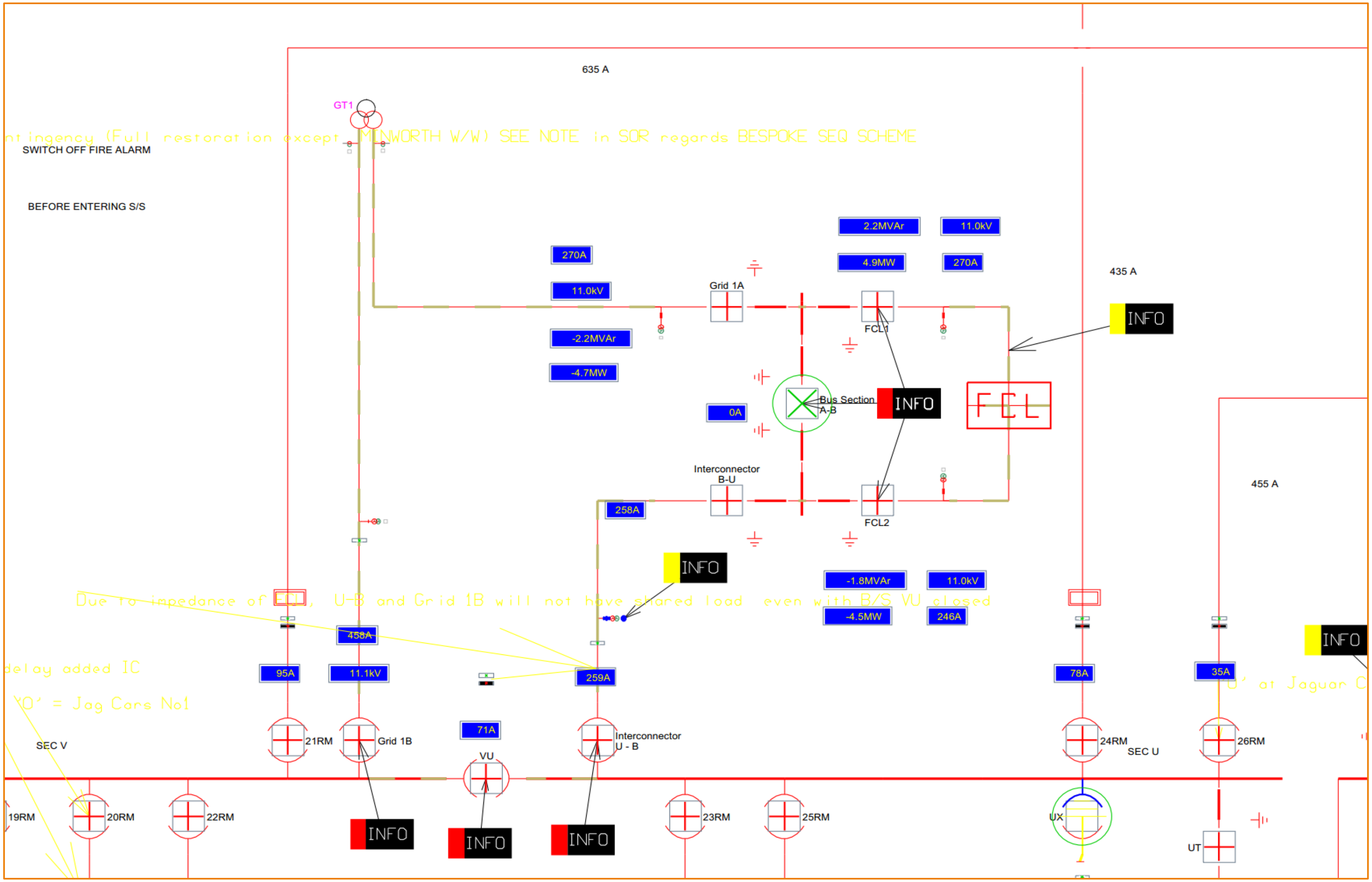
Prospective Current (@10ms) (kA)	Prospective Current (@90ms) (kA)	Applied Phase	Required Limitation (@10ms) (kA)	Required Limitation (@90ms) (kA)	Limited Current (@10ms) (kA)	Limited Current (@90ms) (kA)	Trip Signal (ms)
20.0	7.17	L3	9.90	3.68	9.07	2.86	24.0
20.0	7.17	L3	9.90	3.68	9.11	2.83	15.0
20.0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

Bournville

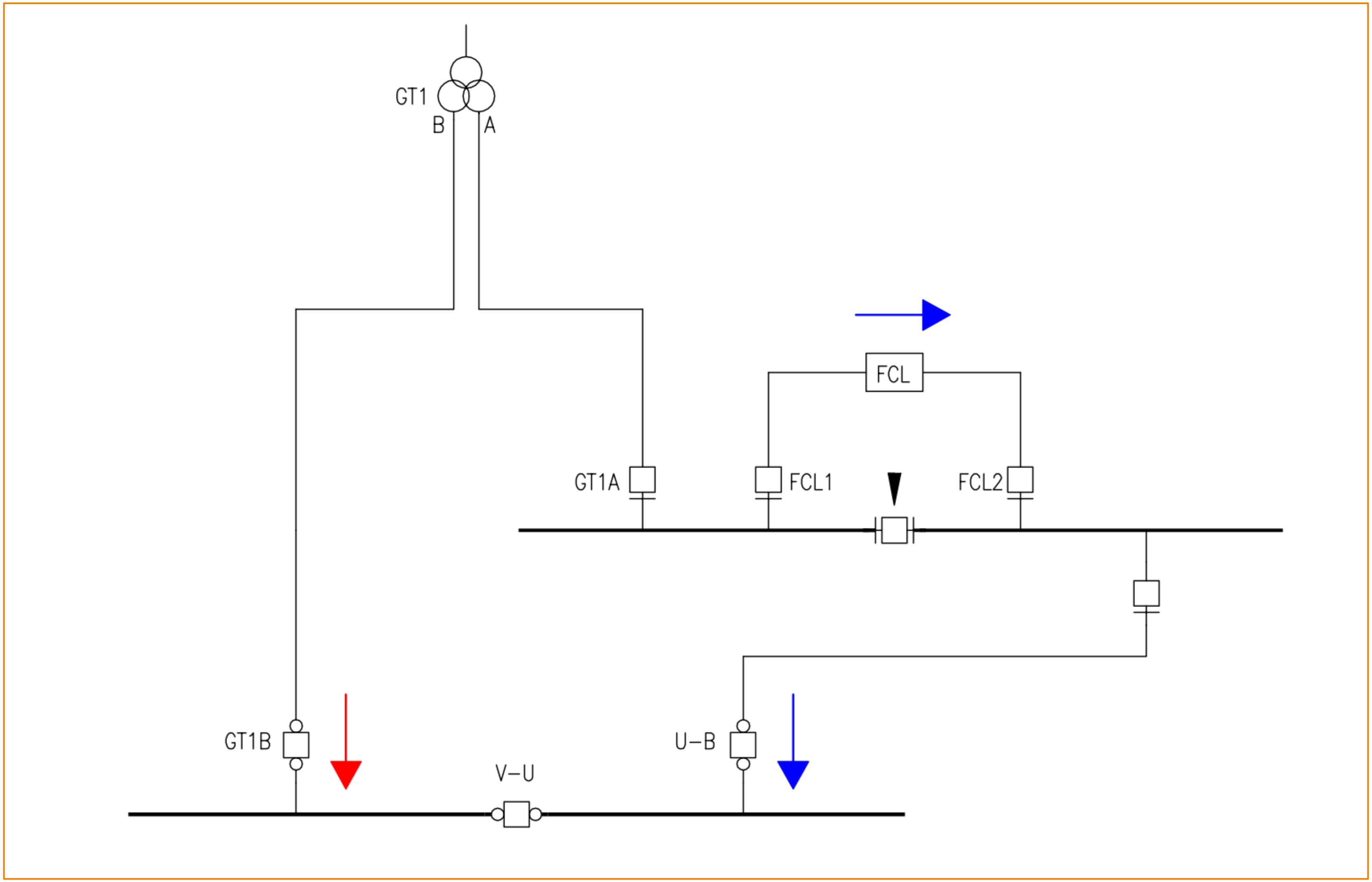
Prospective Current (@10ms) (kA)	Prospective Current (@90ms) (kA)	Applied Phase	Required Limitation (@10ms) (kA)	Required Limitation (@90ms) (kA)	Limited Current (@10ms) (kA)	Limited Current (@90ms) (kA)	Trip Signal (ms)
22.5	8.0	L1	7.70	3.05	6.64	2.05	13.3
22.5	8.0	L2	7.70	3.05	6.56	2.03	13.6
22.5	8.0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

WESTERN POWER DISTRIBUTION
FLEXDGRID

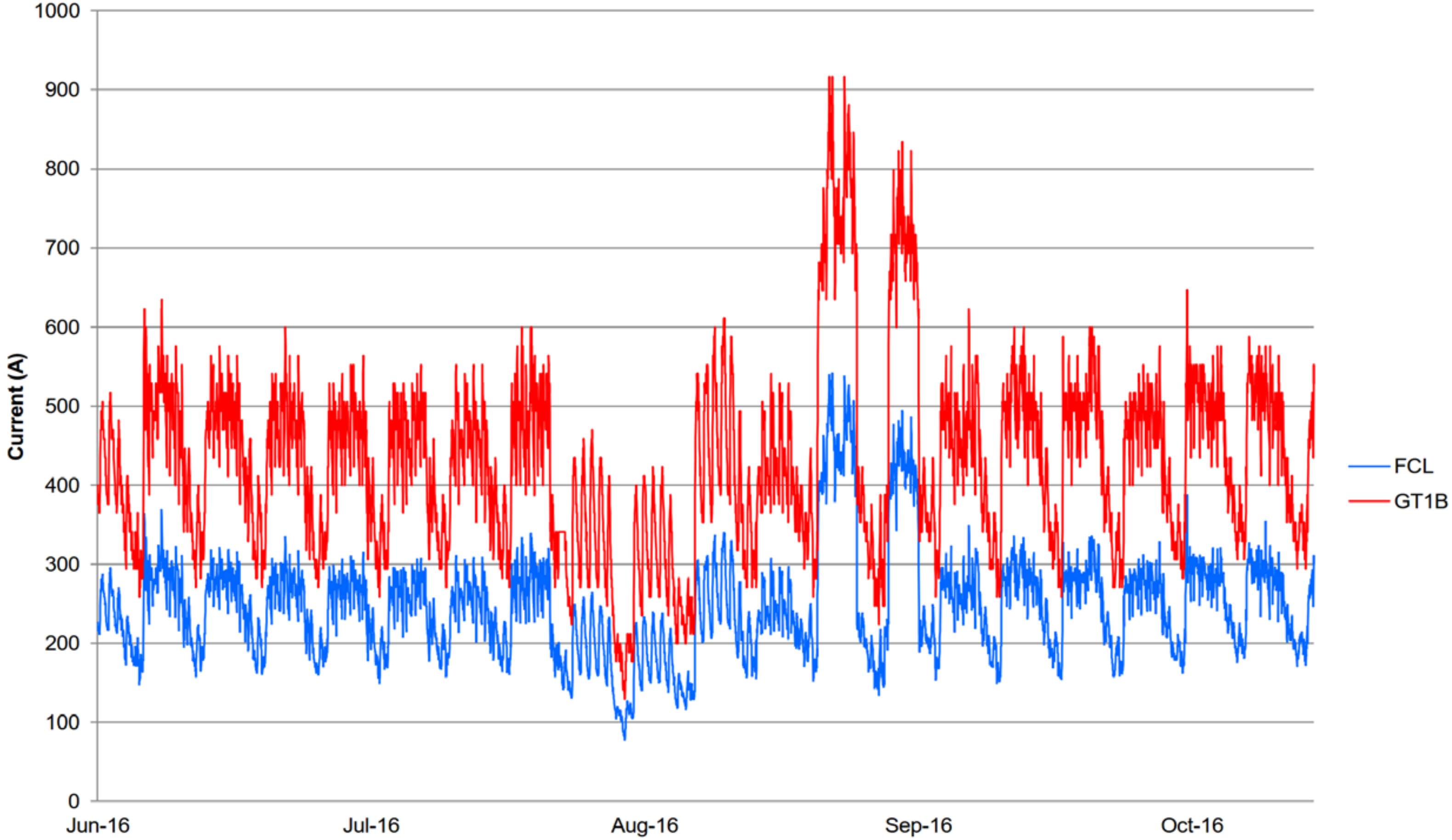
PSCFCL - Operation



PSCFCL - Operation

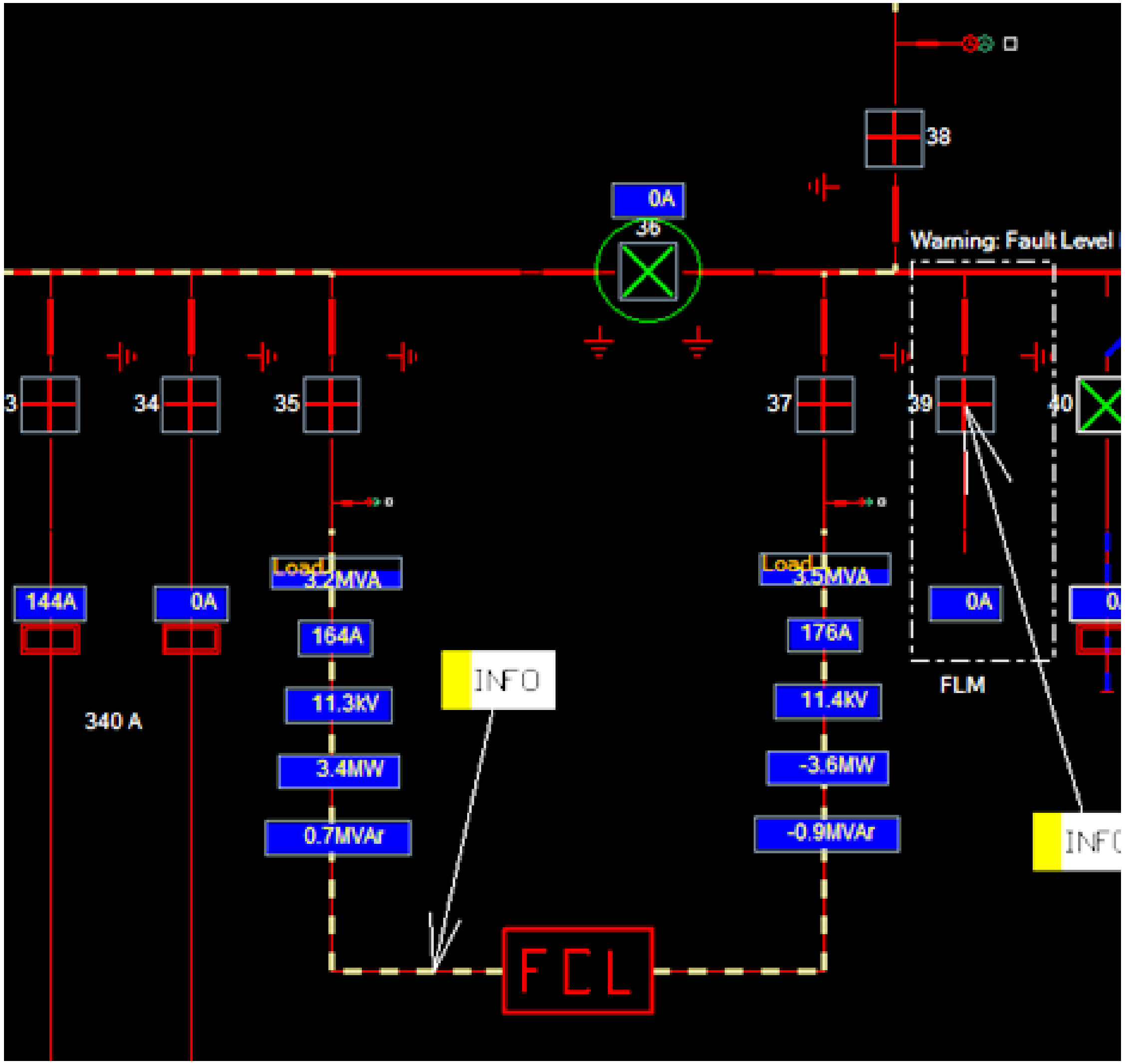


PSCFCL - Operation

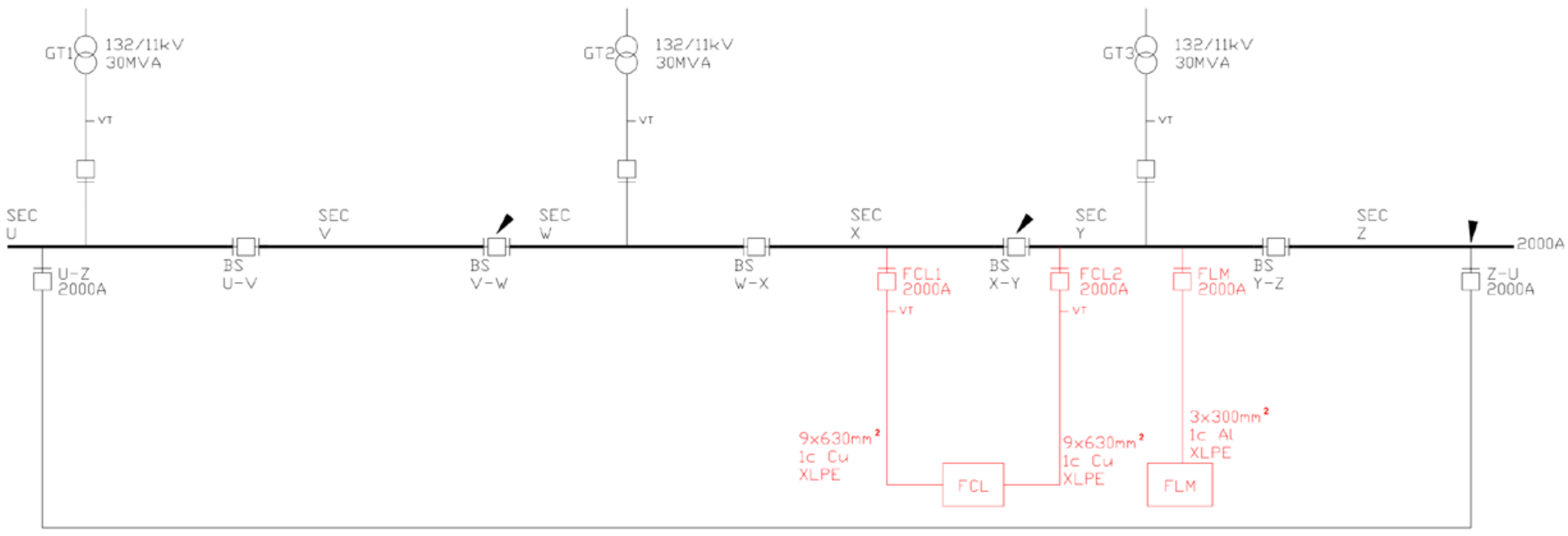


WESTERN POWER DISTRIBUTION FLEXDGRID

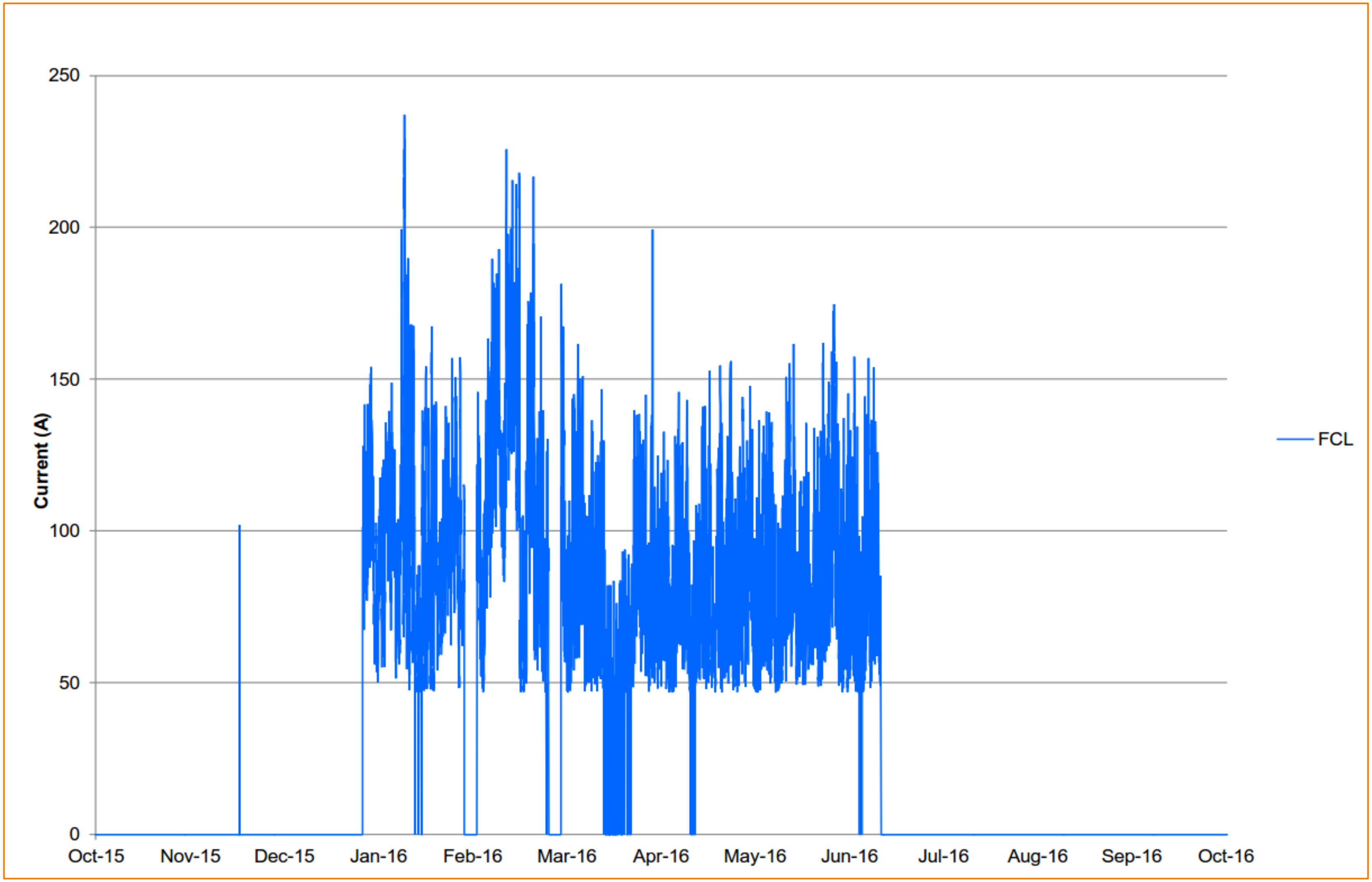
RSFCL - Operation



RSFCL - Operation



RSFCL - Operation



THANKS FOR LISTENING

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

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