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SUCCESSFUL DELIVERY REWARD CRITERIA REPORT

FAULT LEVEL MITIGATION TECHNOLOGIES DNO WORKSHOP

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Report Title	:	Fault Level Mitigation Technologies DNO Workshop
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Document Control

	Name
Prepared by:	Nikki-Dee Haddleton
Reviewed by:	Jonathan Berry
Approved by:	Jonathan Berry

Revision History

Date	Issue	Status
13/09/2013	Draft0.1	Initial for review
30/09/2013	Draft0.2	Draft for approval
10/12/2013	V001	Final

Contents

Introduction

The purpose of this report is to provide a summary of the Fault Level Mitigation Technologies Distribution Network Operator (DNO) Workshop held in Birmingham on Wednesday 4th September 2013 which fulfils the Fault Level Mitigation Technologies Successful Delivery Reward Criterion (SDRC-3). This is summarised below.

Hold a workshop, inviting all GB DNOs and other interested parties by 31 October 2013. At the workshop, the implementing DNO will:

a) provide details of the emerging learning of Method Alpha (Enhanced Fault Level Assessment) and Method Beta (Real-time Management) and the proposed methodology for Method Gamma (Fault Level Mitigation Technologies); and
b) provide GB DNOs and other interested parties the opportunity to provide feedback on the proposed methodology for Method Gamma (Fault Level Mitigation Technologies), based on the emerging learning of Method Alpha (Enhanced Fault Level Assessment) and Method Beta (Real-time Management).

Purpose of the workshop

The aims of FlexDGrid are to enhance the way fault level is modelled; develop a real-time fault level management system; and mitigate fault level using different technologies. Part of this project is to understand the appropriate fault level mitigation technologies for use in specific locations and for varying electrical network requirements.

The workshop presented an opportunity for DNOs to find out more about the FlexDGrid Project and to meet with other DNOs to discuss Fault Level Mitigation Technologies. The main objectives of the workshop were:

a) sharing with other GB DNOs more about emerging learning of Methods Alpha (Enhanced Fault Level Assessment) and Beta (Real-time management of fault level) and give them the opportunity to find out more about and feedback on the proposal for Method Gamma. Method Gamma: Fault Level Mitigation Technologies builds on technologies developed and learning from existing IFI, ETI and LCNF projects to create a system-level approach. Five Fault Level Mitigation Technologies will be selected for installation at five separate substations. During the project design phase the most appropriate technologies will be selected for installation at each site to mitigate fault level issues;
b) consulting with other GB DNOs on whether, based on the information provided, proceeding to Method Gamma would provide the learning outlined in the Full Submission pro-forma; and
c) discussing with other GB DNOs options for continuing to share knowledge, information and learning regarding Fault Level Mitigation Technologies.

The workshop took place on Wednesday 4th September 2013 from 10:00 – 15:30 at the IET, Birmingham. Attendance was excellent with representatives present from all six GB DNOs. In addition we advertised the workshop in our FlexDGrid Newsletter which is distributed to more than 450 interested parties and on our webpage.

Workshop Delivery

During the workshop we presented other DNOs with information on the findings and emerging learning from Methods Alpha and Beta, which provides the background and context for our proposed approach to Method Gamma. We then delivered a presentation on the proposed methodology for Method Gamma (see Appendix 1 –Presentation) which included:

- Method Gamma Objectives;
- Fault Level Mitigation Methods;
- Overview of Emerging Fault Current Limiter Technologies;
- Substation Selection Process;
- Connection Options for Technologies; and
- Technology Integration for FlexDGrid Substations.

Following the presentation we had open discussions about this proposal and wider discussions regarding Fault Current Limiters and Fault Level Mitigation Technologies. We also discussed options for a continuing dialogue between DNOs on this topic.

Workshop Outcomes

Minutes were taken throughout the day and these have been shared with the attendees. There is a general good appetite amongst the DNO community for a Fault Current Limiter Practitioner Group to be developed, however this should be run by an independent party.

Feedback forms were requested at the end of the workshop (see Appendix 2 – Collated feedback forms) and these were very positive. Attendees also gave complimentary verbal feedback on the day about the presentations and expressed their enjoyment of both the workshop content and the networking opportunity the workshop provided.

Next Steps

Validity of approach for Method Gamma – All GB DNOs agreed that the methodology for Method Gamma was sound and could provide a letter endorsing the approach. This will be submitted to Ofgem as part of the SDRC-6 Report, required under the Condition Precedent A) Methodology of Method Gamma (see below).

Condition Precedent A) Methodology of Method Gamma - prior to signing binding contractual agreements for the fault level mitigation technologies, provide a report to Ofgem including the following information:

(i) the progress, including learning to date, of Method Alpha – Enhanced Fault Level Assessment and Method Beta – Real-time Management;
(ii) a proposed methodology for Method Gamma – Fault Level Mitigation Technologies. This must include a functional description of the five proposed fault level mitigation technologies and five proposed substations. It must also include an explanation of why these technologies and substations have been chosen, based on the learning described in (i);
(iii) a description of the process Western Power Distribution has followed to consult with other GB DNOs on whether, based on the information provided in (i) and (ii), proceeding to Method Gamma – Fault Level Mitigation Technologies would provide the learning outlined in the Full Submission pro-forma. This must include a written consultation; and
(iv) the written responses received from other GB DNOs to the written consultation described in (iii) together with summaries of all other feedback received.

Appendices

Appendix 1 – Presentation

Appendix 2 – Collated Feedback Forms

Appendix 3 – Learning outlined in the Full Submission pro-forma

Appendix 1 – Presentation

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Fault Level Mitigation Technologies
DNO Workshop

Wednesday 4th September 2013

LCN Fund Low Carbon Networks THE UNIVERSITY OF WARWICK PARSONS BRINCKERHOFF

Agenda

10:00 – 10:30	**Arrival – Refreshments and Networking**
10:30 – 11:10	Round table introductions to include delegates background in FCL work
11:10 – 11:30	Overview of FlexDGrid and the purpose of the workshop
11:30 – 12:00	Presentation 1 – Topic Focus: Modelling and Enhanced Fault Level Assessment
12:00 – 12:45	Presentation 2 – Topic Focus: Mitigation Technologies and approach to connection
12:45 – 13:30	Lunch and Networking
13:30 – 14:30	Discussion on FCL installation and implementation
14:30 – 14:45	Break
14:45 – 15:15	Sharing best practice options
15:15 – 15:30	Summary of workshop results and next steps
15:30	**Close**

Welcome and Introductions

DNO	Name	Job Title
WPD	Jonathan Berry	Innovation Engineer
WPD (Power Academy)	Aimée Slater	Student Engineer
WPD (Parsons Brinckerhoff)	Samuel Jupe	FlexDGrid EFLA Lead
WPD (Parsons Brinckerhoff)	Neil Murdoch	FlexDGrid Distribution Lead
UKPN	Ian Cooper	Senior Technology Transfer Engineer
UKPN	Allan Boardman	Network Design Standards Manager
UKPN	David Boyer	Solution Design Authority - Low Carbon London
SSE	Tawanda Chitifa	R&D Project Manager
SPEN	Eric Leavy	Head of Design
ENWL	Geraldine Bryson	Future Networks Technical Manager
NPG	Dr. Roshan Bhattarai	System Planning Engineer

Overview of FlexDGrid and workshop aims

Jonathan Berry

Western Power Distribution

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Methods Alpha and Beta

Enhanced fault level assessment and modelling

Samuel Jupe MEng PhD CEng MIET

Senior Engineer, Parsons Brinckerhoff

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Agenda

- Overview of Methods
- Method Alpha
    - Processes
    - Emerging learning
    - Next steps
- Method Beta
    - Trials
    - System design
    - Next steps
- Integrated Methods

Overview of Methods

- There are three separate Methods identified in FlexDGrid:
  - Method Alpha: Enhanced Fault Level Assessment
    - Focus on modelling fault levels at 15 Primary Substations and 11kV network
    - Provide datum metrics by which benefits of practical trials can be assessed
  - Method Beta: Real-time Management of Fault Level
    - Focus on measurement and monitoring of 11kV fault level at 10 Primary Substations
  - Method Gamma: Fault Level Mitigation Technologies

Method Alpha: Enhanced fault level assessment processes

1. Baseline the consistency of application of present fault level assessment methods
2. Explore assumptions and carry out a sensitivity analysis of standard fault level calculation methods
3. Increasing the frequency and granularity of fault level assessments
4. Design and deployment of fault level measurement and monitoring technologies
5. Design and deployment of fault level mitigation technologies
6. Connection offers based on novel commercial frameworks

Emerging learning: DNO Questionnaire Conclusions

1. Engineering Recommendation G74 requires clarifications on its application:
   a) Guidance on new forms of generation
   b) Modelling of aggregated loads
   c) Validity of general load contribution

2. Sensitivity analysis would provide useful learning

3. Open source database of generation / motor plant types would be beneficial

Emerging learning: DNO Questionnaire Conclusions

4. Open source fault current limiter models would be of benefit to the DNO community

5. Increased frequency and granularity of fault level assessments could be beneficial but would need to outweigh increased modelling effort

6. A move to probabilistic fault level assessments was not deemed to be feasible due to ESQCR and H&S implications

7. There is a need for training processes to be documented

Emerging learning: SDRC-1 Recommendations

1. The 6 process identified and detailed in the SDRC-1 document will be followed
2. A follow-on workshop will be organised with other DNOs to feedback baseline and sensitivity analysis results
3. It is not clear how the values for general load contribution were originally derived:
   a) Load mixes and fault contributions will be investigated
   b) Introduction of fault level monitoring equipment

Emerging learning: SDRC-1 Recommendations

4. An industry-wide review of G74 should be conducted with a focus on the consistent application of G74 to HV networks

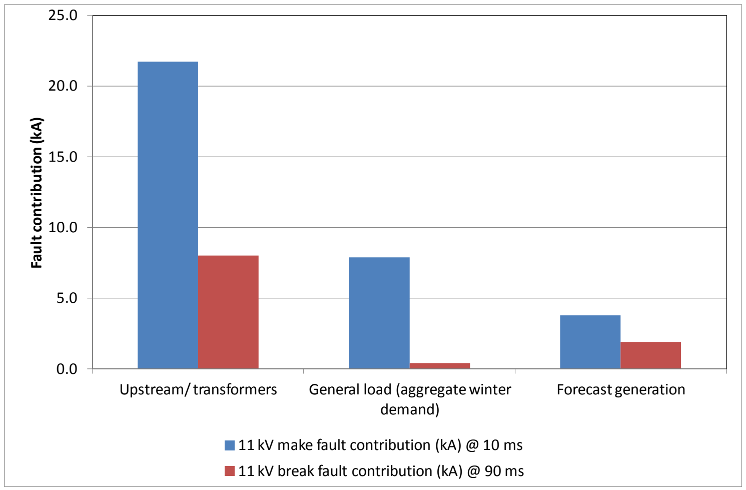
5. For training and consistency, DNOs should formally document their connection study process

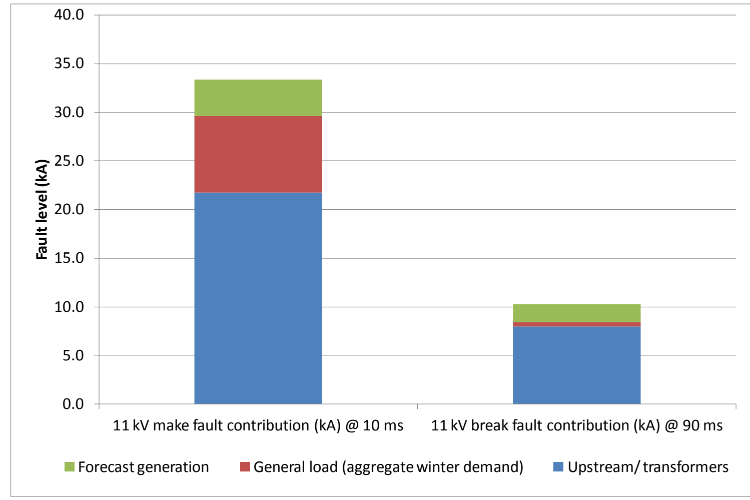
6. Development of integrated EHV and HV electricity network models

7. Confirm the need to de-rate switchgear in line with CIGRE Recommendation 304

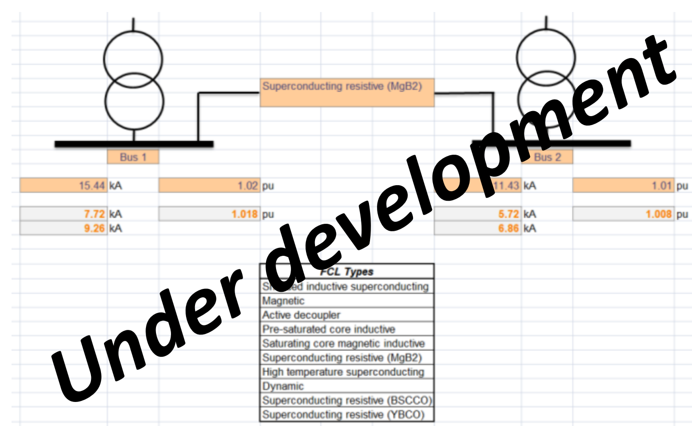
Method Alpha: Next Steps

- Fault level decomposition





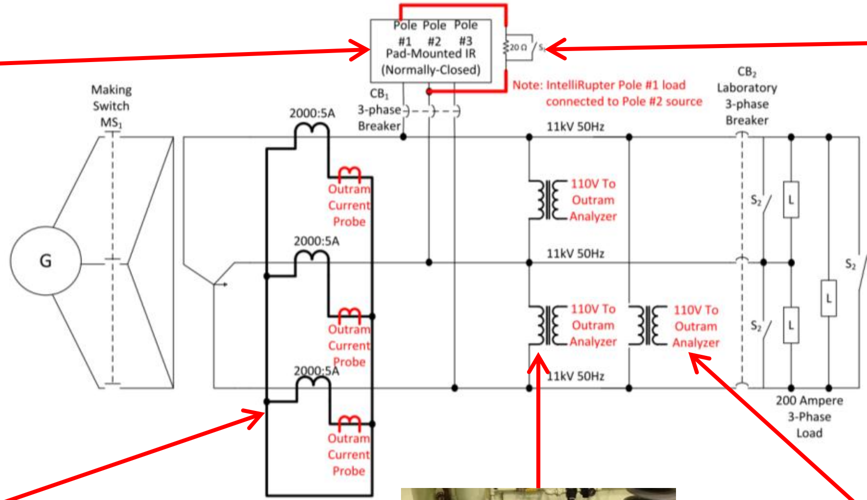
- Fault current limiter models
  - Functional specification
  - Excel interface
  - PSS/E ‘black box’



Method Beta: Real-time fault level management

Example monitoring system

IntelliRupter



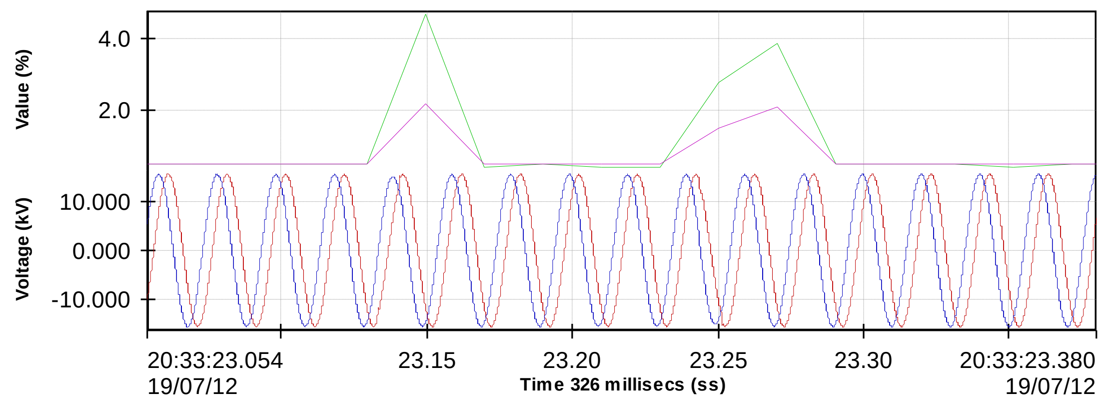
Inductor

Current Transformers

Voltage Transformers

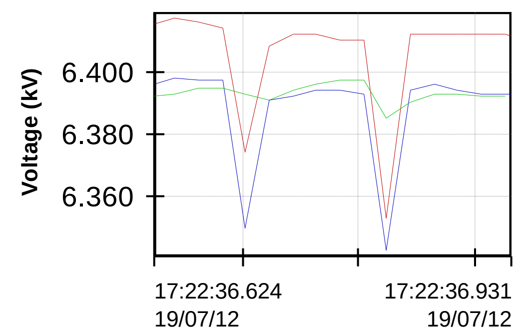
PM7000 - FLM

Method Beta: Results



	Maximum	Minimum	Average
% THD of Vab	4.7	0.4	1.1
% THD of Vcb	2.2	0.5	0.8
Input Vab (V1) (Waveform)	15.787	-15.764	-0.026
Input Vcb (V3) (Waveform)	15.777	-15.756	0.132

Harmonic distortion caused by FLM



	Maximum	Minimum	Average
kV RMS of Van	6.417	6.353	6.406
kV RMS of Vbn	6.398	6.343	6.388
kV RMS of Vcn	6.397	6.385	6.393

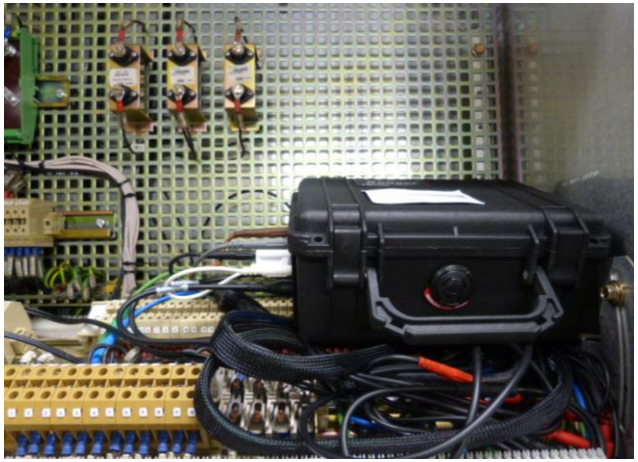
Voltage fluctuation caused by FLM

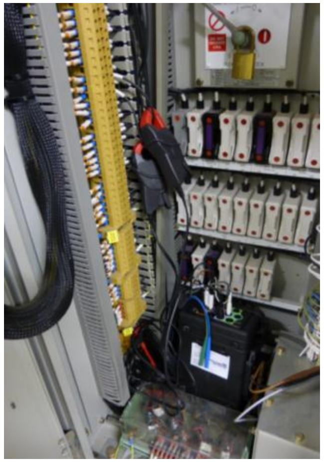
- Both tests were carried out using the factory acceptance test arrangement
- Maximum voltage fluctuation is 1% in a 300ms timeframe (ER P28 compliant)
- Maximum Total Harmonic Distortion is 4.7% in a 300ms timeframe (ER G5/4 compliant)
- **Fault Level prediction accuracy within 4.5%**

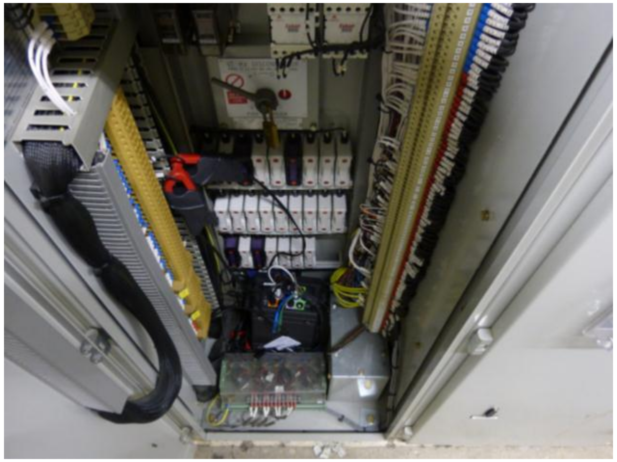
Method Beta: Next Steps

- Currently out to tender for fault level monitoring devices

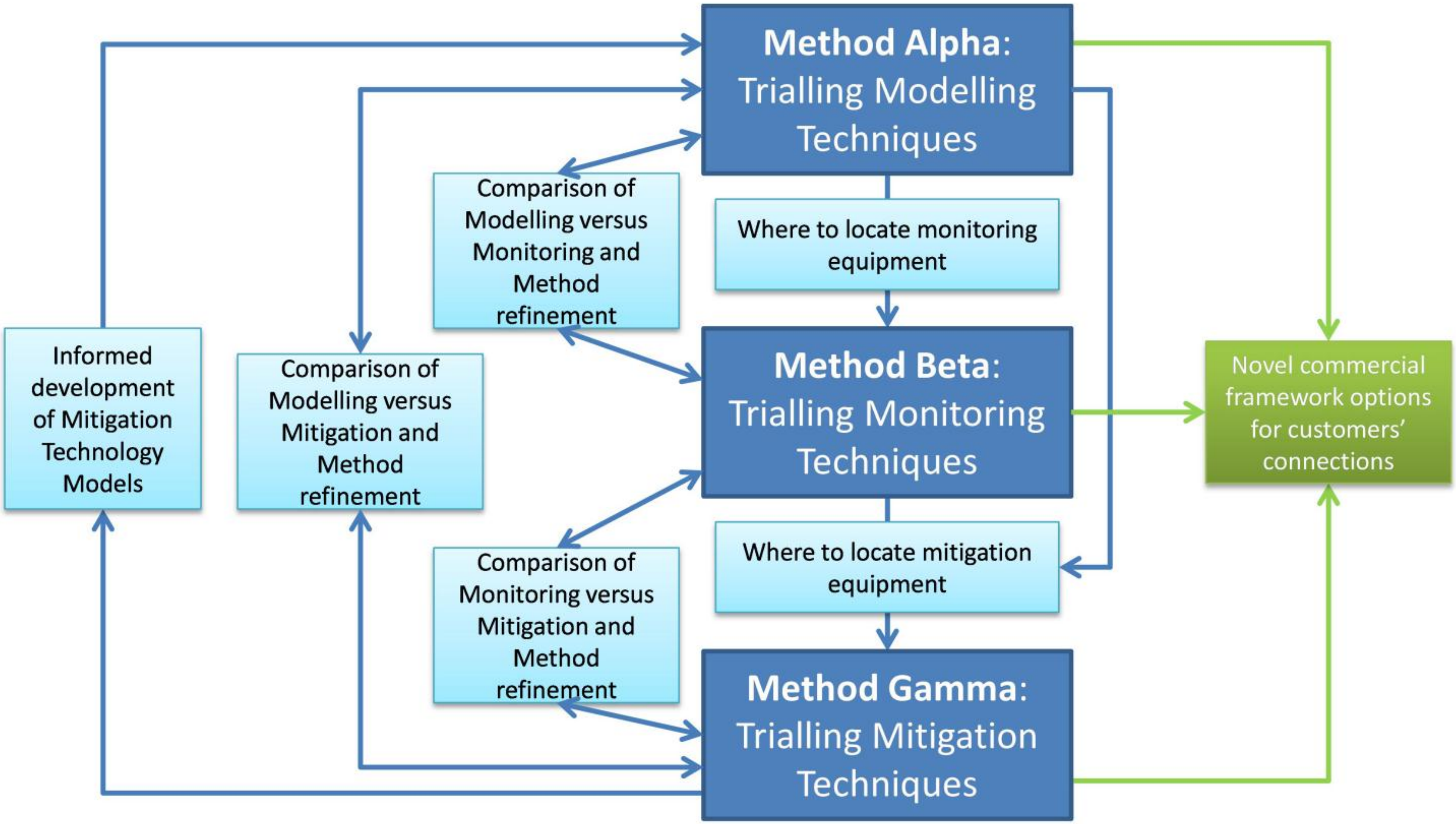
- PM7000 measurement devices have been installed at 3 out of 10 Primary Substations to date







Integrated Methods and Expected Learning



Any Questions?

Date for the diary:
DNO Workshop on the Implementation of
Enhanced Fault Level Assessment Processes
Wednesday 23 October 2013
Austin Court, IET Birmingham

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Method Gamma

Proposed Methodology for Method Gamma

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Agenda

- Method Gamma Objectives
- Fault Level Mitigation Methods
- Overview of Emerging Fault Current Limiter Technologies
- Substation Selection Process
- Connection Options for Technologies
- Technology Integration for FlexDGrid Substations

Method Gamma Objective

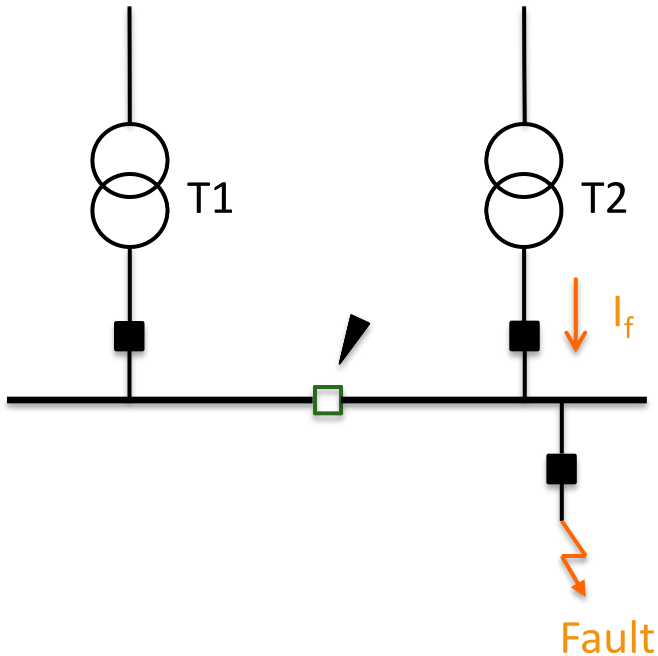
- There are three separate methods identified for FlexDGrid:
  - Method Alpha: Enhanced Fault Level Assessment
  - Method Beta: Real-time Management of Fault Level
  - Method Gamma: Fault Level Mitigation Technologies
    - Build on knowledge learned through IFI, ETI and LCNF Projects
    - Install 5 FL Mitigation Technologies in 5 separate WPD substations
    - Test & Trial Technologies to quantify performance and network benefit

Fault Level Mitigation Methods

- There are number of established and emerging methods to manage Fault Level on Power Networks.
  - Network Operation, running "split" or "open"
  - Bus-section reactor
  - Pre-Saturated Core FCL
  - Resistive Superconducting FCL
  - Power Electronic FCL

Network Running "Open"

- Run the network "open" or "split" to avoid parallels between two sources

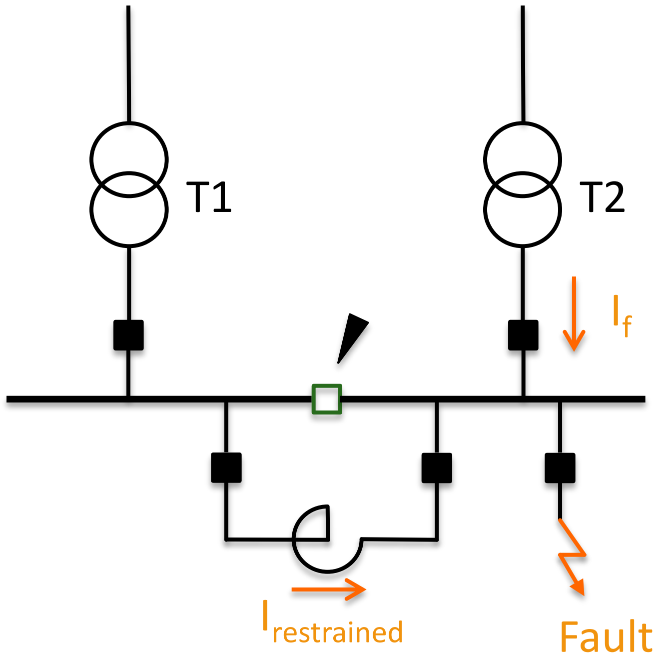


- ✓ Simple to implement
- ✓ Large reduction in FL
- ✓ Zero cost

- ✘ Large reduction in security
- ✘ Can reduce firm capacity
- ✘ Loads on busbars need to be balanced (tx sharing)

Bus-Section Reactor

- Install a reactor between two busbars to create a "loose couple" arrangement



- ✓ Proven technology
- ✓ Security of supply
- ✓ Installation/Maintenance similar to transformer

- ✗ Losses
- ✗ Limited fault level reduction
- ✗ Can limit load flow as well as fault level

Emerging FCL Technologies Considered

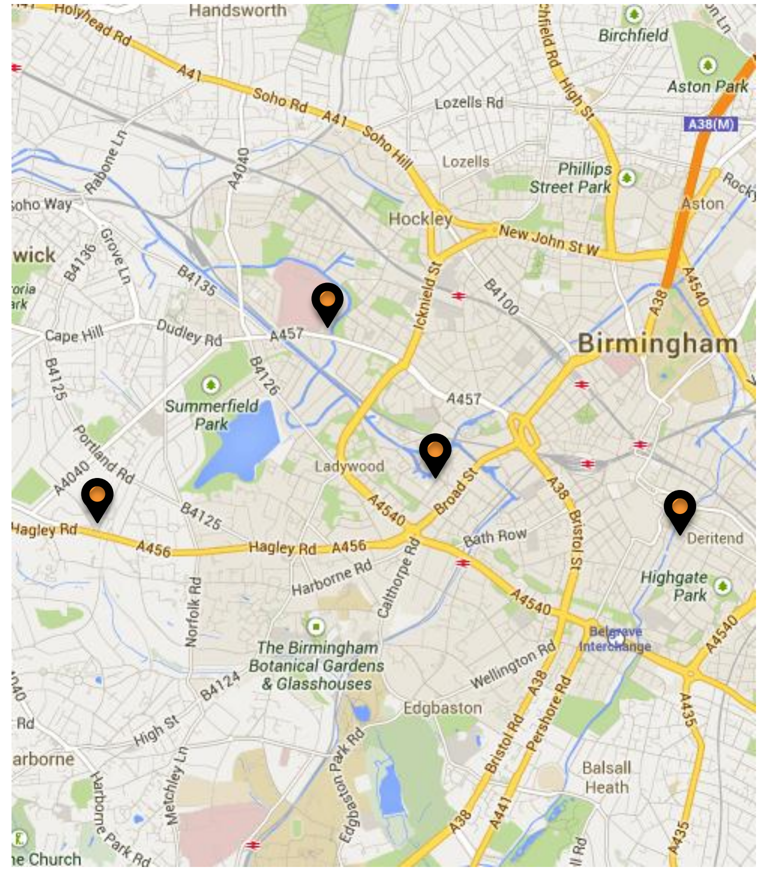
- Pre-Saturated Core FCL
  - Design similar to a transformer, the iron core is normally saturated by a DC coil secondary winding (can be superconducting)
- Resistive Superconducting FCL
  - High Temperature Superconductor inserted in series with the network. Can be used in conjunction with a shunt reactor / resistor
- Power Electronic FCL
  - Uses self-commutated semiconductor devices to interrupt fault current

Emerging FCL Technologies Considered

- Open, competitive tender process currently ongoing for FlexDGrid
- New technologies must be fail-safe to allow connection to the network
- Advantages of new technologies include
  - High percentage FL reduction
  - 'Invisible' during normal operation
  - Low losses

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



Availability of Space

- Purchase of land can be expensive and time consuming
- Use of spare land considered in proximity to the connection point
- Checks with Primary System Engineers to ensure land is not required for future developments

Network Connection

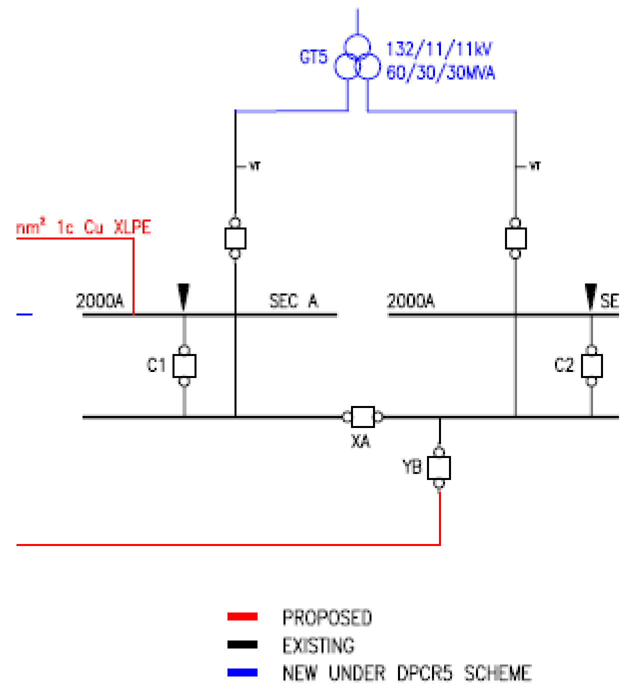
- Consider the complexity of connection to the 11kV network
- Where possible avoid extensive alterations to protection schemes
- Connection options are considered later in the presentation

Substation Access

- FCLs can be large in size
- Ensure delivery and off-loading of equipment in built areas is feasible without major alterations to the substation
- Be aware of clearances and access for future replacement of transformers etc.

Investment Plans

- Careful consideration for substations that are earmarked for load and non-load related reinforcement
- Avoid locating equipment where it may hinder future expansion/replacement
- Savings by incorporating FCL switchgear in plans



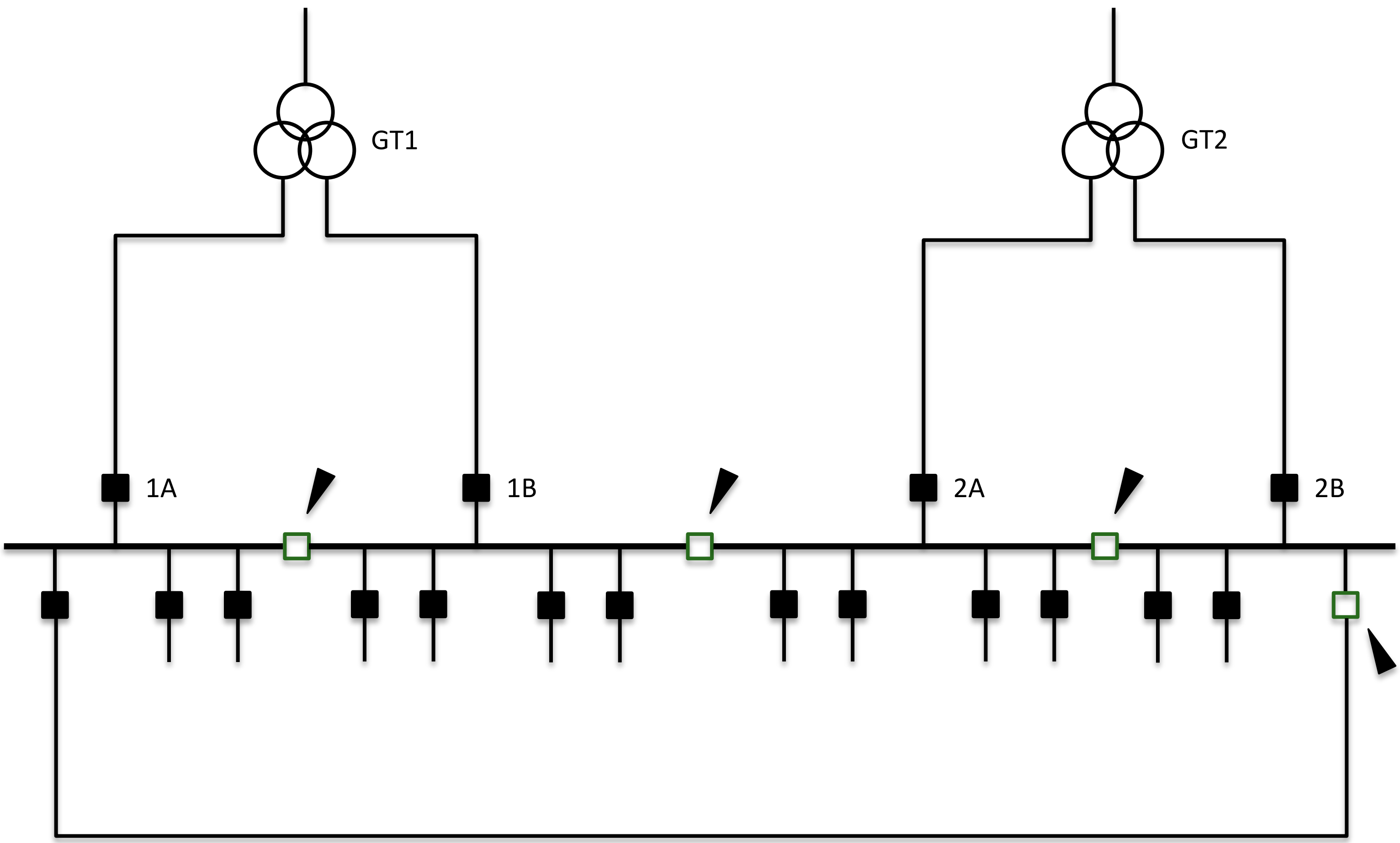
Auxiliaries

- Check the availability/capacity of existing systems (LVAC, 110V, 48V and SCADA)
- New FCL equipment (and switchgear) may require extensions and/or replacement of these systems

Birmingham Distribution Network

- The network in Birmingham has evolved over time and there is limited 33kV network in the area
- All of the sites shortlisted for FlexDGrid were 132/11kV substations with higher 11kV fault levels than would be seen at a normal 33/11kV substation
- The majority of substations have dual wound, 132/11kV, 60/30/30MVA transformers

Typical substation configuration



Operating Arrangement

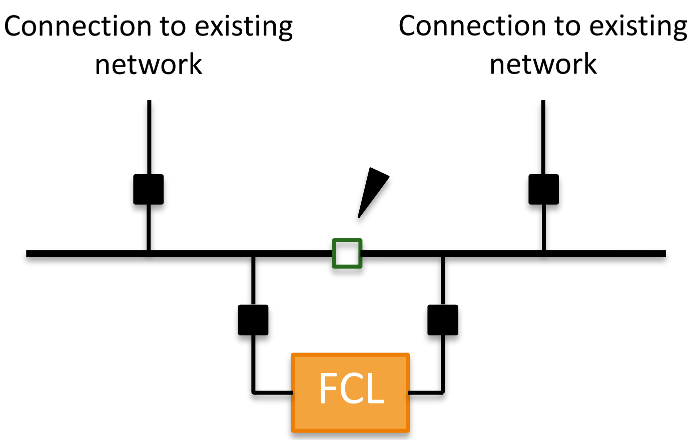
- To minimise the impact of fault level on the network, bus-sections are run open
- 11kV primary and secondary switchgear have a ‘break’ rating of 250MVA
- Auto-switching schemes are in place to restore customers following interruptions to the incoming supply

FCL Connection Options

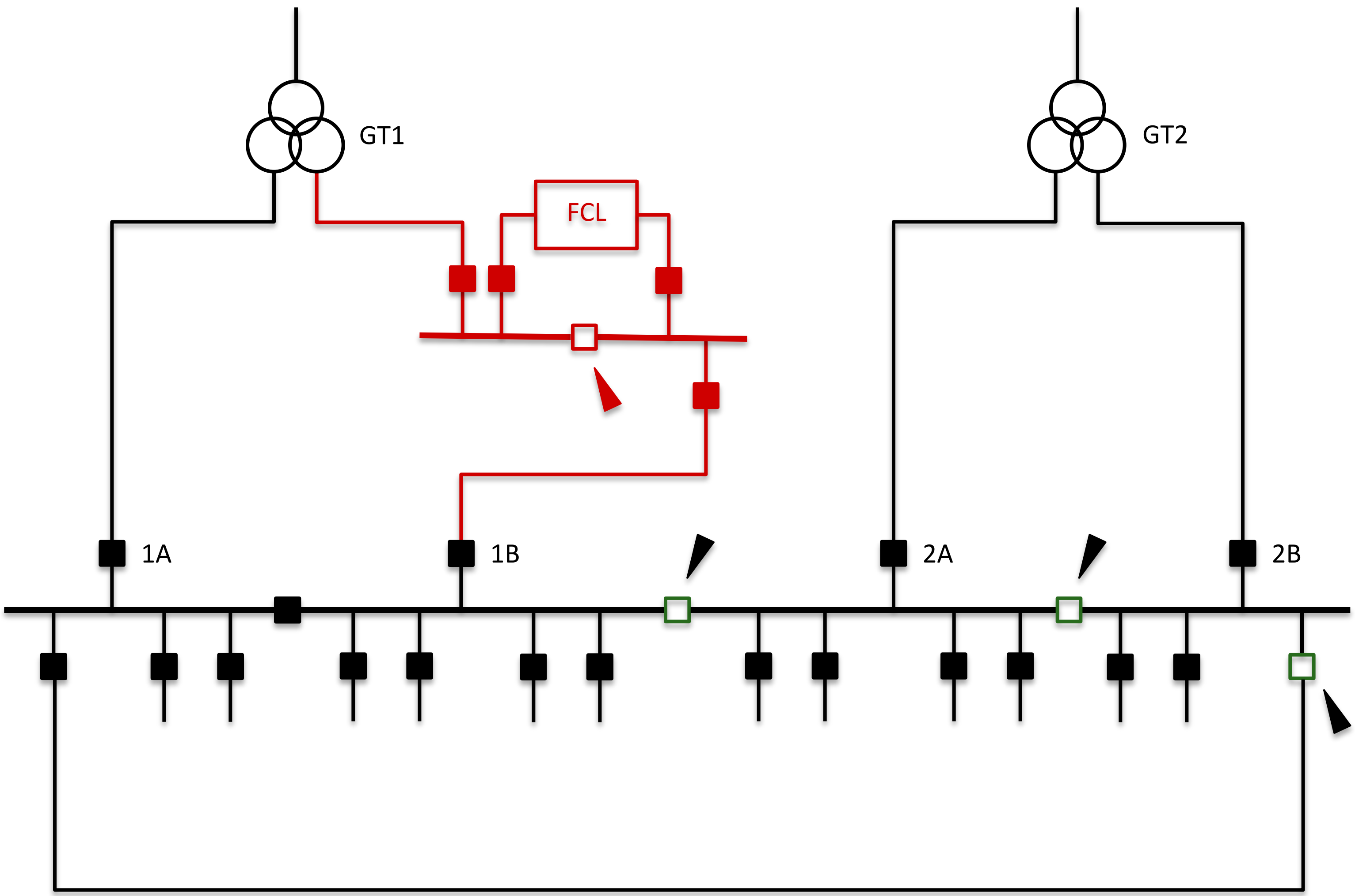
- In series with secondary winding
- Across Bus-Section
- Within Interconnector
- Between Transformers

Network Integration

- Connection of the FCL shall provide the facility to return to the existing network configuration
- FCL can be by-passed for maintenance or during abnormal running

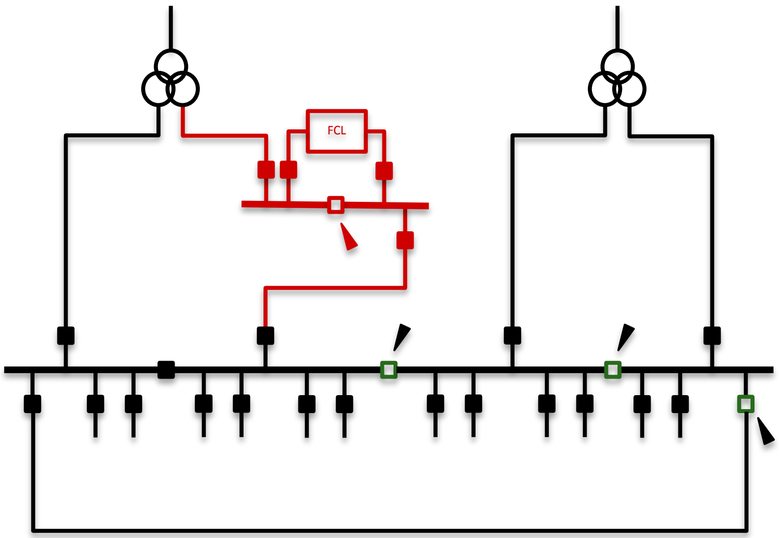


FCL in series with secondary winding



FCL in series with secondary winding

- GT1A and GT1B in parallel
- Consider this option when paralleling two separate transformers is not possible



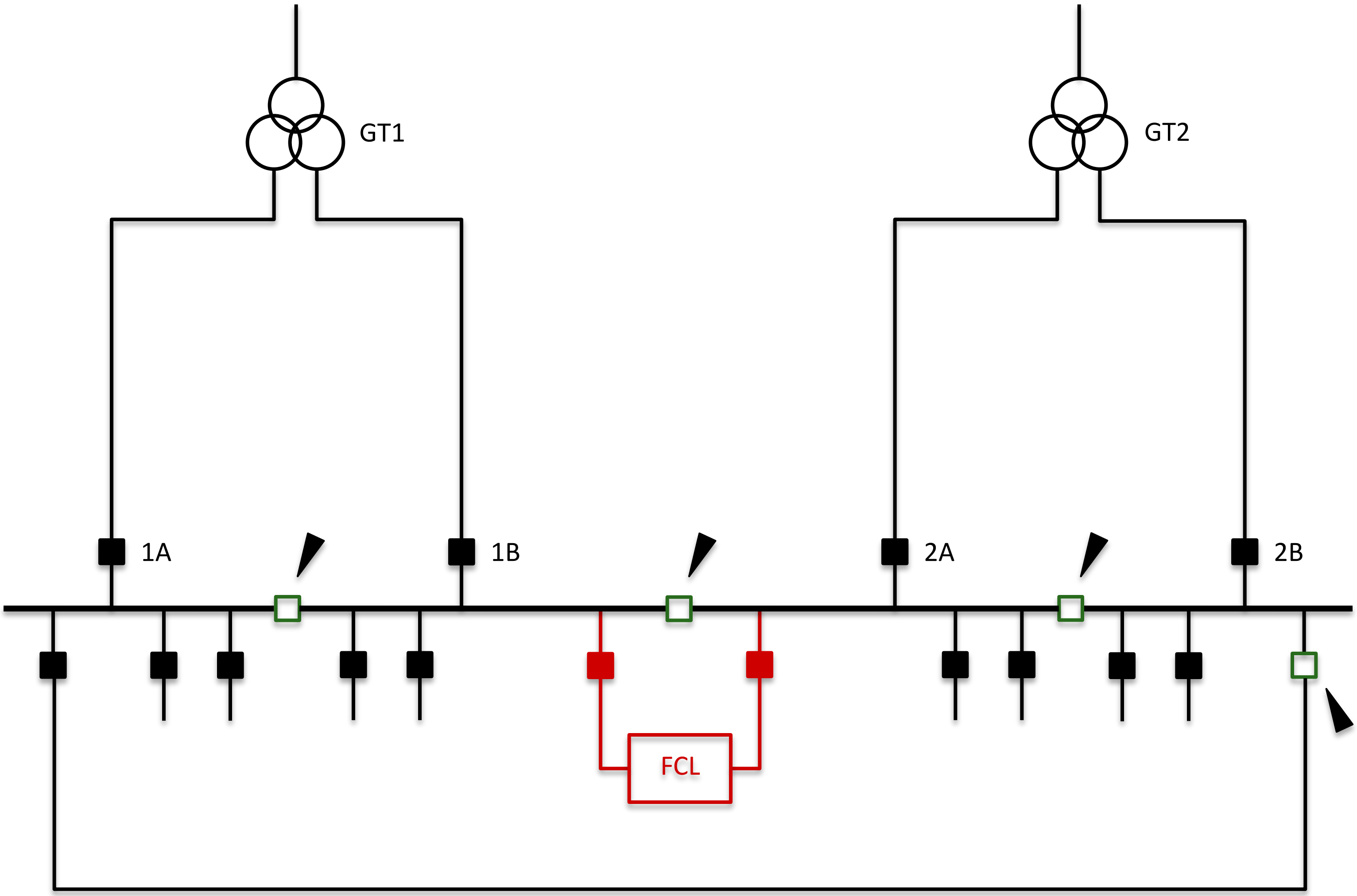
✓ Security of supply

✓ Equipment can be installed off line prior to final connection

✘ Transformer outage required

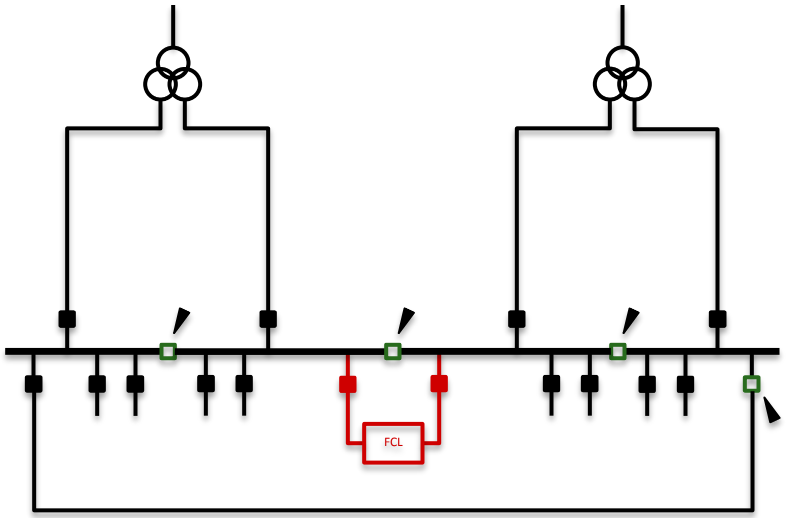
✘ Modifications required to transformer protection

FCL across Bus-Section



FCL across Bus-Section

- GT1B and GT2A in parallel
- Considered for installations where new switchgear is being installed



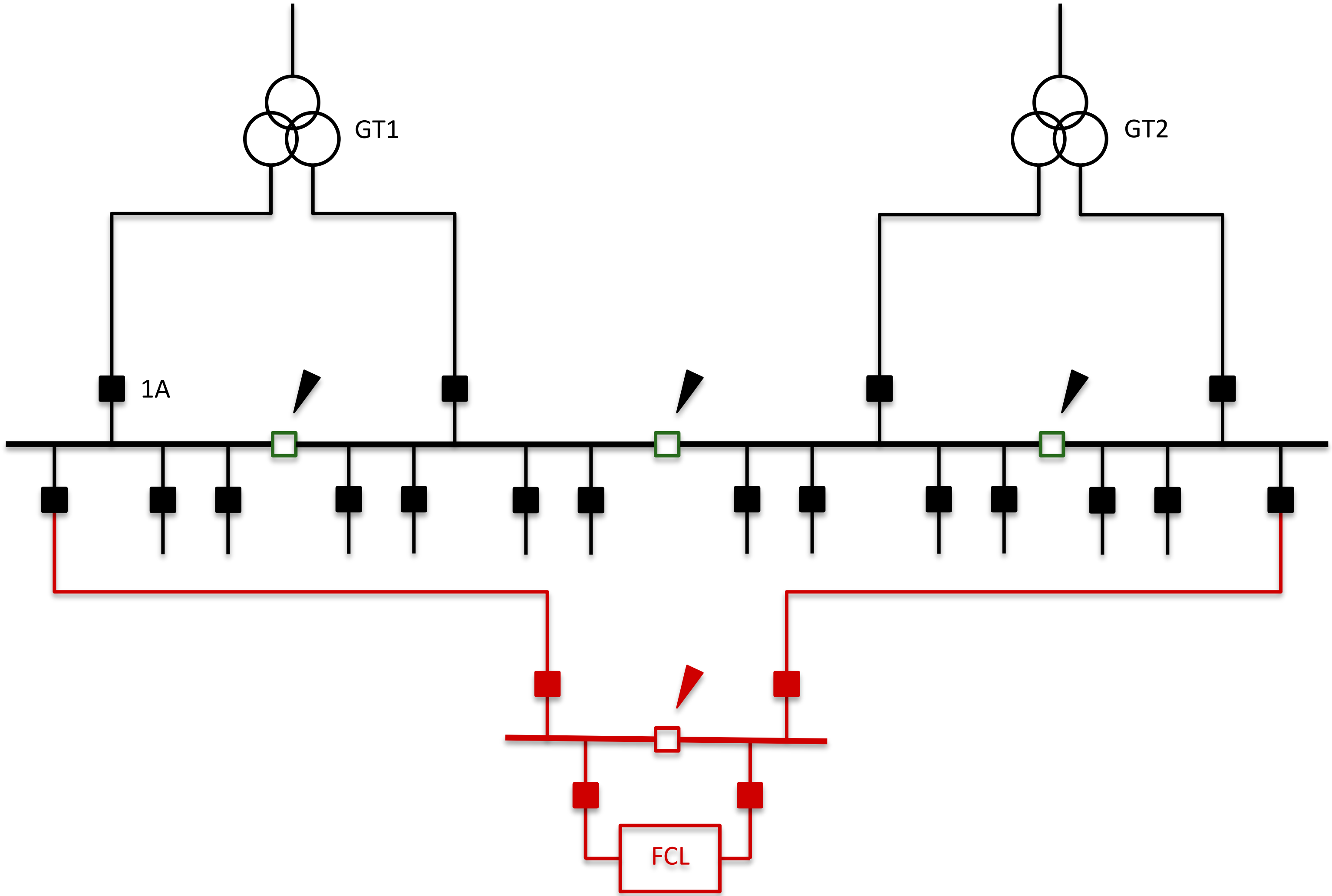
✓ Equipment can be installed off line prior to final connection

✓ Security of supply

✓ Only two circuit breakers required for connection

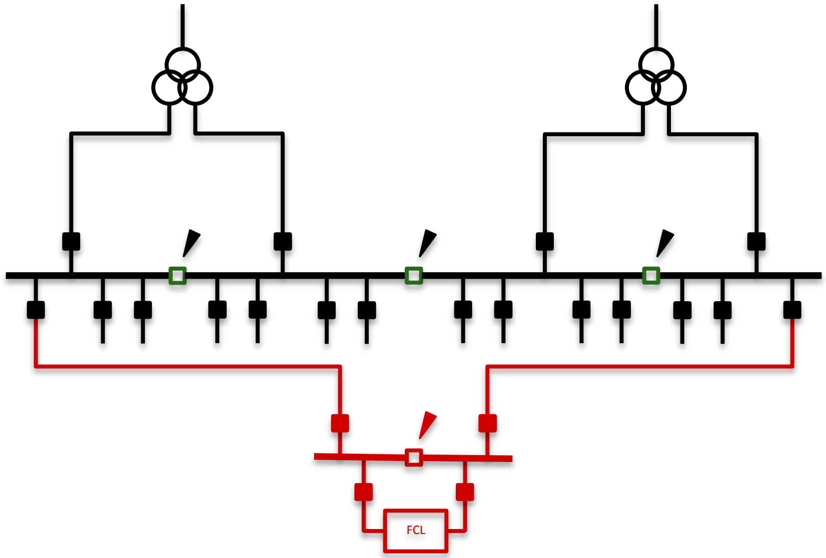
✗ Only applicable where existing switchgear is being replaced

FCL within interconnector



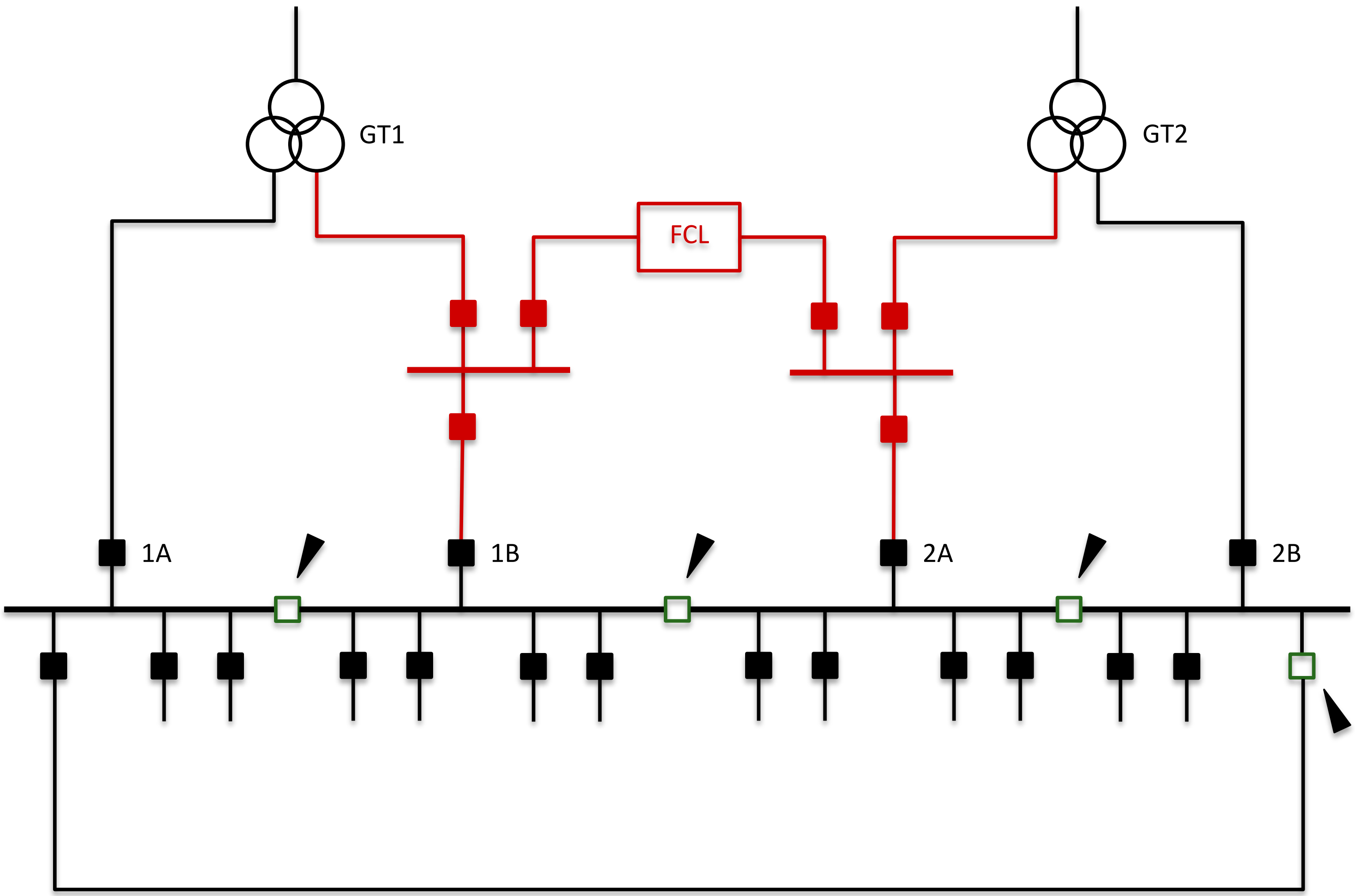
FCL within interconnector

- GT1A and GT2B in parallel
- FCL is connected into the 11kV interconnector



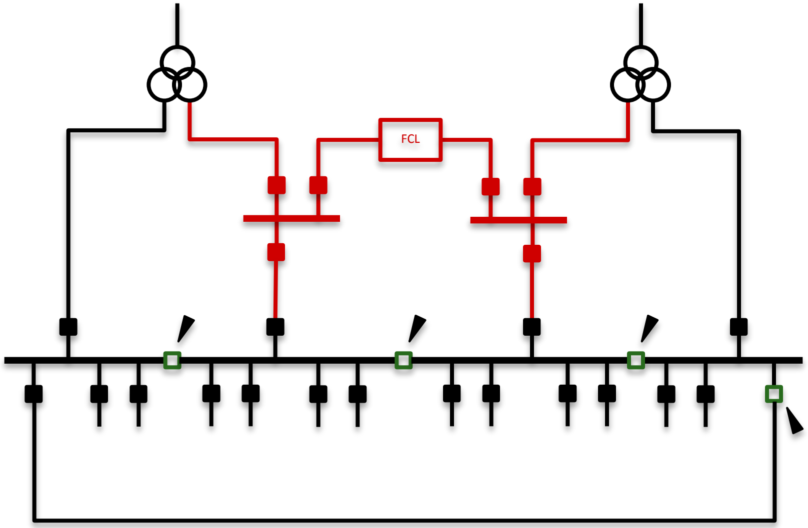
- ✓ Equipment can be installed off line prior to final connection
- ✓ Security of supply
- ✗ Interconnector (or busbar) outages required for connection

FCL between transformers



FCL between transformers

- GT1B and GT2A in parallel
- Considered generally as a last resort for FCL connection



- ✓ Equipment can be installed off line prior to final connection
- ✓ Security of supply

- ✘ Two transformer outages required for connection
- ✘ Six circuit breakers required for connection
- ✘ Complex operating arrangement

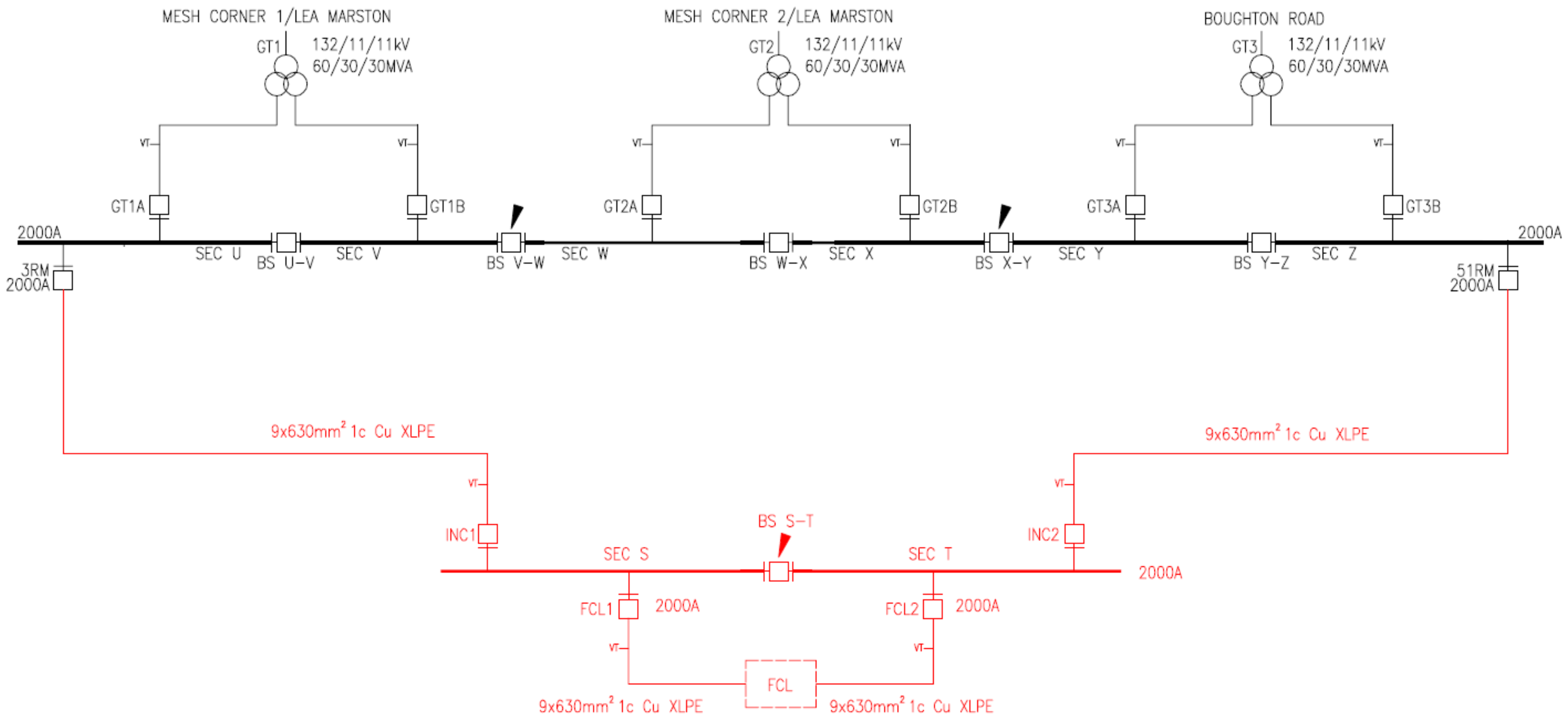
Proposals for FlexDGrid

- Kitts Green
- Castle Bromwich
- Chester Street
- Bournville
- Sparkbrook

Kitts Green 132/11kV

- 3 no. 132/11/11kV transformers
- When operating in parallel at 11kV, 3ph break FL is 15.7kA
- Target 3ph break FL is 9.4kA with FCL
- FCL to be connected into 11kV interconnector
- Spare land is available within the substation compound

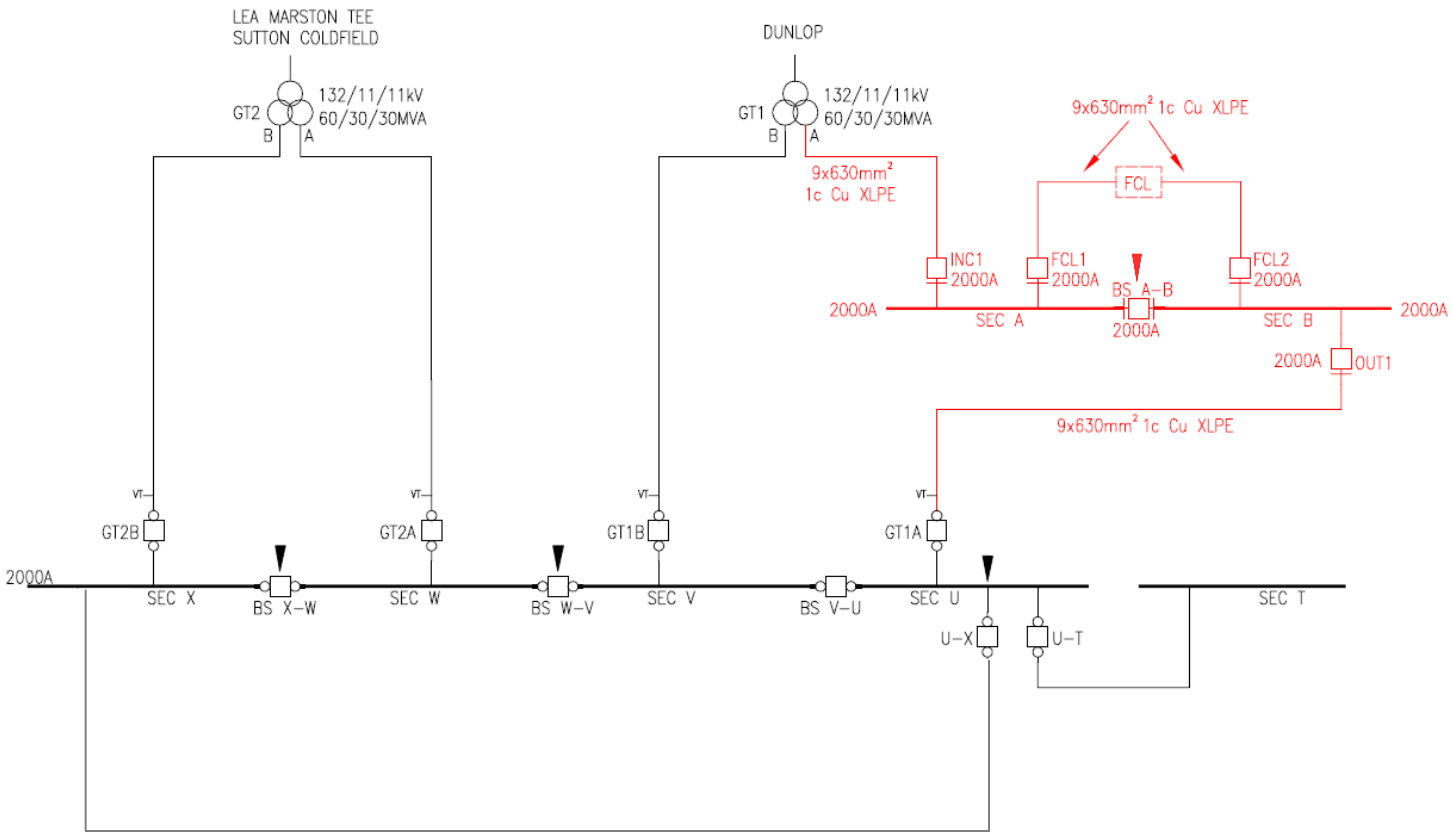
Kitts Green 132/11kV



Castle Bromwich 132/11kV

- 2 no. 132/11/11kV transformers supplied from separate Grid Supply Points
- When operating in parallel at 11kV, 3ph break FL is 13.7kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected into 11kV transformer ‘tails’

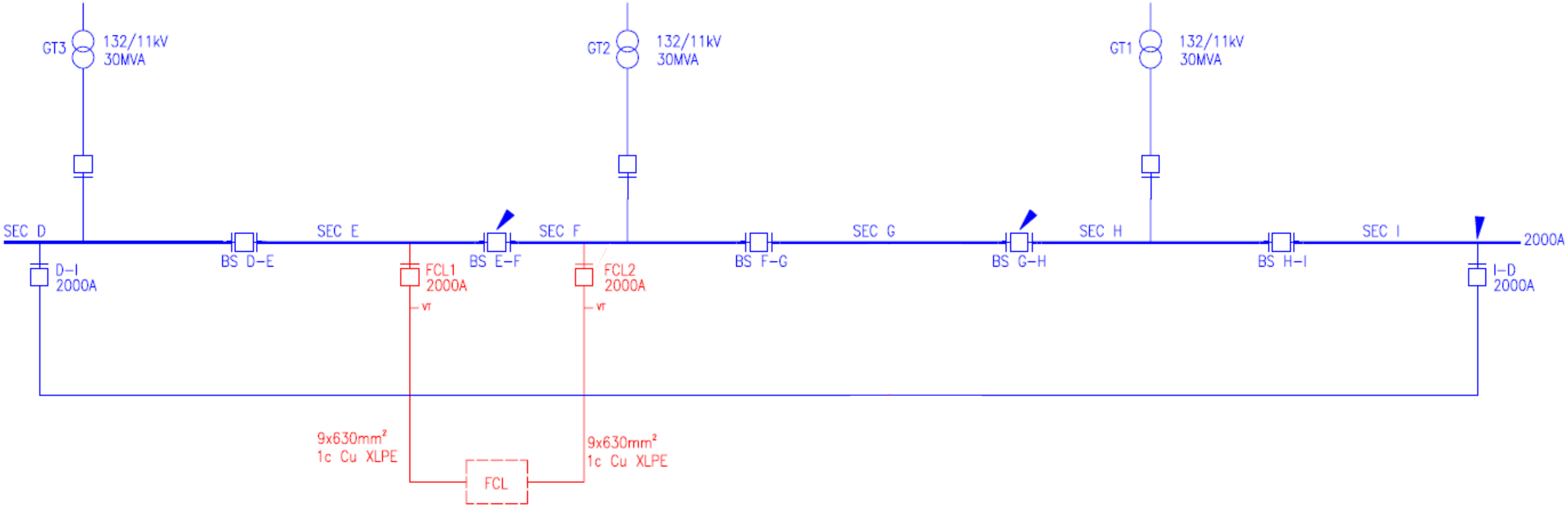
Castle Bromwich 132/11kV



Chester Street 132/11kV

- 3 no. 132/11kV transformers, one supplied from separate Grid Supply Point
- 11kV switchgear is being replaced under DPCR5
- When operating in parallel at 11kV, 3ph break FL is 14.1kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected across bus-section

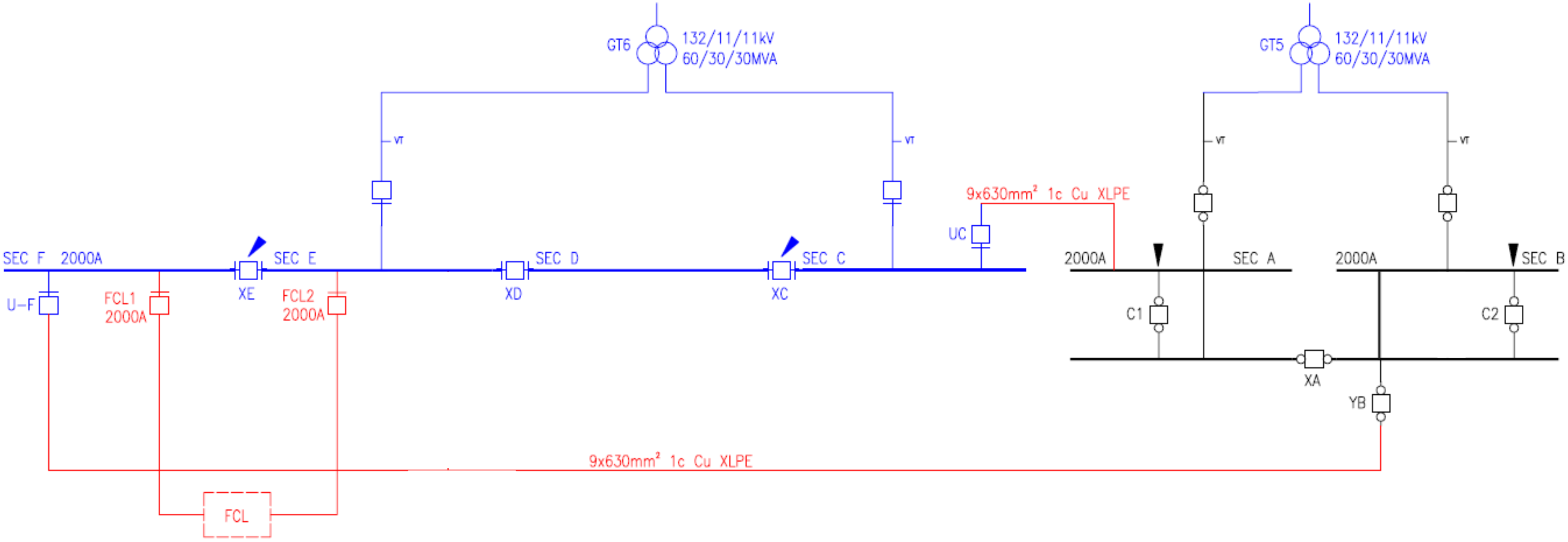
Chester Street 132/11kV



Bournville 132/11kV

- 4 no. 132/11kV transformers
- Transformers and 11kV switchgear are scheduled for replacement
- When operating in parallel at 11kV, 3ph break FL is 15.3kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected across bus-section

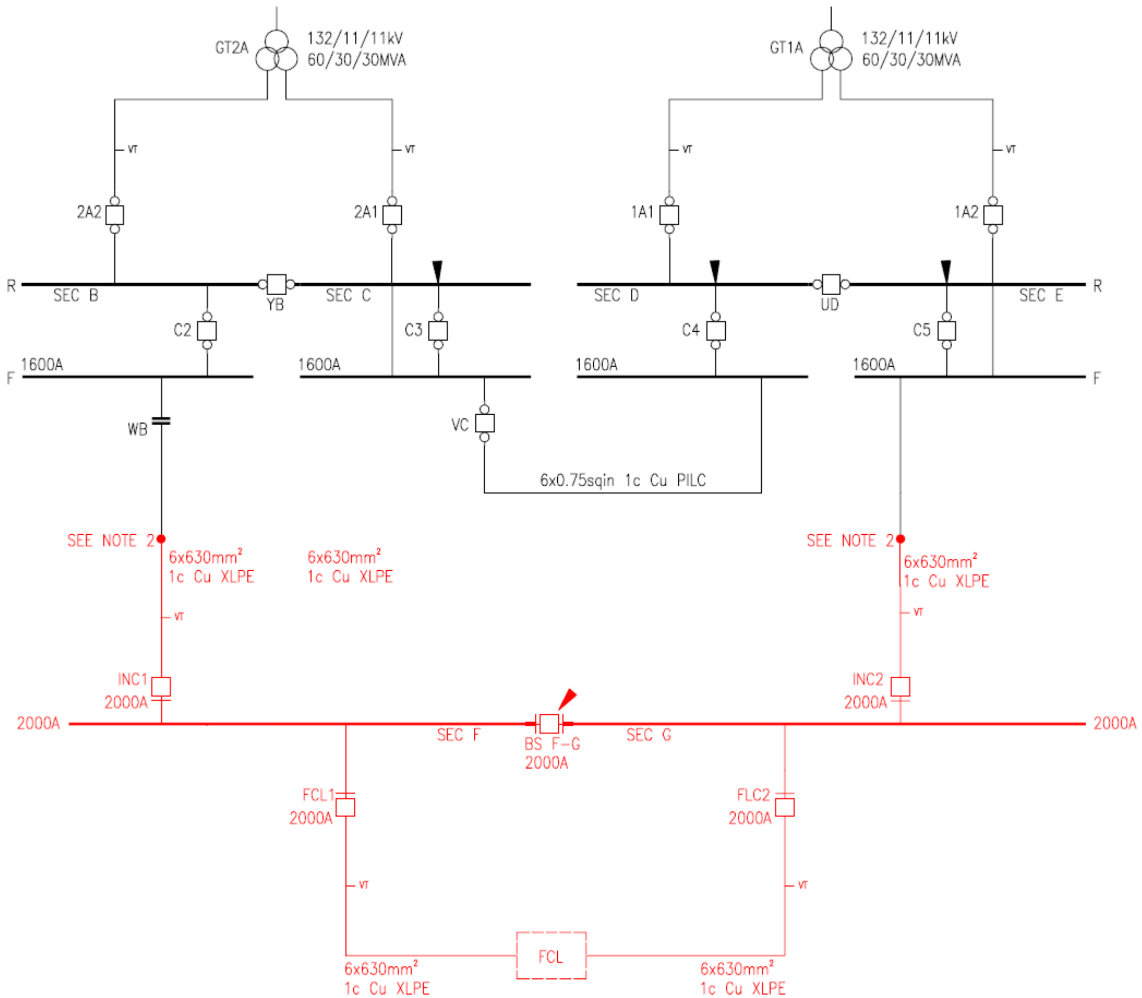
Bournville 132/11kV



Sparkbrook 132/11kV

- 2 no. 132/11/11kV transformers
- When operating in parallel at 11kV, 3ph break FL is 16.1kA
- Target 3ph break FL is 11.3kA with FCL
- FCL to be connected into 11kV interconnector
- Spare land is available within the substation compound

Sparkbrook 132/11kV



Summary

- Principle of Method Gamma
- Existing and emerging methods for fault level mitigation
- Substation Selection Process
- Connection Options for Technologies
- Proposals for FlexDGrid substations

Questions

Lunch and networking

Lodge Room 3

45 minutes

Discussion on FCL installation and implementation

Round table discussion led by:

Jonathan Berry

Break

Sharing best practice options

Round table discussion led by:

Jonathan Berry

Summary of workshop results and next steps

Jonathan Berry

Thank you for joining us

Please complete your feedback form and leave this with us

Have a safe journey home

Appendix 2 – Collated feedback forms

WESTERN POWER DISTRIBUTION
FLEXDGRID

FEEDBACK FORM

Fault Level Mitigation Technologies DNO Workshop

Thank you for attending our workshop. We appreciate your attendance and your feedback is valuable to us. Please return your completed feedback form to the event organisers.

Date:	Wednesday 4th September 2013
Title:	Fault Level Mitigation Technologies DNO Workshop
Venue:	IET, Birmingham

Overall how satisfied were you with the event:

	1	2	3	4	5	
Very Dissatisfied	**0**	**0**	**0**	**14%**	**86%**	Very Satisfied

Overall how satisfied were you with the registration process and our communications prior to the event:

	1	2	3	4	5	
Very Dissatisfied	**0**	**0**	**0**	**71%**	**29%**	Very Satisfied

Overall how satisfied were you with the venue:

	1	2	3	4	5	
Very Dissatisfied	**0**	**0**	**0**	**57%**	**43%**	Very Satisfied

Overall how satisfied were you with the presentations:

	1	2	3	4	5	
Very Dissatisfied	**0**	**0**	**0**	**43%**	**57%**	Very Satisfied

Additional comments:

- **Very well presented and very informative and interesting**

LCN Fund
Low Carbon Networks

FEEDBACK FORM

Overall how satisfied were you with the workshop session:						
	1	**2**	**3**	**4**	**5**	
Very Dissatisfied	**0**	**0**	**0**	**43%**	**57%**	Very Satisfied
Additional comments:						

What did you enjoy the most?

- **Feedback/update on project status/work to date.**
- **Open discussion and challenge.**
- **Useful discussions – interesting concept of fault level.**
- **Presentations and early discussions. Networking.**
- **Workshop discussion was really interesting.**
- **Information provided during presentation.**
- **The presentations were good. The discussion sessions were thought provoking.**

What could be improved?

- **Feedback requested from attendees could have been slightly more structured/prompted.**
- **More technical detail, although I appreciate this is not always practical, especially around commercially sensitive info.**
- **A room with air conditioning?**
- **N/A.**
- **Nothing.**

Any other comments?

- **Well done so far!**

Alongside a number of other events, we are planning to hold a number of workshops relating to the FlexDGrid Project, specifically in the interests of knowledge sharing and capturing best practice and learning across DNOs. Would you be interested in attending our future events?

Yes 86% No **0** Did not respond **14%**

Appendix 3 – Learning outlined in the Full Submission pro-forma

1 Introduction

As part of the funding precedent for the fault level mitigation technologies, WPD must demonstrate that proceeding to Method Gamma (Fault Level Mitigation Technologies) would provide the learning outlined in the Full Submission Pro-forma (FSP) for FlexDGrid. The scope of the learning encompasses Method Alpha (Enhanced Fault Level assessment) and Method Beta (Real-time Management of Fault Level).

This document summarises the expected learning outlined in the FSP.

2 Expected Learning outlined in the FSP

1. Developing novel connection processes which, by being shared with other DNOs, can be applied to all UK networks with fault level constraints for new connections.
2. Building on the learning outcomes from previous IFI, ETI and LCNF trials, this project will accelerate the Technology Readiness Level (TRL) of fault level management technologies.
3. Helping to develop the business case that will attract and engage generators to adopt a more flexible solution (in line with the Carbon Plan) as opposed to a traditional fixed network reinforcement solution.
4. Due to the integrated nature of the project, Methods Alpha and Beta inform Gamma. The installation of Method Gamma will provide significant learning that will inform Methods Alpha and Beta. This means that the greatest benefit is gained through the implementation of all three Methods. [The integrated Method approach was presented to other DNOs in the workshop].
5. Other LCNF projects focus on voltage and thermal issues. As DG integration increases these networks too will start to experience fault level issues. By carrying out the proposed Trials in FLEXGRID the learning and processes will be generated ready to inform these projects. Through considered design processes fault level Mitigation Technologies will be deployed such that the impact on other technical issues (thermal and/or voltage) is minimised.
6. At present all DNOs plan for worse-case fault level contribution and equipment ratings when planning demand and generation connections. By gaining a more in-depth understanding of the assumptions that underpin fault Level calculations, this will enhance network knowledge and allow these assumptions to be verified and refined.
7. Through the advanced modelling and measurement carried out an open-source fault level quantification methodology will be developed. This methodology will use probabilistic approaches that can be shared with all DNOs.
8. New fault level monitoring equipment will allow the monitored fault level to be compared with the calculated fault level. This will generate new learning by analysing the differences between monitored and calculated values. This knowledge can be used to inform network planning and operational decisions, to increase network utilisation.

The expected learning from the integration of Methods Alpha, Beta and Gamma is given in Figure 1.

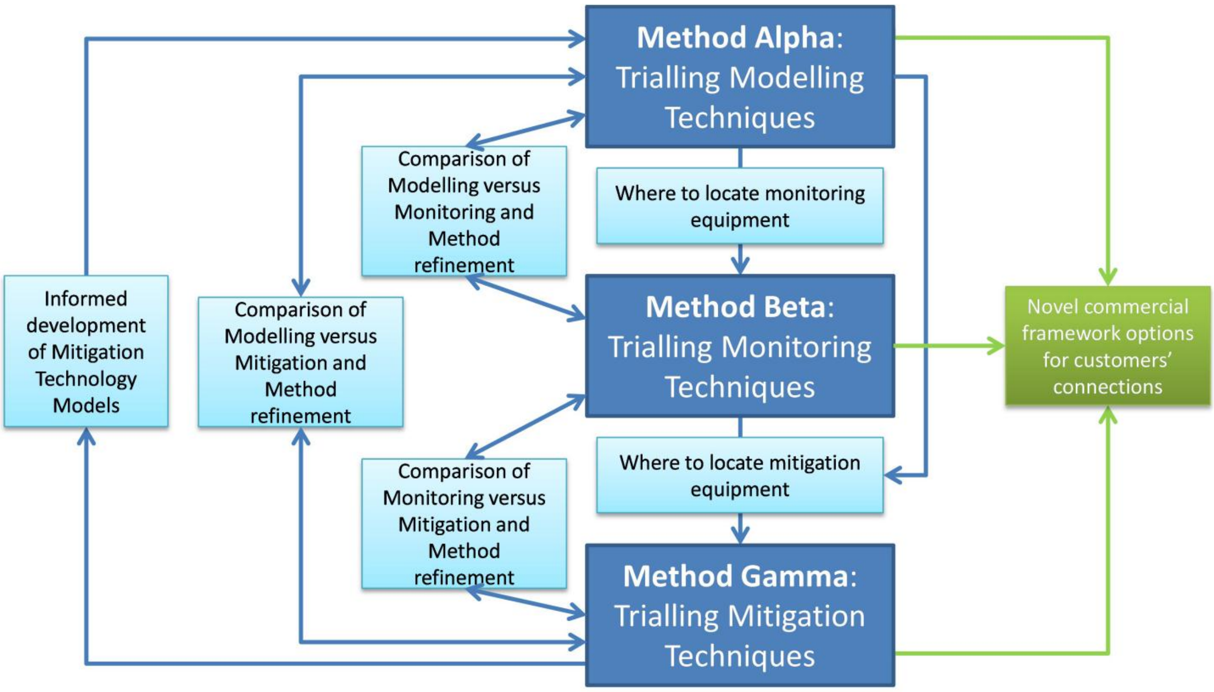


Figure 1: The expected learning from the integration of Methods Alpha, Beta and Gamma