WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

PROJECT PROGRESS REPORT

REPORTING PERIOD:

JUNE 2016 – NOVEMBER 2016

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

Report Title	:	Six monthly progress report Reporting period: JUNE 2016 to NOVEMBER 2016
Report Status	:	FINAL
Project Ref	:	WPDT2004 - FlexDGrid
Date	:	09.12.2016

Document Control

	Name	Date
Prepared by:	Jonathan Berry	09.12.2016
Reviewed by:	Roger Hey	12.12.2016
Recommended by:	Nigel Turvey	13.12.2016
Approved (WPD):	Philip Swift	15.12.2016

Revision History

Date	Issue	Status
25.11.2016	1	DRAFT
09.12.2016	2	FINAL

Contents

Glossary

Term	Definition
AC	Alternating Current
AFD	Active Fault Decoupler
BaU	Business as Usual
BCC	Birmingham City Council
CBD	Central Business District
CHP	Combined Heat and Power
DC	Direct Current
DG	Distributed Generation
DNO	Distribution Network Operator
DPCR5	Distribution Price Control Review 5
ER G74	Engineering Recommendation G74
EU	European Union
FCL	Fault Current Limiter
FLM	Fault Level Monitor
FLMT	Fault Level Mitigation Technology
GT	Grid Transformer
HV	High Voltage - 6.6kV or 11kV
IEC	International Electrotechnical Commission
KPI	Key Performance Indicator
LCNI	Low Carbon Networks & Innovation
PEFCL	Power Electronic Fault Current Limiter
PSFCL	Pre-saturated Core Fault Current Limiter
PSS/E	Power System Simulator for Engineering
RAMs	Risk Assessment Method statement
RII0-ED1	DNO Price Control from 1 April 2015 to 31 March 2023
RSFCL	Resistive Superconducting Fault Current Limiter
SDRC	Successful Delivery Reward Criteria
SoW	Scope of Work
ST	Standard Technique
TCA	Testing and Certification Australia
UoW	University of Warwick
WPD	Western Power Distribution
X/R ratio	The X/R ratio is the ratio of the system reactance to the system resistance looking back towards the power source from any point in the network

1 Executive Summary

FlexDGrid is funded through Ofgem's Low Carbon Networks Second Tier funding mechanism. FlexDGrid was approved to commence in January 2013 and will be complete by 31st March 2017. FlexDGrid aims to develop and trial an Advanced Fault Level Management Solution to improve the utilisation of Distribution Network Operators' (DNO) 11kV (HV) electricity networks while facilitating the cost-effective and early integration of customers' generation and demand connections. This report details progress of FlexDGrid, focusing on the last six months, June 2016 to November 2016, which is the final six monthly report for FlexDGrid. The next submission will be the closedown report three months following the closure of the project.

1.1 Business Case

The business case for FlexDGrid remains unchanged. Birmingham City Council (BCC) continue to have a policy in place for the inclusion of combined heat and power (CHP) plants in new domestic and commercial construction sites. The district heating scheme is being considered for expansion to a large energy from waste plant.

1.2 Project Progress

During this report period FlexDGrid has concluded construction activities and moved on to the trials and dissemination activities. As planned these trials focus on the three methods individually and importantly the positive interactions between each.

As reported in the previous progress report we have encountered significant issues with the design and build activities of GE's active fault de-coupler. In this reporting period the formal decision to terminate GE's contract was made; this was after several re-planning and senior management meetings with the aim to develop a suitable resolution plan to support the delivery of the two devices by the end of 2016 and generate the required industry learning. Following this decision work has been undertaken with Ofgem to re-baseline the finance of the project, which is reported in Table 4-1. A formal change request has also been agreed.

As all FLMs and FLMTs are now installed this reporting period has continued to focus on the operational learning of both devices and the use of the data output from the FLMs. Another key development is the inclusion of the first FLM device's operational ability in to WPD's network management system, meaning that control engineers can now generate both peak and make fault levels on request.

During this reporting period SDRCs 8, 9 and 10 have been submitted and significant progress has been made working towards the delivery of the final SDRC, 11. A description of the submitted SDRCs in this period is described below:

- SDRC-8 – Open-loop trialling of FLMTs;
- SDRC-9 – Closed-loop trialling of FLMs and FLMTs; and
- SDRC-10 – Quantification of benefits of the Solutions.

1.3 Project Delivery Structure

1.3.1 Project Review Group

The FlexDGrid Project Review Group met once during this reporting period. The main focus of this meeting was the GE Active Fault De-coupler (AFD) design and delivery and the decision to submit a formal change request.

1.3.2 Resourcing

There have been no significant project team resourcing changes during this reporting period.

1.4 Procurement

The procurement activity for the technologies (FLMs and FLMTs) is now complete, where all contracts are in place. An overview of these technologies and their installation dates is provided below in **Error! Reference source not found.**.

For clarity, following GE's purchase of Alstom in this reporting period the Alstom AFD has been re-branded to GE.

Manufacturer	Technology	Applicable Substations	Anticipated Delivery Dates
S&C Electric	Fault Level Monitors	10 Sites	Phased throughout 2014 and 2015 **(Complete)**
GridON	Fault Current Limiter – Pre-saturated Core	Castle Bromwich	April 2015 **(Complete)**
Nexans	Fault Current Limiter - Resistive Superconducting	Chester Street Bournville	October 2015 **(Complete)** December 2015 **(Complete)**
GE	Fault Current Limiter - Power Electronic	Kitts Green Bartley Green	De-scoped De-scoped

Table 1-1: FlexDGrid Technology Contracts

1.5 Installation

All 10 FLMs are now installed, commissioned and operational.

Three FLMTs are now fully operational. Following the submission of the FLMT change request there will be no further installation activities.

1.6 Project Risks

A proactive approach in ensuring effective risk management for FlexDGrid is taken. This ensures that processes have been put in place to review whether risks still exist, whether new risks have arisen, whether the likelihood and impact of risks have changed, reporting of significant changes that will affect risk priorities and deliver assurance of the effectiveness of control.

Contained within Section 8.1 of this report are the current top risks associated with successfully delivering FlexDGrid as captured in our Risk Register along with an update on the risks captured in our last six monthly project report. Section 8.2 provides an update on the most prominent risks identified at the project bid phase.

As expected at this stage of the project the risks are low as the construction work has been completed and the project is in the trial and dissemination phase.

1.7 Project Learning and Dissemination

Project lessons learned and what worked well are captured throughout the project lifecycle. These are captured through a series of on-going reviews with stakeholders and project team members, and will be shared in lessons learned workshops at the end of the project. These are reported in Section 6 of this report.

A key aim of FlexDGrid is to ensure that significant elements of the work carried out for network modelling, monitoring, design and installation are captured and shared within WPD and the wider DNO community. During this period the main focus has continued to be capturing learning in the form of producing, reviewing and revising WPD policy documents.

Key dissemination activities in this reporting period have been a presentation on a technical paper at CIRED, Helsinki in June, focussing on the results of the FLM devices and their use, the LCNI conference in Manchester in October and Hubnet's Power Electronics in Distribution Networks conference in November in London.

In addition to this we have shared our learning (where applicable), through discussions and networking at a number of knowledge sharing events hosted by other organisations.

2 Project Manager’s Report

2.1 Project Background

The FlexDGrid Low Carbon Networks Fund project aims to develop and trial an Advanced Fault Level Management Solution to improve the utilisation of Distribution Network Operators’ (DNO) 11kV (HV) electricity networks while facilitating the cost-effective and early integration of customers' generation and demand connections. The FlexDGrid project was awarded funding through Ofgem’s Low Carbon Networks Second Tier funding mechanism and commenced on the 7th January 2013.

The Carbon Plan aims to deliver carbon emission cuts of 34% on 1990 levels by 2020. This national target is devolved, in part, through local government carbon emission reduction targets as set out in their strategy planning documents. The Carbon Plan sets out ways to generate 30% of the UK's electricity from renewable sources by 2020 in order to meet the legally binding European Union (EU) target to source 15% of the UK's energy renewable sources by 2020. The UK Government has identified Distributed Generation (DG) as a major low carbon energy enabler and an important part of the future electricity generation mix.

Fault level is a measure of electrical stress when faults occur within networks. It is a growing issue in the connection of DG, especially in urban networks, as the majority of DG increases the system fault level. Conventional solutions to manage Fault Level often entail significant capital costs and long lead times.

In order to address the Fault Level Management Problem, three methods will be trialled and evaluated within the Central Business District (CBD) of Birmingham. The findings from these three methods will be extrapolated in order to understand the wider applicability to GB urban networks.

These Methods are:

Method Alpha (α) - Enhanced Fault Level Assessment;
Method Beta (β) - Real-time Management; and
Method Gamma (γ) - Fault Level Mitigation Technologies.

These three methods aim to defer or avoid significant capital investment and create a wider choice of connection options for customers who can accept a flexible connection to the network. These benefits will be provided to customers through advanced and modified generation connection agreements. Each method on its own will help customers to connect DG more flexibly. The three methods used together will aim to create greater customer choice and opportunities for connection.

2.2 Project Progress

This is the eighth reporting period and during this period FlexDGrid has concluded construction activities and moved to the trials and dissemination activities. The trials have been in the form of the three methods individually and importantly the positive interactions between each.

As reported in the previous progress report there have been significant issues with the design and build activities of GE's active fault de-coupler. In this reporting period the formal decision to terminate GE's contract was made. This was after several re-planning and senior management meetings with the aim to develop a suitable resolution plan to support the delivery of the two devices by the end of 2016 and generate the required industry learning. Following this decision work has been undertaken with Ofgem to re-baseline the finance of the project, which is reported in Table 4-1. A formal change request has also been submitted.

2.3 Fault Level Monitors - Method Beta

2.3.1 FLM measurements and MVA/MVA contribution

During 2014 and 2015 Fault Level Monitors (FLMs) were installed at 11 Birmingham primary substations. ENA ER G74 provides some guidance on allowances to be made for general load initial three-phase symmetrical RMS short-circuit contribution at 33kV busbars from LV and HV customers. This analysis aims to determine MVA/MVA infeeds at 11kV busbars based on data taken from the FLMs in order to provide data at 11kV and to determine if correlations exist between MVA per MVA contributions and load type: domestic, commercial or industrial and whether there are temporal variations.

To recap on the operation of the FLMs, infeed (upstream) 11kV fault levels through 132/11kV transformers are measured with Outram Research PM7000 power quality analysers. These detect voltage and current natural disturbances (NDs) from which peak make and rms break fault levels are estimated. The frequency at which these NDs occur is not controlled; larger NDs give rise to larger confidences in the estimated data.

S&C Electric Company IntelliRupter® PulseCloser® Fault Interrupters are connected to a particular busbar at each of the primary substations. These are used to create artificial disturbances (ADs), phase to phase faults lasting around 4 milli-seconds. Dedicated PM7000s are connected to these fault interrupter feeders which measure the peak make and estimate the RMS break fault currents. These ADs represent the total fault level at these 11kV busbars. ADs are created and measured four times daily at midnight, 06:00, noon and 18:00.

Previous Reporting Period

In the previous six month report an update was given on MVA per MVA fault infeeds at each FLM substation with MVA per MVA load infeed presented against the percentage of domestic demand at each substation. It was found that while some substations with a high level of domestic load generally follow the G74 recommendation of 1 MVA/MVA infeed further analysis was required to determine what level of MVA per MVA infeed might be applicable to substations with a higher mix of commercial and industrial load.

This Reporting Period

There has been a significant revision of the analysis methodology used in this reporting period and this section provides an overview of this methodology and specifically at three sites, Elmdon, Chad Valley and Kitts Green. This learning has illustrated that it is a requirement to have AD data, if the data is going to be used for either historic trending or real-time operational purposes. The full analysis methodology and justification for AD data is provided in SDRC-9.

Continuing with the analysis method used in the previous reporting period, one month average MVA per MVA infeed have been calculated and are shown in Figure 2-1. There are three substations where a consistent set of data exists for consecutive months: Kitts Green, Elmdon, and Chad Valley. Analysing these sets of data across the seasons has not shown a consistent relationship between MVA per MVA and seasonal demand variations. At some substations weekend MVA per MVA values are greater than weekday MVA per MVA values and midnight/06:00 values are greater than midday/18:00 values although there seems to be no apparent correlation between this and the load mix (domestic/commercial/industrial) fed from each substation.

The gaps in the results in Figure 2-1 are due to several reasons, the main one being the lack of measured data. Improvements to the analysis method may be gained by making use of the measured upstream fault levels, so called natural disturbances (NDs), and by examining measurements on a specific day where the configuration of the network including position of normally open points is known.

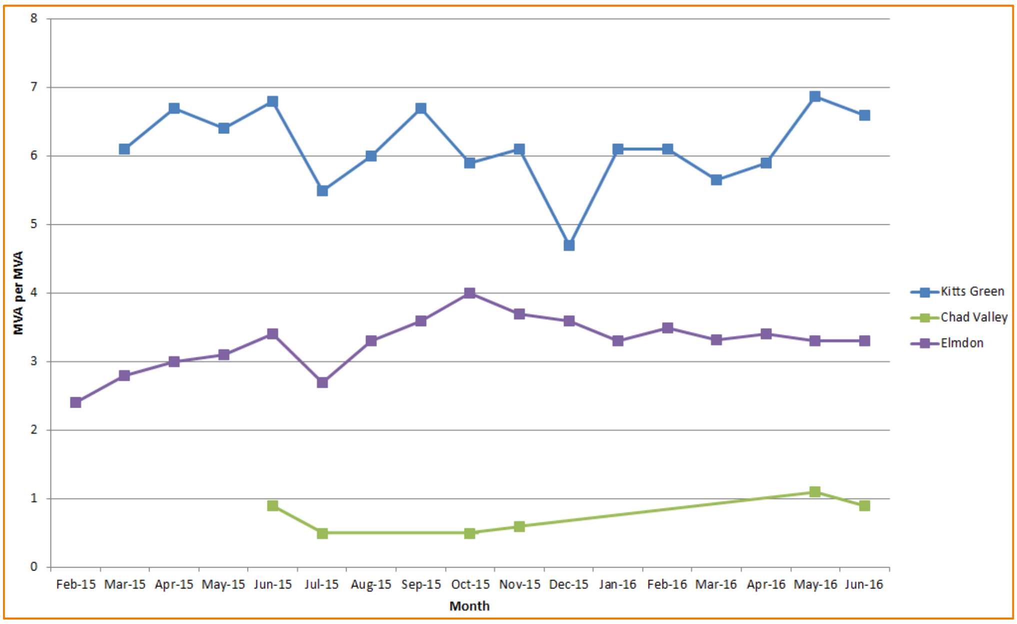


Figure 2-1: One month average peak make MVA per MVA

Elmdon

This substation is dominated by commercial and light industrial customers rather than domestic with the shape of the demand profiles being similar between winter and summer but the winter demand (7 - 10MVA) being slightly higher than the summer demand (6 – 9MVA), Figure 2-5.

Measurements of peak make ND and AD fault levels are shown in Figure 2-2 and fault levels do not vary across the seasons. ND measurements have a lower precision than AD measurements as they rely on the FLM detecting natural voltage and current disturbances on the network which are of a lower magnitude than those created during an AD measurement where an actual phase-phase fault is applied.

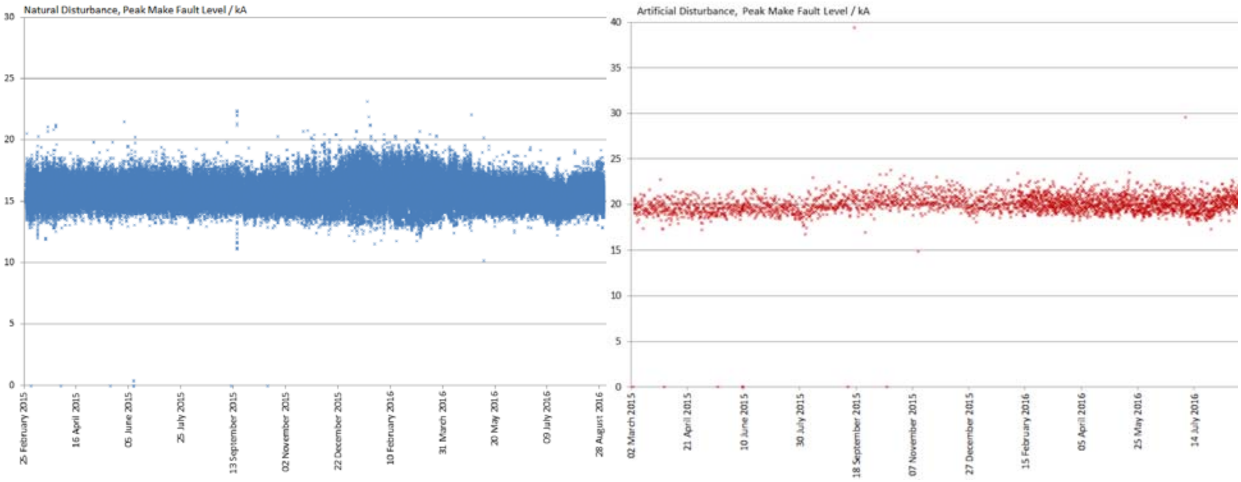


Figure 2-2: One month average peak make MVA per MVA

Examining a day of winter maximum demand and summer minimum demand shows a difference between the mean peak make ND and AD of 4kA during the winter, Figure 2-3, and 5kA during the summer, Figure 2-4. This represents a peak make infeed contribution to the total fault level at the 11kV primary of between 76 – 95MVA. With the substation loading appropriately considered this equates to an initial three phase symmetrical RMS short-circuit contribution from the general load of between 3 and 5 MVA/MVA. This is slightly higher than the 2.6MVA/MVA of aggregate winter demand given in G74 for HV customers (generally considered to be large industrial and commercial).

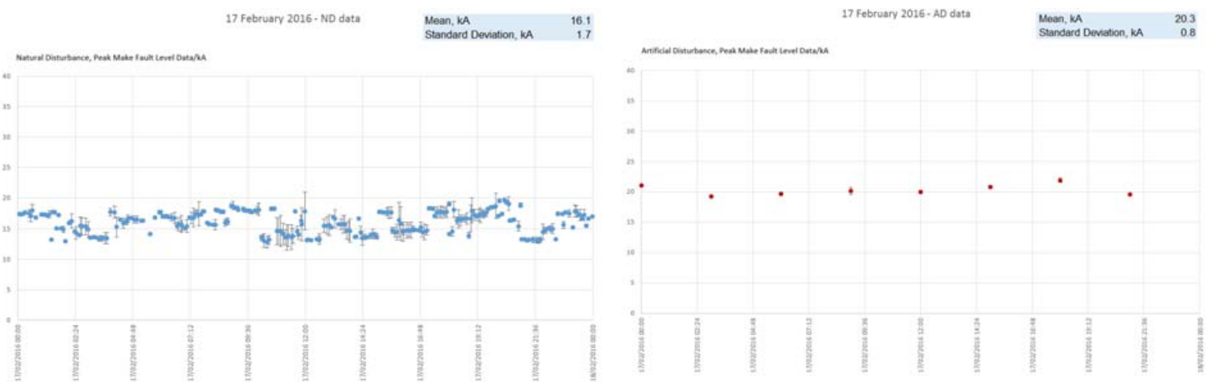


Figure 2-3: Peak Make ND and AD at Elmdon on a winter maximum demand day

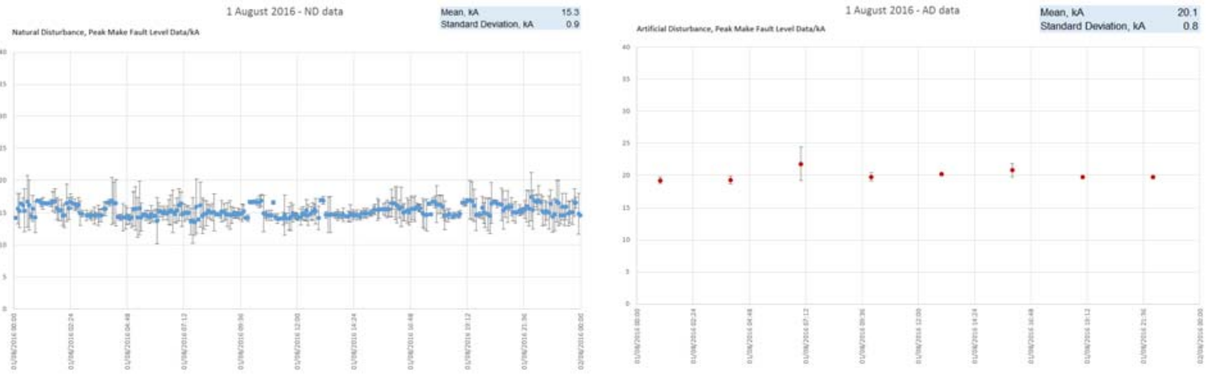


Figure 2-4: Peak Make ND and AD at Elmdon on a summer minimum demand day

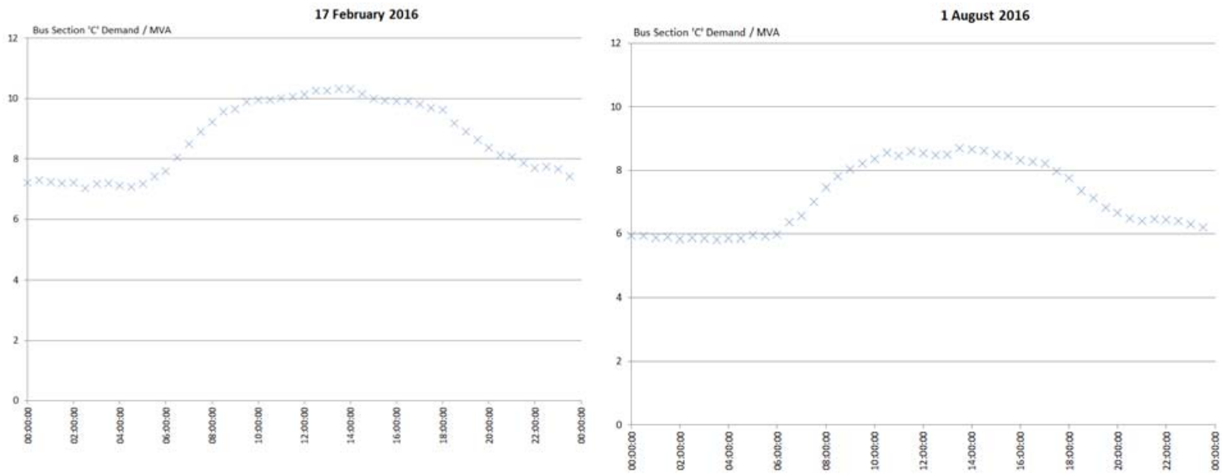


Figure 2-5: Bus Section Demand, winter maximum demand and summer minimum demand day

Chad Valley

Chad Valley load make up is an equal split of domestic demand to commercial / industrial.

At Chad Valley no seasonal variations are seen in fault levels and the increased precision of the AD measurements compared to the ND measurements is evident, Figure 2-6. Focusing on a day of winter maximum demand and summer minimum demand shows a mean ND and AD of 22kA. Attempting to resolve the data to a higher degree of accuracy is not possible due to the large standard deviation of the data. Demand on the feeders monitored by the FLM varies between 5MVA and 10MVA on the winter day and between 4MVA and 6MVA on the summer day. In order to determine a peak make MVA per MVA general load infeed value to within ±1MVA/MVA would require measurement accuracy higher than the ±5% tolerance of the FLM.

The G74 recommendation of an initial three phase symmetrical RMS short-circuit contribution of 1.0 MVA per MVA of aggregate low voltage network substation winter demand which is generally applied to domestic load would seem reasonable.

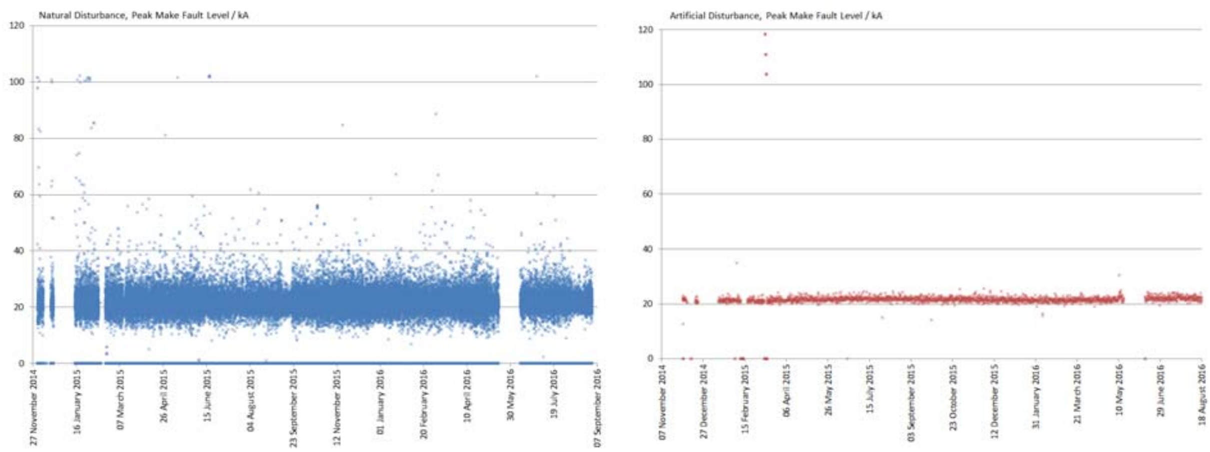


Figure 2-6: Peak Make ND and AD at Chad Valley Feb 2015 – July 2016

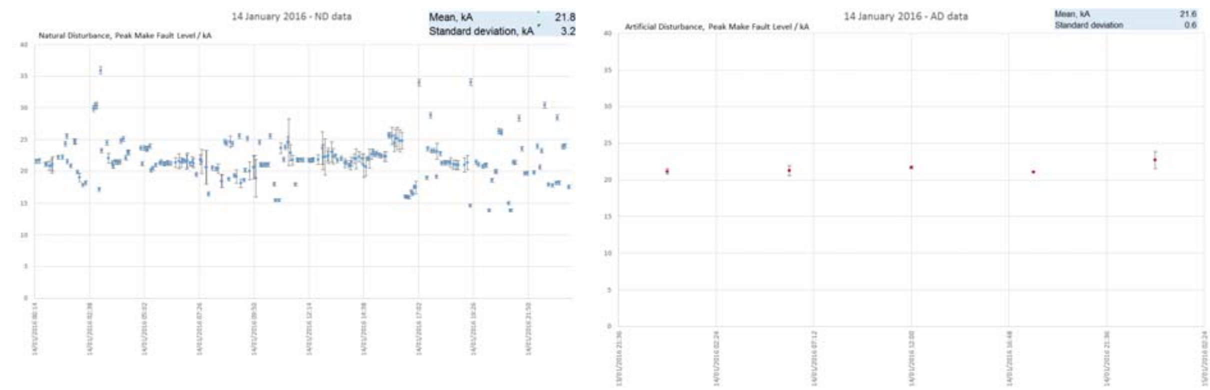


Figure 2-7: Peak Make ND and AD at Chad Valley on a winter maximum demand day

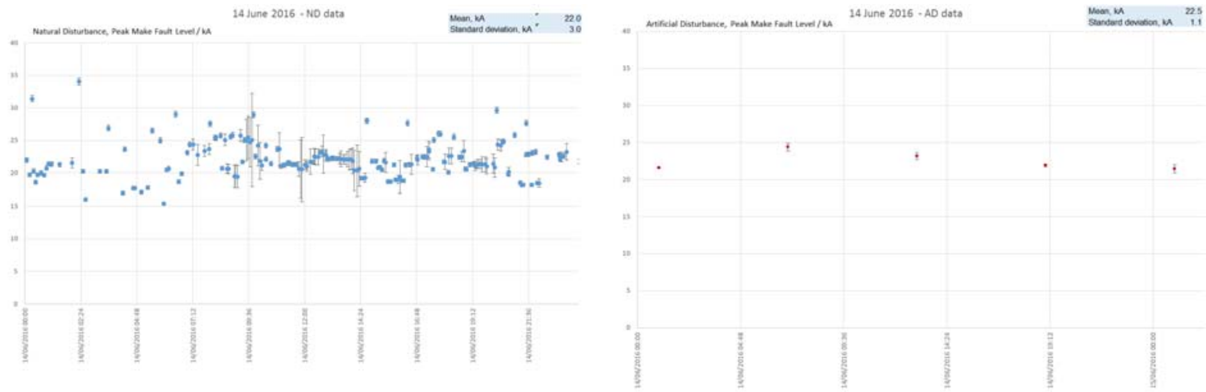


Figure 2-8: Peak Make ND and AD at Chad Valley on a summer minimum demand day

Kitts Green

The load connected to Kitts Green is largely dominated by domestic connections and small commercial premises, however, there is one large, dominating, heavy industrial customer connected to the same section of network as the FLM.

At Kitts Green the mean AD is generally larger than the mean ND by approximately 8kA, as shown in Figure 2-9. However at certain periods in the year the AD dips to a value similar to the ND. These periods coincide with large demand dips from a nearby large high voltage (HV) industrial customer generally occurring during holiday periods: Christmas / New Year and a fortnight in the summer. From this we can conclude that the majority of downstream fault level infeed is caused by this one customer. Examining the changes in demand and fault level during and after the holiday period shows very large initial three phase symmetrical RMS short-circuit contribution of between 7 and 9 MVA/MVA from this one customer. This would imply that the load causing this fault level contribution is mainly motors.

An additional learning can be taken from Figure 2-9: the precision of ND measurements are much higher when the large industrial customer is consuming load. This is likely to be caused by switching of large loads by the customer causing higher measured voltage step changes leading to higher precision and potentially more accurate ND measurements.

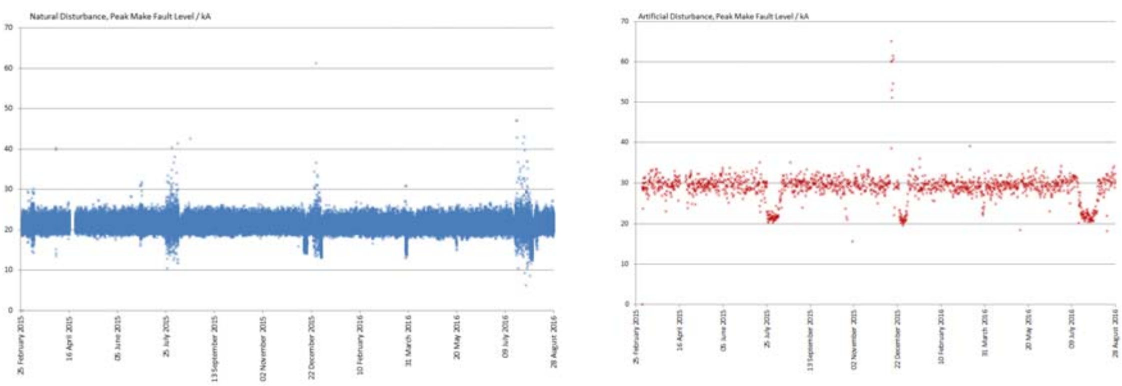


Figure 2-9: Peak Make ND and AD at Kitts Green Feb 2015 – Aug 2016

Conclusions and Further Work

The following conclusions can be drawn:

- Substations where the demand is mainly domestic have a relatively low fault level contribution and an initial three phase symmetrical RMS short circuit contribution of 1 MVA / MVA of aggregate LV load to the 11kV fault level at the primary is a reasonable approximation;
- Where the demand is mainly commercial and industrial a value of up to 4 MVA / MVA should be considered;
- The large industrial customer identified in the study had a value up to 9 MVA/MVA. However, where possible, and where records allow, explicit modelling of large asynchronous motors and distributed generation involving synchronous machines such as landfill gas, biomass and CHP will always be required.

Fault level measurements have been shared with the main business in order that the company's network models can be updated to accurately reflect measured values. Further work could focus on refining system models to reflect measured data. Total fault levels at 11kV are dominated by the upstream rather than downstream network. 11kV upstream infeed fault levels at primary substations are mostly affected by upstream transformer impedances and the EHV network so emphasis should be placed in refining models in these areas so that modelled infeeds align more closely with long term ND measurements. Transmission system (400 and 275kV) fault levels have relatively little impact on 11kV fault levels.

2.3.2 FLM Data in to WPD's Systems and Operation

Throughout this reporting period a significant deliverable has been enabling the fault level date generated through the FLMs to be visible directly by WPD's control engineers in the standard network management system (NMS), PowerON. A secondary functionality that has been made available is the operation of an FLM by the control engineers. Previously the FLMs operated at a specific time interval, every six hours for example, but now the operation can be instigated through a control engineer driven action. This has significant benefits in terms of understanding the state of the network before and after another action is taken on the system.

This section further documents the processes taken to make control and visibility of the FLMs available in the NMS.

Data Integration

During initial commissioning of the FLMs it was determined that the data gathered would be held on an online system; this afforded product suppliers and third parties to have direct, view only, access to the data. In order to enable the FLM data to view in WPD's standard NMS the data paths had to be transferred to WPD's standard system. This was carried out in two parts. The FLM data was originally stored on Nortech's online iHost system so this data was re-routed to WPD's in house offline iHost server. In order to facilitate the communications facilities had to be updated at each of the 10 sites, which involved FLM device firmware upgrades and SIM card changes.

Once the transfer of FLM data in to WPD's offline iHost server was complete and it was confirmed that the connection was robust and secure the second phase was undertaken, which was to transfer the data to WPD's iHost server that directly communicates with the NMS and would allow the data to be directly presented on this system.

Figure 2-10 - FLM Control Cubicle

FLM Control

With data from the FLM now available in the WPD NMS connected IHost a standard NMS schematic insert was developed and embedded adjacent to the FLM schematic on the network diagram, see Figure 2-11, which allowed control engineers to view the latest fault level data held within IHost. The insert displayed the latest 'AD Peak Fault Level' value and the 'AD RMS Fault Level' value together with the last update time as taken from IHost. This detail was added as throughout the project the standard Artificial Disturbance operation time had been set at every six hours therefore it was seen as important that the control engineer understood how up-to-date the information was he had available to him. Initially the insert was rolled out to the Nechells West Primary Substation.

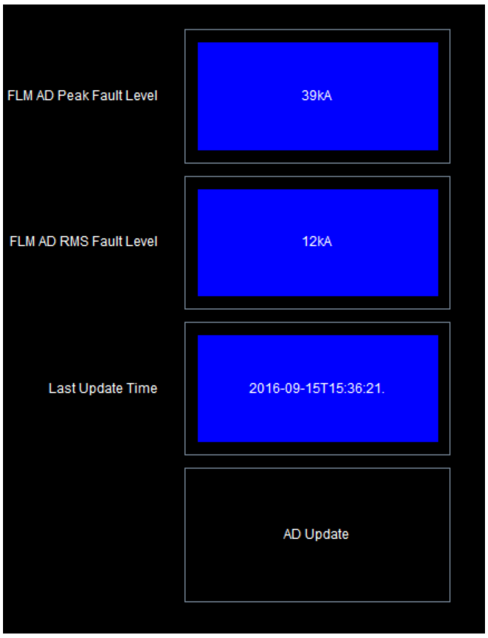


Figure 2-11 - NMS Interface

The 'AD Update' was subsequently developed to allow control engineers to undertake a manual update of the fault level values to provide a more real-time view. The AD update function effectively gives the control engineers control of the Intellirupter operation. To develop the 'AD Update' functionality, updates to the Envoy, IHost and NMS were required. Nortech were commissioned to carry out the necessary development works to IHost and the Envoy and worked closely with the WPD NMS support team to establish the necessary additional communications links between IHost and NMS. 'AD update' developments were first trialled using the NMS test system with Nortech undertaking their development offline.

In order to roll-out the developments online to the Nechells West site an outage of the FLM was arranged. The outage was required to isolate the 'Intellirupter' from the network to test the 'on-demand' functionality without introducing unnecessary disturbances on to the network. This was carried out successfully on the 10th November. In line with the development of the 'on-demand' functionality the policy OC1V covering the 'Operation and Control of 11kV Network Fault Level Monitors (FLMs) for use on the FlexDGrid project' has been updated. The updates cover the guidance on the displayed data and how to update it.

Customer Connections using FLM Data

Following the provision of real-time FLM data in to the NMS system the opportunity to flexibly connect customers, based on the FLM data, becomes available. Significant work, within WPD, has taken place to make available alternative connections to customers based on voltage and current / thermal data, the principle of offering connections to customers using FLM data must be consistent with the existing policies and procedures in place.

WPD's existing alternative connections focus on a full Alternative Network Management (ANM) system, soft-intertrip and timed offering. Following preparatory investigation in to the suitable solutions for fault level related customer connections the soft-intertrip was selected.

Soft-Intertrip

Soft-intertrip is a current WPD offering on networks which are constrained due a single upstream asset requiring reinforcement, or a single limit being infringed under certain conditions. Through monitoring these conditions, further capacity can be released when these limits or assets are within normal operating parameters. Once installed, the on-site soft-intertrip RTU will provide two normally open contacts for the customer's control system to monitor; Stage 1 and Stage 2. When both sets are open, the connection will be free of constraints. The levels of curtailment corresponding to the operation of the Stage 1 and Stage 2 contacts are defined at the planning stage.

Fault level constraints fit well with the existing soft-intertrip philosophy and the existing generator constraint panel can be used to control customers generators with only a change to the measured thresholds and timers. A significant difference between a thermal soft-intertrip scheme and a fault level scheme is that no Network Management Sequence switching Scheme is required for a fault level application. The reason for this is because the control engineer must still have the final say before a parallel is made because the fault level on the network on to which the parallel is being made is unknown.

Network Operations

Parallel Operation

As control engineers now have visibility of the fault levels on a particular section of the network a set of rules has been established for the use of this information, to include network connectivity and therefore security. The rules took the form of Table 2-1, which are presented to the control engineer in the NMS and enable the engineer to make an informed decision as to the availability to parallel, or split, the network.

GT1B De-Energisation	
AD FL Peak Value	**Action**
>13.7kA	Open Bus-Section V-U prior to paralleling

Table 2-1: GT1B De-Energisation Actions

These values were calculated by using the enhanced IPSA model, as developed as part of Method Alpha, whereby the worst case conditions were considered and the electrical summation of the fault level of the section with the FLM was considered. This methodology can be expanded to any other sites with FLMs in operation.

Customer Actions

A similar approach can be used to identify customer applications where fault level monitoring may be more appropriate than conventional reinforcement. Using the enhanced network model and incrementally increasing fault levels on the constrained section of network a point is reached where the customers load or generation causes a potentially unsafe parallel operation. Using these values as a marker a table can be included on the NMS detailing what mitigating actions should be undertaken in order to undertake a safe parallel operation based on the real-time Fault Level Monitor values.

Table 2-2 provides an example of the data to be presented.

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 12.703	4.7MVA CHP Disconnected Bus-Section Z-Y Open
≤10.674	Bus-Section Z-Y Open

Table 2-2 - Customer Actions around Fault Level Constraints

In order to facilitate this control on site WPD standard generator constraint panels can be installed at the customer's site to enable the control engineer to disconnect or isolate the customer's plant if required.

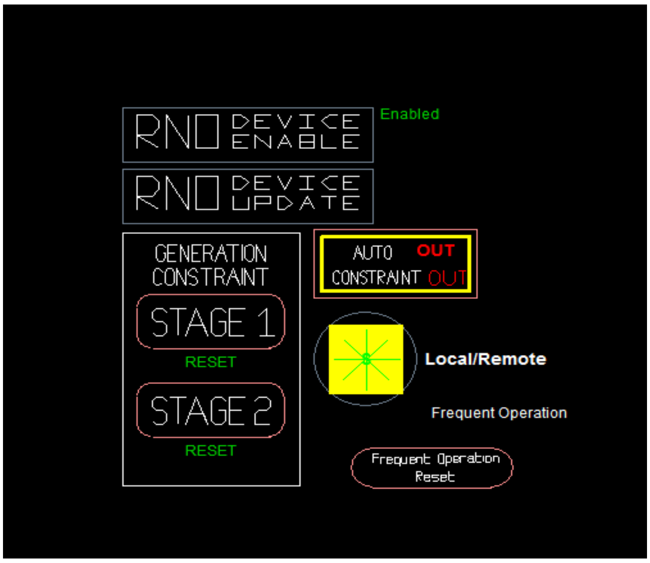


Table 2-3 - Constraint Panel Schematic

Using the historically collected fault level values together with experience built on previous active network management scheme curtailment studies analysis can be undertaken to give the customer a view of expected times in which they may be curtailed. By providing customers with a curtailment study, in line with other alternative connection offers, for a connection with fault level constraints they can then make a decision on whether to pursue a conventional connection or accept an alternative connection with the associated probability of disconnection, as detailed in their site specific curtailment study.

Next Steps

Following this learning and to support the successful delivery of SDRC-11 in the New Year the installation of constraint panels will be installed at a customer's premises and the requirements for constraint will be closely monitored and robustly reported.

2.4 Fault Level Mitigation Technologies – Method Gamma

2.4.1 GridON Pre-Saturated Core FCL

Overview

The previous six monthly report provided detail on the investigation and subsequent repair on the DC sensing circuit for the GridON FCL, which cause a short term interruption in the device's availability. Following successful re-energisation on the 6th May 2016, the GridON FCL has been in service and has not experienced any further issues.

Figure 2-12 below shows a snapshot of WPD's PowerON control system which shows the GridON FCL successfully reconnected to the 11kV network with windings GT1A and GT1B operating in parallel.

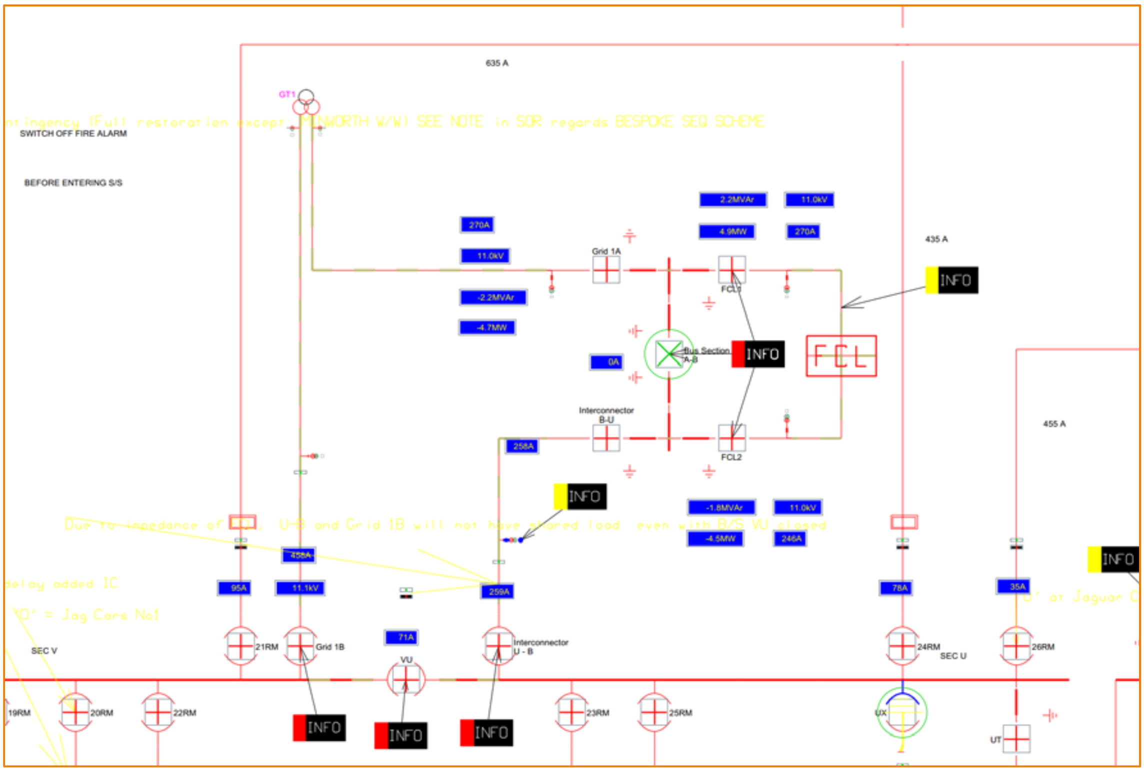


Figure 2-12: GridON FCL following re-energisation at Castle Bromwich 132/11kV substation

There have been no faults on the 11kV network supplied by the FCL during this reporting period therefore it has not been possible to analyse the performance of the device.

Load Flow

The GridON pre-saturated core FCL has the ability to 'ride through' faults without disconnection. Therefore, it was the preferred choice for installation at Castle Bromwich where it is connected in series with an 11kV winding of a transformer. However, the design of this FCL has the slight disadvantage of having a residual impedance in the normal operating range. When operating the network in parallel as shown in Figure 2-13, this additional residual impedance results in non-symmetrical sharing across windings GT1A and GT1B.

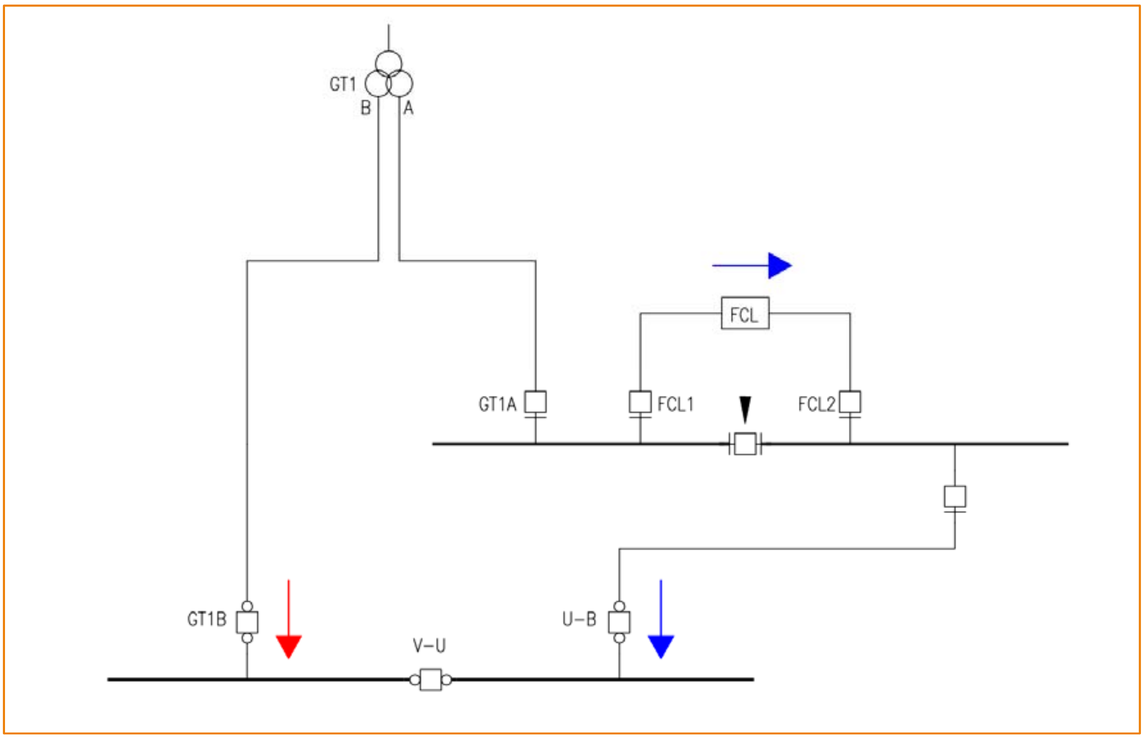


Figure 2-13: SLD of GridON FCL at Castle Bromwich 132/11kV substation

The arrows shown on Figure 2-13 represent the current flows which have been monitored at the site. Due to the impedance of the FCL, the current represented by the blue arrow (FCL) would be less than the current represented by the red arrow (GT1B).

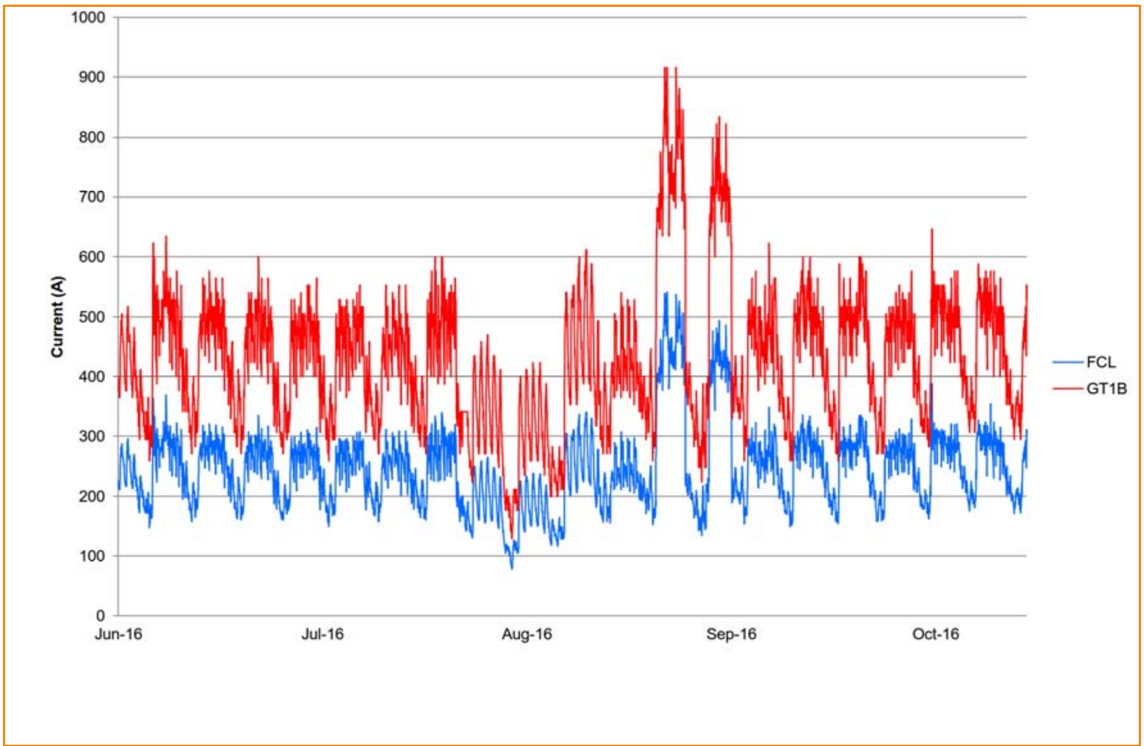


Figure 2-14: Current flow measured at Castle Bromwich substation - GT1B and FCL

Figure 2-14 shows the current flow through these circuit breakers as measured over a six month period. It can be seen that due to the FCL impedance, GT1B carries around 60% of the total current on GT1. This effect on the network at Castle Bromwich was studied prior to the design and installation of the FCL. Using estimated data from the GridON the study revealed that the firm capacity of the substation would be reduced. However, as the forecasted load is less than 50% of the firm capacity and there was limited new load connection activity, there were no perceived issues with accepting a reduced firm capacity. Comparing the results of the study against the actual measurements on site has revealed that the residual impedance is slightly more than estimated by GridON. Further details of this can be found in SDRC-9.

The load flow graphs presented in Figure 2-14 show large swings of load during August and September. These fluctuations were due to changes on the 11kV network and maintenance activities on GT2 at Castle Bromwich. The change in loads had no effect on the performance of the GridON FCL with the DC bias current reacting as expected.

2.4.2 Nexans Resistive Superconducting FCL

Summary

Previous Reporting Period

The previous six monthly report provided detail on the testing and installation of the Bournville RSFCL as well as a summary of the initial operation of the Chester Street RSFCL after being connected to the 11kV network.

The Bournville RSFCL was successfully tested at KEMA's laboratory in Arnhem, Netherlands on the 7th December 2016. It was then transported to site where it was successfully installed in its final position. The device was successfully connected to the 11kV network on the 23rd February 2016.

The Chester Street device was connected to the 11kV network on the 25th November 2015. A number of alarms were identified after the connection of the device which indicated malfunctions associated with its cooling system. The device was able to continue its operation due to the built in redundancy in the cooling system.

This Reporting Period

Both the Chester Street and Bournville RSFCLs have experienced significant unavailability due to problems with their associated cooling systems. These issues have been experienced in the early phase of device operation and a small issue on the complete system has caused a large impact, i.e. disconnection of the device from the network. Throughout the remainder of the project and for a period after the long term operational availability of the two devices will be assessed.

There have been no faults on the 11kV network supplied by the RSFCLs during this reporting period therefore it has not been possible to analyse the performance of the devices.

The following sections of this report give an update on the progress from the last reporting period and also document the operation of both RSFCLs in service. The issues encountered with the RSFCLs during their time in service are also described.

Chester Street

General

Chester Street RSFCL successfully passed the type tests at the KEMA laboratory in Arnhem, Netherlands on the 5th October 2015. The RSFCL was energised and connected to the 11kV network on the 25th November 2016. The graph shown in Figure 2-15 shows the current flow through the RSFCL from the energisation date to the end of this reporting period.

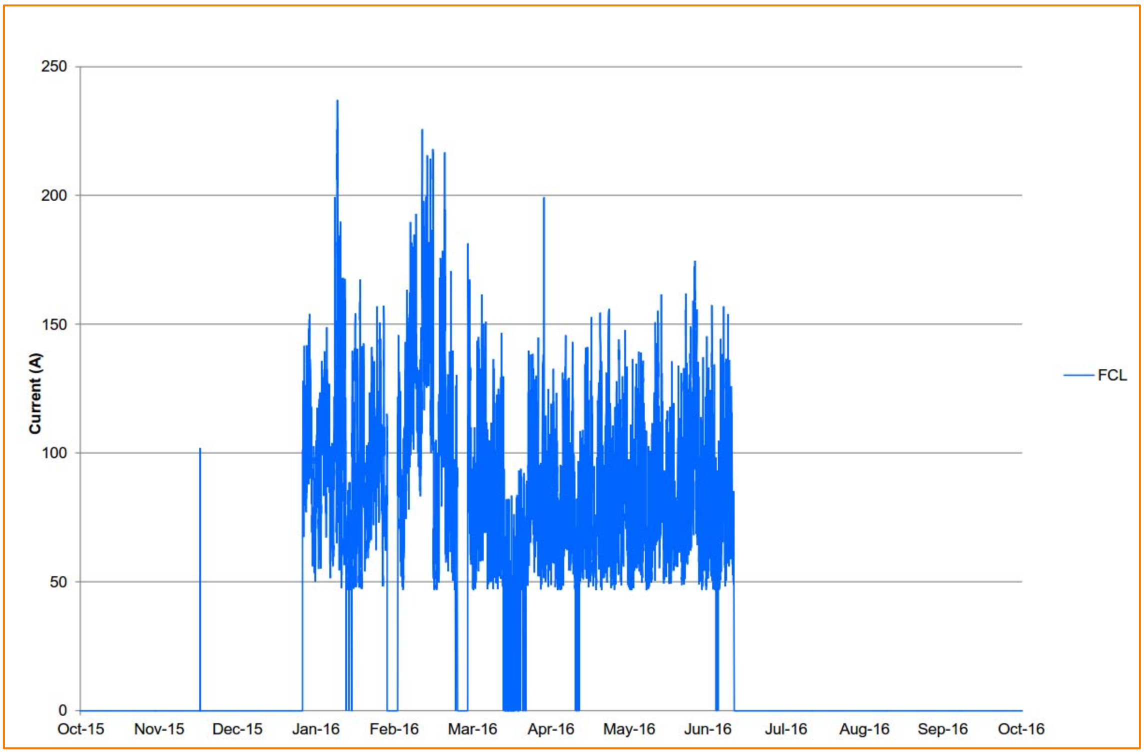


Figure 2-15: Graph of current flow through the Chester Street RSFCL

The RSFCL was disconnected from the network shortly after energisation to allow for modifications to the substation AVC scheme. The device was reconnected to the network on 5th January 2016. Refer to the last six monthly report for details of the AVC modifications and the initial operation of the RSFCL in service. Since the reconnection of the device in January 2016 the RSFCL has been in sustained operation on the network for approximately six months until being disconnected on the 25th June 2016. The following sections describe the reasons for the disconnection of the RSFCL.

Operational Issues and Solutions

A number of cooling system alarms were present on the Chester Street RSFCL control system during the last reporting period. These indicated an over-temperature condition with two of the compressors. Both of the compressors had correctly tripped to avoid damage due to the over-temperature. It should be noted that there are a total of six compressors in the cooling system. The remaining four were fully operational and were able to maintain stable cooling of the cryogenic material due to the redundancy built into the system. This allowed the RSFCL to remain connected to the network during this period. For further detail refer to the previous six monthly report.

Nexans carried out an investigation and determined that the issues with the compressors were caused by residual air in the compressor water cooling circuit. Work was carried out at site to release the residual air by opening a number of valves on the compressor assembly which resolved the issue.

The Chester Street device was operational from the 5th January 2016 to the 25th June 2016. On the 25th June 2016 WPD network control centre received an auxiliary system alarm from the RSFCL and took the decision to remove the RSFCL from service. This decision was taken to avoid the further risk of system failures even though the device could have continued to operate. An investigation was carried out at site and a number of alarms relating to the cooling system were present on the RSFCL HMI. These are shown below in Figure 2-16.

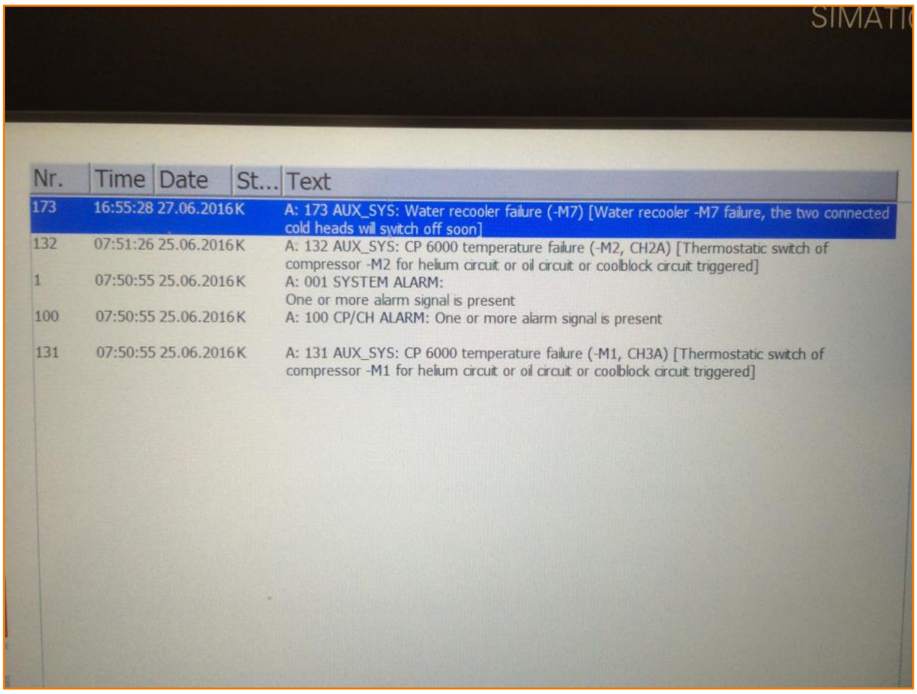


Figure 2-16: Screenshot from Chester Street RSFCL HMI showing cooling system alarms

WPD issued Nexans with the required information from the RSFCL control system to allow the manufacturer to investigate the source of the issue. Nexans determined that the helium pressure was low in the affected compressors and scheduled a site visit on the 17th July 2016 to investigate and remedy the issues with the RSFCL. The site visit confirmed the existing issues but also identified additional problems with the cooling system that had occurred in the intervening time prior to the site visit. The complete list is as follows:

- Over-temperature on compressor M1.
- Over-temperature on compressor M2.
- Low helium pressure in compressor M3.
- Recooler M9 failure.
- Compressor M5 and M6 were switched off due to failure of Recooler M9.

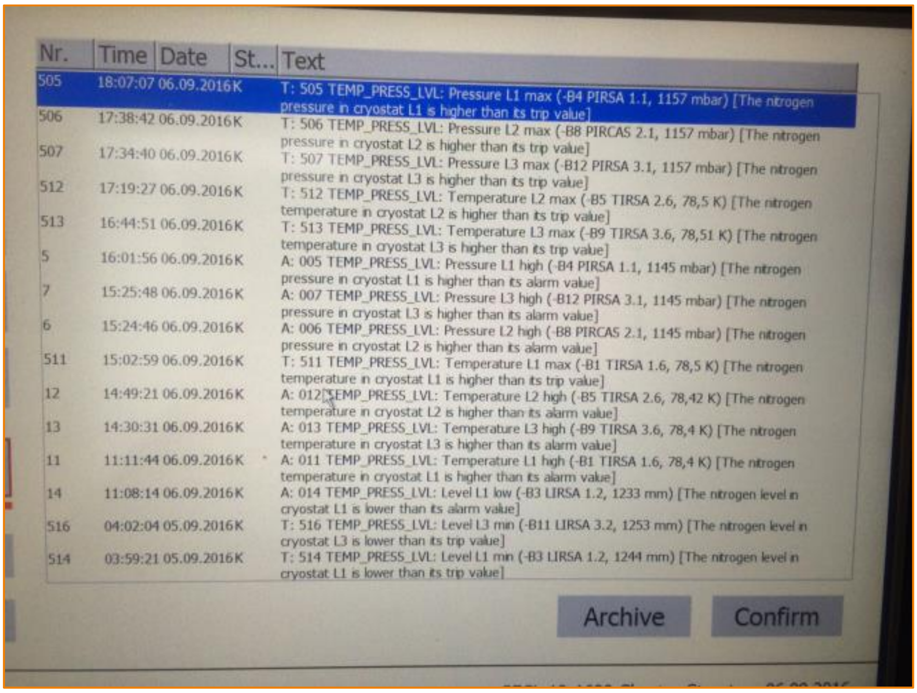
The RSFCL requires at least three compressors to be running to ensure the stabilisation of the cryogenic material at the required pressure and temperature set-point. The investigation determined that only a single compressor was in operation. This caused the pressure in the cryostat vessels to rise, instigating the operation of the electromechanical pressure release valve. The continued release of pressure caused a reduction in the liquid nitrogen level inside the RSFCL below its minimum trip value.

The low helium pressure in compressor M3 was attributed to a loose screw connection on one of the flexible pipes. The connection was tightened and a helium leak test was performed to confirm no further leakage. The issues associated with the recoolers were attributed to the lack of air supply to the heat exchanger due to debris obstructing the condenser. A picture of the debris is shown in Figure 2-17. This caused the temperature of the recooler to increase, leading to the evaporation of cooling water. The recoolers were refilled to the correct level and reset. All compressors were also reset and operational. However, the device was unable to be reconnected to the network until the liquid nitrogen level was restored to its normal value.

Figure 2-17: Photograph of the debris obstructing the air flow to the re-cooler condenser

Nexans attended the Chester Street site for a second time on the 23rd August 2016 to refill the RSFCL cryostats with liquid nitrogen. A liquid nitrogen storage vessel was connected to the RSFCL and the nitrogen level was increased to the nominal value. During the site visit a further issue was identified. The recooler M9 had experienced an over-temperature trip. The unit's condenser was cleaned and it was reconnected to the cooling system; however, the temperature of the device rose rapidly and disconnected itself for a second time. This indicated that the device had an internal fault. Nexans instructed that the recooler manufacturer to repair the faulty unit. The decision was taken to keep Chester Street RSFCL disconnected from the network even though it was possible for reconnection due to the restoration of the liquid nitrogen level. This decision was taken to avoid further damage to the cooling system and subsequently further loss of nitrogen level.

A further WPD site visit to Chester Street on the 6th September 2016 identified that there had been further trip signals received from the RSFCL control system. The temperature, pressure inside the RSFCL cryostats had reached their trip levels. The further exhaust of nitrogen gas had decreased the nitrogen level to below its trip level. The alarms and trips are shown in Figure 2-18. Based on this information Nexans had to schedule the refilling of the device for a second time.



Nr.	Time	Date	St...	Text
505	18:07:07	06.09.2016	K	T: 505 TEMP_PRESS_LVL: Pressure L1 max (-B4 PIRSA 1.1, 1157 mbar) [The nitrogen pressure in cryostat L1 is higher than its trip value]
506	17:38:42	06.09.2016	K	T: 506 TEMP_PRESS_LVL: Pressure L2 max (-B8 PIRCAS 2.1, 1157 mbar) [The nitrogen pressure in cryostat L2 is higher than its trip value]
507	17:34:40	06.09.2016	K	T: 507 TEMP_PRESS_LVL: Pressure L3 max (-B12 PIRSA 3.1, 1157 mbar) [The nitrogen pressure in cryostat L3 is higher than its trip value]
512	17:19:27	06.09.2016	K	T: 512 TEMP_PRESS_LVL: Temperature L2 max (-B5 TIRSA 2.6, 78,5 K) [The nitrogen temperature in cryostat L2 is higher than its trip value]
513	16:44:51	06.09.2016	K	T: 513 TEMP_PRESS_LVL: Temperature L3 max (-B9 TIRSA 3.6, 78,51 K) [The nitrogen temperature in cryostat L3 is higher than its trip value]
5	16:01:56	06.09.2016	K	A: 005 TEMP_PRESS_LVL: Pressure L1 high (-B4 PIRSA 1.1, 1145 mbar) [The nitrogen pressure in cryostat L1 is higher than its alarm value]
7	15:25:48	06.09.2016	K	A: 007 TEMP_PRESS_LVL: Pressure L3 high (-B12 PIRSA 3.1, 1145 mbar) [The nitrogen pressure in cryostat L3 is higher than its alarm value]
6	15:24:46	06.09.2016	K	A: 006 TEMP_PRESS_LVL: Pressure L2 high (-B8 PIRCAS 2.1, 1145 mbar) [The nitrogen pressure in cryostat L2 is higher than its alarm value]
511	15:02:59	06.09.2016	K	T: 511 TEMP_PRESS_LVL: Temperature L1 max (-B1 TIRSA 1.6, 78,5 K) [The nitrogen temperature in cryostat L1 is higher than its trip value]
12	14:49:21	06.09.2016	K	A: 012 TEMP_PRESS_LVL: Temperature L2 high (-B5 TIRSA 2.6, 78,42 K) [The nitrogen temperature in cryostat L2 is higher than its alarm value]
13	14:30:31	06.09.2016	K	A: 013 TEMP_PRESS_LVL: Temperature L3 high (-B9 TIRSA 3.6, 78,4 K) [The nitrogen temperature in cryostat L3 is higher than its alarm value]
11	11:11:44	06.09.2016	K	A: 011 TEMP_PRESS_LVL: Temperature L1 high (-B1 TIRSA 1.6, 78,4 K) [The nitrogen temperature in cryostat L1 is higher than its alarm value]
14	11:08:14	06.09.2016	K	A: 014 TEMP_PRESS_LVL: Level L1 low (-B3 LIRSA 1.2, 1233 mm) [The nitrogen level in cryostat L1 is lower than its alarm value]
516	04:02:04	05.09.2016	K	T: 516 TEMP_PRESS_LVL: Level L3 min (-B11 LIRSA 3.2, 1253 mm) [The nitrogen level in cryostat L3 is lower than its trip value]
514	03:59:21	05.09.2016	K	T: 514 TEMP_PRESS_LVL: Level L1 min (-B3 LIRSA 1.2, 1244 mm) [The nitrogen level in cryostat L1 is lower than its trip value]

Figure 2-18: Screenshot from Chester Street RSFCL HMI showing liquid nitrogen level, pressure and temperature trips

Nexans visited Chester Street on the 12th September 2016 to assist the recooler manufacturer carry out the repairs required to recooler M9. The visit was timed to coincide with the first scheduled maintenance of all recoolers. The technician from the recooler manufacturer repaired the recooler M9 on the 15th September 2016 and also performed routine maintenance on the remaining recoolers. The technician discovered that the fan on the recooler M7 was slow to start during the routine maintenance. The technician advised that the control unit for the fan speed and an associated transmitter needed replacement.

The repair of the recooler M7 and the refilling of the liquid nitrogen level were scheduled for another site visit by Nexans in October.

Nexans carried out final repairs to the Chester Street device on the 17th October 2016. During their initial investigations at site some additional issues were identified with the RSFCL cooling system. These are as follows:

- The compressors M1 and M3 were switched off due to an over-temperature condition in the helium circuit.
- The compressor M4 was working but not in operation. It was found that a small amount of oil had leaked from the unit. Nexans informed WPD that the technician from the compressor supplier will perform checks on all compressors at the next scheduled maintenance of the cold heads.
- A new alarm was identified on the RSFCL HMI indicating that the burst disc had operated on the L3 cryostat vessel. Nexans performed an investigation and found that the burst disc was intact. The source of the issue was a faulty burst disc indicator.

Nexans implemented the repairs to the recooler M7 by replacing the transmitter and control unit for the fan speed control. The compressors M1 and M3 were switched on without further problems. The burst disc indicator for cryostat L3 was replaced and the nitrogen level in cryostats replenished. All cooling issues were resolved and the Chester Street RSFCL was reconnected to the network on 8th November 2016.

Bournville

General

Bournville successfully passed the type tests at the KEMA laboratory in Arnhem, Netherlands on 7th December 2015. The device was then successfully transported and installed at site. The RSFCL was energised and connected to the 11kV network on 17th February 2016. The graph shown in Figure 2-19 shows the current flow through the RSFCL from the energisation date to the end of this reporting period.

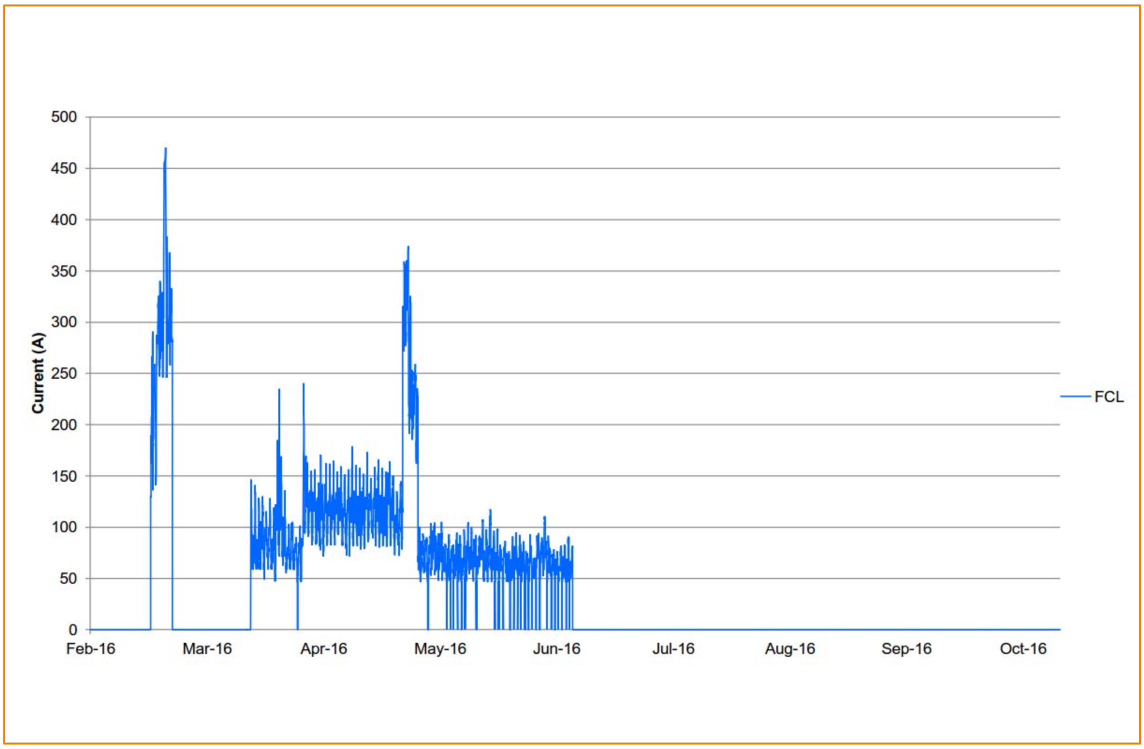


Figure 2-19: Graph of current flow through the Bournville RSFCL

The RSFCL was disconnected from the network from 23rd February 2016 to 15th March 2016 to allow for modifications to the substation AVC scheme. Refer to the last six monthly report for details of the AVC modifications and the general testing, installation and energisation activities. Since the reconnection of the device in March 2016 the RSFCL sustained operation on the network for approximately four months until being disconnected on 9th June 2016. The following sections describe the reasons for the disconnection of the RSFCL.

Operational Issues and Solutions

On the 9th June 2016 the WPD control centre received a “system initialise alarm” from the Bournville RSFCL. The control operator took the decision to remove the device from service. This decision was taken to avoid the further risk of system failures even though the device could have continued to operate. An investigation was carried out at site and a further alarm relating to the cooling system was present on the RSFCL HMI. The alarm indicated a failure of recooler M7 and is shown in Figure 2-20.

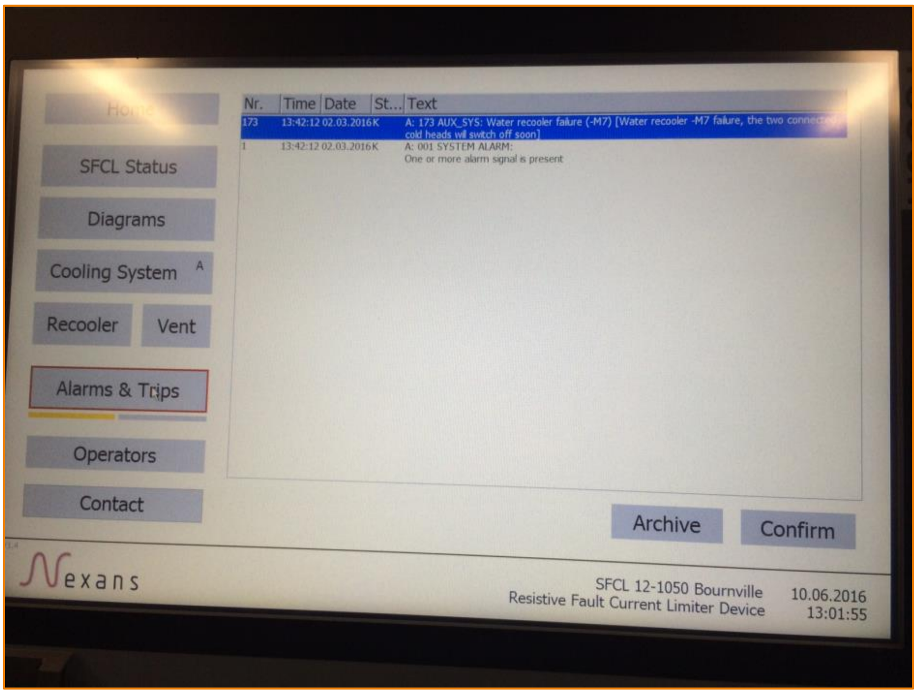


Figure 2-20: Screenshot of the Bournville RSFCL HMI showing the auxiliary system alarm relating to recooler M7 failure

The system initialise alarm was originally designed to indicate to the WPD control operator that the device was ready for reconnection to the network following operation of the RSFCL to limit a network fault. It was agreed with Nexans during the testing of both Chester Street and Bournville devices that the system initialise alarm was not required in the control system. Nexans removed the signal from the software; however, the signal was still wired at site for possible future reconfiguration. The WPD control centre should not have received this alarm and consequently an investigation was carried out to confirm that the signal wiring from the Nexans control panel was wired correctly as per the design schematics.

Nexans visited the Bournville site on the 20th July 2016 to investigate and resolve the issue with the recooler M7. During the investigation Nexans discovered an additional alarm on the RSFCL HMI indicating a fault with the serial communication link to the compressor M5. This was initiated on the 9th July 2016 and is shown in the Figure 2-21.

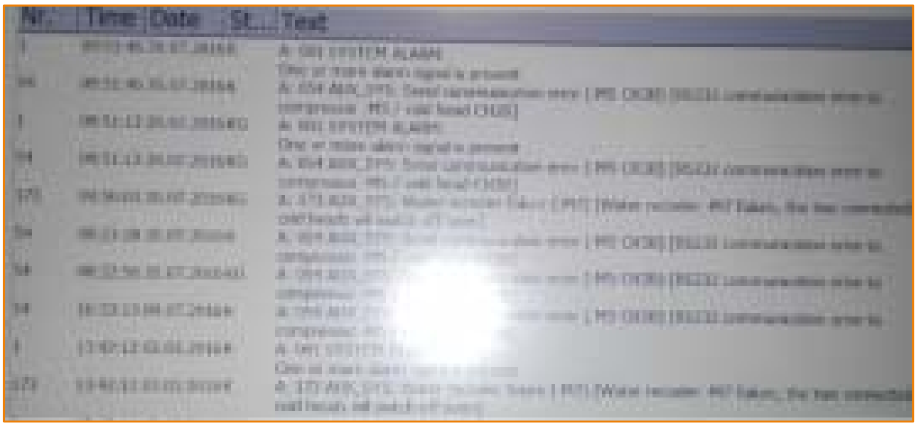


Figure 2-21: Screenshot of the Bournville RSFCL HMI showing the failure of the serial comms link to compressor M5

It was discovered that the recooler M7 was tripped by an over-temperature condition attributed to a reduction of cooling water caused by residual air in the water cooling circuit. This issue was similar to those experienced at Chester Street. Nexans refilled the recooler water to the correct level and reset the recooler and connected compressors (M1 & M2). It was identified that the failure of the compressor M5 was caused by a faulty power supply unit which would require replacement. It was decided to keep the RSFCL disconnected from the network until all cooling system issues were resolved and the control panel wiring was checked.

Nexans scheduled repairs to the Bournville RSFCL on 24th August 2016. WPD received further alarms from the RSFCL on 17th August 2016 prior to Nexans' arrival at site. The alarms and trips are shown in Figure 2-22. Nexans investigated the additional alarms on 24th August 2016 and confirmed the following:

- The compressor M4 had suffered a power supply failure similar to the failure on compressor M5. This required another replacement power supply unit to be sourced.
- The compressors M3 and M6 were found to be out of service.
- The recooler M9 was not in service due to insufficient cooling water in the cooling circuit. This was likely caused by debris clogging the recooler condenser similar to the problems seen in Chester Street.
- A water leak was observed at a connecter to the M5 compressor.

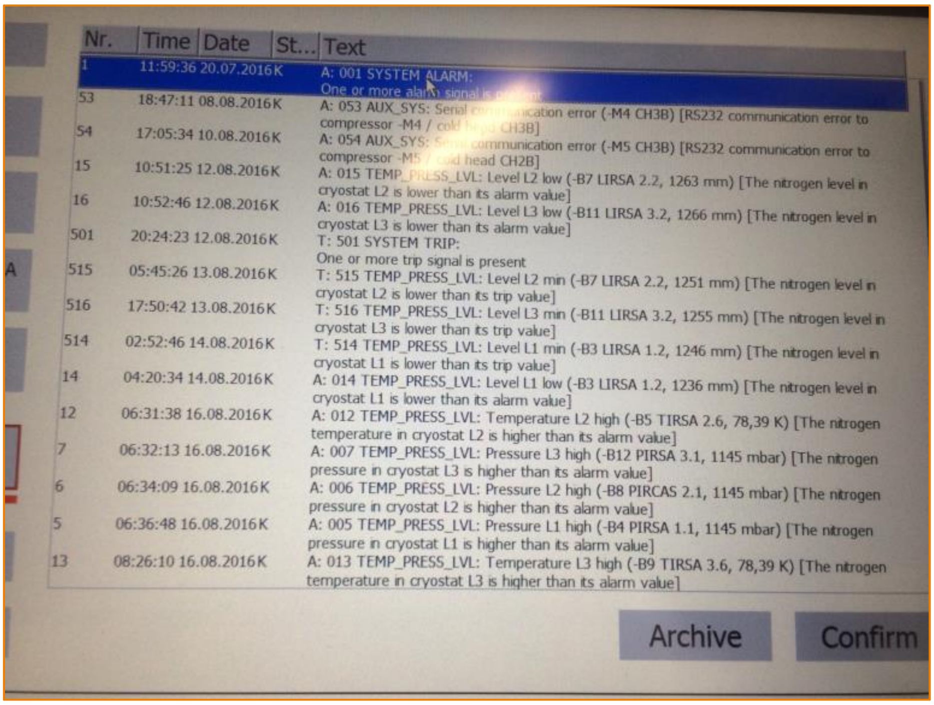


Figure 2-22: Screenshot of the Bournville RSFCL HMI showing further alarms and trips during August

Due to the unavailability of the compressors M3, M4, M5 and M6 the temperature and pressure had increased inside the cryostat vessels above their respective trip limits. The RSFCL control system attempted to reduce pressure by venting nitrogen gas causing a reduction of the nitrogen level below its minimum level.

Nexans replaced the M4 compressor power supply unit with the spare unit that was designated for compressor M5. Compressor M5 was left switched off and water supply turned off until the water leak could be resolved and another replacement power supply could be sourced. The cooling water was replaced in recooler M9 and the unit was reset and switched on. All the compressor units excluding M5 were reset and switched on. The RSFCL was left disconnected from the network. The reconnection of the RSFCL would only able to take place after repair of compressor M5 and refilling of the liquid nitrogen to the nominal value. The repair of the compressor M5 was scheduled by Nexans to coincide with the routine maintenance of the recoolers in September 2016.

WPD carried out a wiring check on the signals between the RSFCL control cabinet and the WPD protection panel on 17th August 2016. The investigation found that the wiring conformed to the design schematics; however, the auxiliary relay attributed to the system initialise alarm was latched in the energised state.

Nexans visited Bournville on 13th September 2016 with a technician from the recooler manufacturer. The visit was timed to coincide with the first scheduled maintenance of all recoolers. The technician replaced the defective power unit in the M5 compressor and proceeded with the routine maintenance of the recoolers. The glycol level in the coolant was found to be insufficient. It was concluded that the glycol level would have to be replaced during the site visit to refill the RSFCL with nitrogen. This was organised for October 2016.

Nexans attended a final site visit to Bournville on 18th October 2016 to complete the outstanding repairs on the RSFCL cooling system and to refill the cryostat vessels with nitrogen. During the visit Nexans discovered some additional issues. The recooler M8 was found to be tripped off due to low coolant level. This was attributed to debris being present on the recooler condenser causing high temperatures in the equipment and evaporation of the coolant. The compressor M4 was also switched off due to overheating of the helium circuit. The recooler M8 was refilled with coolant and restarted. The compressor M4 was restarted without further issue. At this point Nexans investigated the source of the problem with the system initialise alarm. The PLC program and the alarm was correctly disabled in the software, however, the Nexans relay contact was inverted and so the signal was incorrectly present at the WPD protection panel. The software was modified to invert the relay contact output and the issue was resolved. The final step in the repairs was to refill the nitrogen level in the RSFCL cryostat vessels. No further issues with the cooling system have been observed.

The Bournville RSFCL was successfully reconnected onto the 11kV network on 9th November 2016.

Learning

Further details on the learning of the FCL installations and open loop/closed loop testing of the FCLs can be found in both SDRCs 8 and 9.

2.4.3 GE Power Electronic FCL

GE was contracted by WPD to design, build and install two PEFCLs devices onto WPD's 11kV distribution network. During the previous reporting period progress had been made to redesign of the PEFCL after a number of major design issues were discovered towards the end of the initial build phase and prior to third party type testing at the KEMA laboratory in Arnhem, Netherlands.

During this reporting period it was determined that GE was unable to provide WPD with a safe and operational device that is compliant with WPD specifications and available for connection onto the 11kV distribution network. As such the contract for the two PEFCLs has terminated.

Table 2-4 below shows the timeline of events leading to the termination of WPD's contract with GE.

Table 2-4: Summary of key dates

Event	Date
Discovery of design flaws	06/11/2015
Scheduled date of original KEMA testing	16/11/2015
GE presents findings of internal investigation	27/11/2015
Start of redesign	29/01/2016
Rescheduled date of KEMA testing	29/08/2016
WPD informed of significant delays with redesign	22/07/2016
Termination of contract	29/07/2016

The following sections provide an overview of the events that transpired prior to the termination of the contract.

PEFCL Design Issues Part 1

Overview

The root cause of the device being unable to meet the required project timescales was the fundamental issues associated with the design of the PEFCL. These were identified as a result of the GE investigation into the PEFCL design. The following sections highlight these issues and the actions taken to resolve them.

Issue 1 - Current Interruption

The AFD was designed to "switch-off" high levels of current in around 20µs after fault inception to limit the fault current before it reaches the first prospective peak. When the current is suddenly interrupted, the energy generated is transferred into a significant transient over voltage. The design of the AFD did not allow for this energy to be fully absorbed and hence the AFD and adjacent equipment would be subject to unacceptable levels of over voltage.

Issue 2 - IGBT Voltage Sharing

The AFD comprises of a number of "banked" IGBTs to allow for the passage of current up to 2000A and operation at 11kV. The investigation into the design flaws found that there was a high risk that the voltage across the bank of IGBTs would not be shared equally across each of the units. This would mean that certain IGBTs may be subject to more stress than others.

Issue 3 - Insulation Level

The functional and contractual requirements of the AFD require a dielectric design to withstand 28kV (rms) and 95kV lightning impulse (peak). After investigation into the design flaws GE identified it would not be able to undergo the insulation tests and withstand the aforementioned figures.

Actions Taken

Issue 1

GE commissioned an assessment of the transient over voltage for a range of scenarios. In addition, GE specified new surge arresters capable of absorbing the anticipated stored energy in the circuit. The study calculated the energy which had to be absorbed by these surge arresters to ensure this was within their energy rating. The proposed surge arresters were found to limit the transient over voltages both across the IGBTs and from the line to ground.

Issue 2

GE investigated a number of solutions during the redesign and determined that a resistor-capacitor snubber circuit was best suited to ensure the voltage was distributed evenly across the IGBT modules. The snubber also had the additional advantage of smoothing the voltage spike from the current interruption of the device.

Issue 3

A number of changes were implemented by GE to rectify this design issue:

- A full redesign of the IGBT layout in the IGBT room was carried out to ensure adequate insulation clearances.
- Many parts of the galvanised steel frame that supported the IGBT units were replaced with GRP.
- The cooling fluid in the cooling system was replaced by de-ionised water. The entire cooling system equipment was also replaced.
- A new power supply circuit for the IGBT power drives was designed and built to ensure the correct isolation from the 11kV supply.

PEFCL Design Issues Part 2

Overview

GE proceeded with a redesign and build phase after the issues with the initial design and build were investigated and solutions proposed. The following section identifies and explains the further issues GE experienced with the redesign which ultimately led to the termination of WPD's contract with GE.

IGBT Monitoring and Control Cards

The IGBT monitoring and control cards are located in the device's Local Control Cubicle (LCC). They are electronic components that allow the interface and communication between the FCLs control systems and the IGBT modules in the AFD.

GE assumed that the initial IGBT monitoring and control card design was suitable to be reused in the redesigned PEFCL. This was not the case and GE found that they had to implement significant modifications to these components at a late stage in the device redesign. In addition, GE experienced significant problems with the design and testing of the control and monitoring PCBs. This meant that GE had to delay the factory testing of the device from 25/07/2016 to 12/09/2016 due to the cards being unavailable.

The issues with the IGBT cards meant that the PEFCL device was unable to be tested on the agreed date for the KEMA laboratory tests (29/08/2016).

System Studies

GE implemented a system study to enable the correct sizing of the line to ground surge arresters. These surge arresters are critical to the mitigation of large over-voltages when the device operates to break fault current. The output of this study was critical to the redesign as the layout of the equipment in the PEFCL was dependent on the surge arrester units that were selected.

GE initially proposed a 0.9kV rated device which was found to be suitable for the calculated energies in the study. However, the study had to be performed a second time when the manufacturer of the 0.9kV surge arrester informed GE that this unit was inappropriate and a more suitable 1kV unit was available.

GE had difficulty receiving information from the surge arrester manufacturer to run the studies on the new 1kV surge arrester. This led to significant delays to the schedule. A finalised study report had not been approved by WPD as late as 06/05/2016. As a result of this GE had to purchase both surge arrestors to avoid delay to the build schedule of the first redesigned unit.

Design Documentation

To meet the project timescales GE proposed an ambitious project programme. The design and build tasks were often overlapped to ensure adherence to the testing and energisation milestones. However, complications in the redesign and build phase meant that design documentation was significantly delayed for submission to WPD for review.

Critical documentation which was delayed is listed below:

- **Testing documentation** - A reworked revision of the testing specification was not submitted at the point where there was two weeks before the start date of the factory testing. The testing specification is an important document to ensure that the testing activities are conducted safely and the device operates as required to enable the safe connection of the device to the network.
- **General Arrangement drawing** – A detailed general arrangement drawing was not submitted to WPD during the redesign phase. This drawing was required to enable WPD to review and comment on the positioning of equipment, access/egress clearances and electrical clearances in the PEFCL enclosure. This represented a serious risk that testing of the device would be unsuccessful.
- **Installation and Operation Manual** - GE did not submit a revised installation and operation manual in the redesign phase. This document is required prior to the testing activities to ensure that the operation of the device is understood by all parties so that the testing activities are conducted safely and the device operates to the designated specification.

Contract Termination

Taking into account the issues that occurred during the first design stage and subsequent issues that were discovered during the redesign phase it was clear that the GE AFD devices would not be able to be safely built, installed and connected to WPD’s network with the timescales of FlexDGrid. Following review and considerable rationale WPD determined it was required to terminate the contract with GE for these devices and they would not be connected as part of FlexDGrid. All details relating to this have been submitted to Ofgem in the form of a Change Request.

2.5 Policy Documents – All Methods

As part of Method Alpha, Enhanced Fault Level Assessment Method, the internal Standard Technique for switchgear short circuit duty calculation was reviewed and some clarifications points was added to the document. The updated document is now in formal review and will be used by WPD engineers once approved. The updated points are as follows:

- A terminology sections which include the definition of various terms together with the relevant illustrations to provide clarifications about the parameters which are referred in the main body;
- A standard fault breaking time which should be considered for calculation of fault levels at different voltage levels where the actual protection response time is unknown;
- The typical transient and sub-transient parameters of synchronous generators where the manufacturers data is not available; and
- The fault contribution of the converter-connected generators e.g. PV.

Other Policies have also been updates as part of this reporting period, focussing on the development of FLM control.

Relating to Soft-Intertrip Schemes – Standard Technique OC9E

Standard technique OC9E sets out the process and procedures followed by the Control Centres when creating and managing Soft-Intertrip Control Schemes. This policy was updated to include the principles for managing Fault Levels using the existing WPD Soft-Intertrip philosophy.

Relating to Managing Processes for Alternative Connections – Standard Technique SD10/2

Standard Technique SD10/2 covers policy for managing processes directly relating to alternative connections. The policy was updated to include the 'Smart Mitigation' available around Fault Level Constraints i.e. Introduce Fault Level Soft Intertrip Scheme. The table containing location suitability for alternative connections has also been updated to cover Soft-Intertrip (Fault Level).

Relating to the Process of Offering a Soft-Intertrip Connection – Standard Technique: SD10B

Standard Technique SD10B which relates to the process for offering a Soft-Intertrip Connection has been reviewed and found not to require any updates for the provision of the system around Fault Level Constraints.

Application of Generator Constraint Panels – Standard Technique: TP18A

Standard Technique TP18A which relates to the Application of Generator Constraint panels was reviewed and found not to require amendments to accommodate Fault Level response functionality. This was specifically due to the future proofing and consideration of the fault level requirements during its initial production.

2.6 Fault Level Mitigation Technology (FLMT) Modelling

2.6.1 Pre-Saturated FLMT

The data used for modelling of the pre-saturated FLMT have been updated. This update was due to a discrepancy which was identified between the laboratory results of factory acceptance test and the initial data manufacturer had provided.

After identifying this discrepancy, pre-saturated FLMT manufacturer was requested to update their in-house developed transient model based on the findings in factory acceptance test to reach an accurate digital model for the pre-saturated FLMT installed at Castle Bromwich primary substation. Using the updated model, the manufacturer carried out various simulations to calculate the impedance of the pre-saturated FLMT in various network conditions at Making and Breaking times. The updated impedance data is shown in Figure 2-24 and Figure 2-25 for Making and Breaking times, respectively.

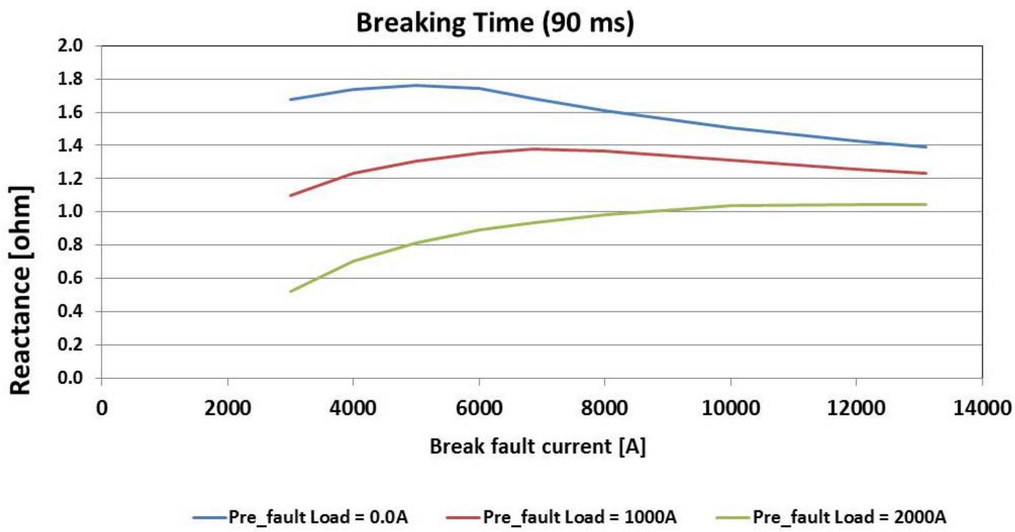


Figure 2-0-1: Reactance of pre-saturated FLMT at Break Time and for different currents

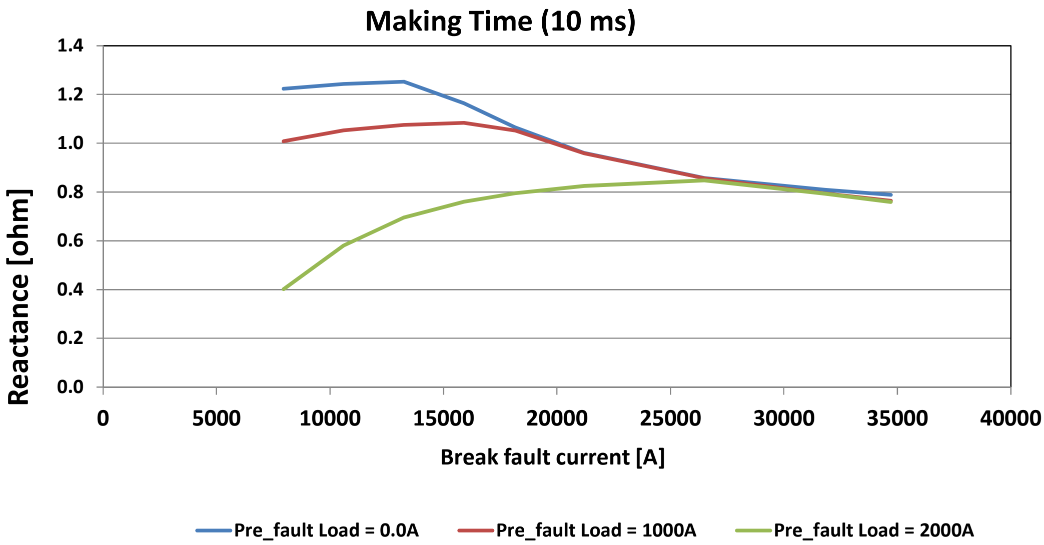


Figure 2-0-2: Reactance of pre-saturated FLMT at Making Time and for different fault currents

2.6.2 FLMT impedance look up table tool

In order to provide WPD engineers a process for obtaining the FLMT impedance data, the "FCL Impedance Lookup Table" Excel-based tool has been developed. This tool contains the data obtained from FLMT manufacturers and it can estimate Resistance (R) and Reactance (X) values of FLMTS trialled in FlexDGrid in different post-fault conditions. The tool can be used, in conjunction with Power Systems analysis software, for the fault level calculations where FLMT is deployed.

The functional specifications of the tool are as follows:

- The user can specify the Fault Current Limiter technology using a dropdown menu. The available options are:
    - Pre-saturated Core FLMT Castle Bromwich
    - Resistive Superconducting FLMT Chester Street
    - Resistive Superconducting FLMT Bournville

- Upon selection of the FLMT, a single line diagram showing the FLMT connection arrangement at the primary substation appears on the dashboard.

- The user can enter the pre-fault and post-fault network condition as required based on FLMT technology:
    - For Castle Bromwich FLMT, the R and X values are calculated based on the FLMT pre-fault current and the prospective Make and Break fault currents.
    - For Chester Street and Bournville, the R and X values are calculated based on FLMT prospective Make and Break fault currents.

- The estimated R and X values are shown in tabular format and on the FLMT impedance graphs.

Figure 2-26 shows a screenshot of the "FCL Impedance Lookup Table" User Interface.

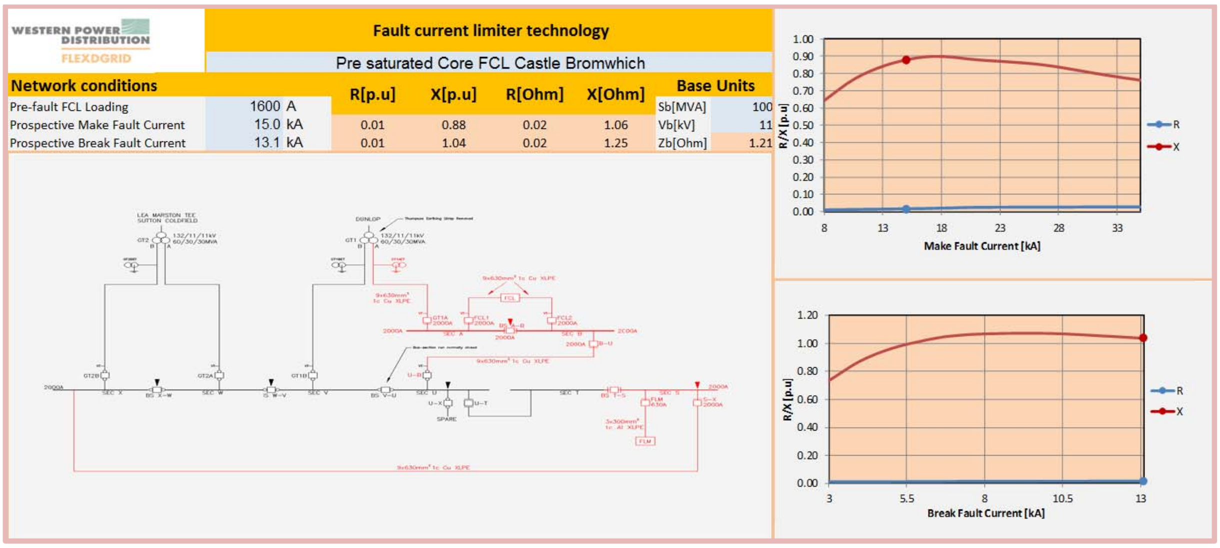


Figure 2-0-3: "FCL Impedance Lookup Table" excel tool user Interface screenshot

2.7 "Fault Level Guidance" Tool

The "Fault Level Guidance" is an Excel-based tool which has been developed in FlexDGrid as part of Method Alfa, Enhanced Fault Level Assessment Method. It can be used by HV planner engineers or those who do not have access to Power Systems analysis tool to estimate the fault levels at HV networks for any generation connection fault level assessments.

The tool works in conjunction with the "Birmingham HV network fault level report" which contains the necessary information for the fault level estimation as well as equipment short circuit ratings. The "Fault Level Guidance tool" has been updated as explained in the following sections.

2.7.1 Updates

The HV networks of three more primary substations, namely Shirley, Bartley Green and Nechells West, have been added to this tool. This is in addition to the information of the 12 primary substations which had been already populated in the previous version of this tool. In total, Fault Level Guidance Tool can be used for fault level estimation at HV networks of 15 primary substations listed below:

- Bartley Green
- Bournville
- Castle Bromwich
- Chad Valley
- Chester Street
- Elmdon
- Hall Green
- Kitts Green
- Ladywood
- Nechells West
- Perry Bar

- Shirley
- Sparkbrook
- Summer Lane
- Winson Green

2.7.2 System Update

The input data to this tool for Castle Bromwich, Chester Street and Nechells West Primary Substations have been updated in order to consider the operation of the FLMTs installed in these substations.

2.7.3 Dashboard

The dashboard has been enhanced to show the normal connection arrangements of the primary substations which are considered for fault level estimation in Fault Level Guidance Tool.

A screenshot of the Fault Level Guidance Tool is shown in Figure 2-27.

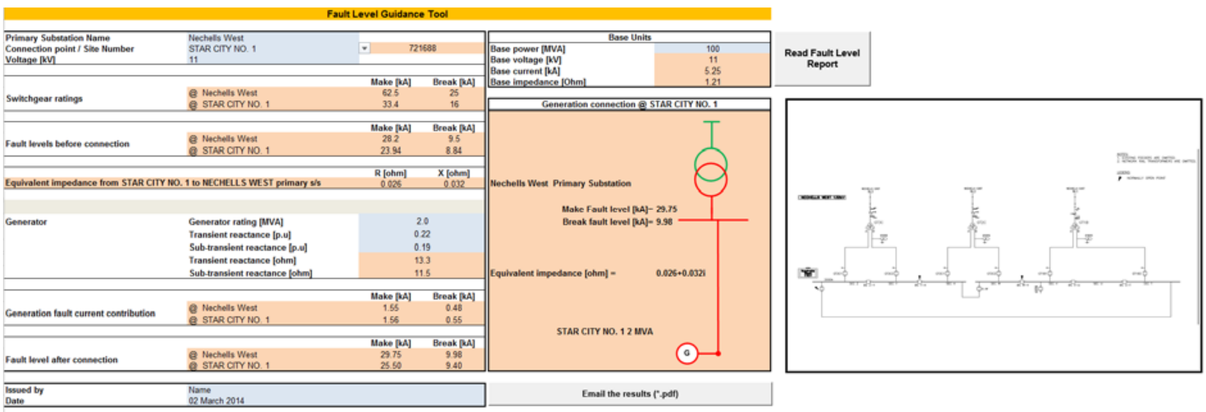


Figure 2-0-4:"Fault Level Guidance Tool" excel tool snapshot of the user interface

2.7.4 Manuals and Processes

In order to ensure that all the necessary information for deploying and updating Fault Level Guidance Tool has been provided, two documents have been produced:

1- A how-to-use guidance document which may be used by WPD Primary System Design engineers or HV planner Engineers for fault level estimation required in any connection application assessments.

2- A how-to-update document which may be used by WPD Primary System Design engineers for updating the Fault Level Guidance Tool when required.

3 Business Case Update

There is no change to the business case. The business case was to facilitate the increased connection of DG, specifically combined heat and power (CHP), in urban HV networks. This is still applicable.

4 Progress against Budget

Following the agreement of the change request as discussed previously in this report a re-baselined budget column has been included and therefore the variance values relate to this re-baselined data.

Table 4-1 - Progress against budget

	Original Total Budget	Rebase lined Budget	Expected Spend to Date Nov 2016	Actual Spend to date	Variance £	Variance %
Labour	**1809.49**	**1480.68**	**1449.91**	**1094.13**	**-355.78**	**-25%[1]**
WPD Project management	320.00	320.00	300.41	233.37	-67.04	-22%
Detailed Investigation of Substation for Technology Inclusion	71.26	71.26	71.26	29.44	-41.82	-59%
Detailed Investigation of Technologies	71.14	71.14	71.14	29.43	-41.71	-59%
Detailed design of substation modifications for Technology Inclusion	72.43	72.43	72.43	0.00	-72.43	-100%
Determine Enhanced Assessment Processes	71.88	71.88	71.91	0.00	-71.91	-100%
Create Advanced Network Model	72.32	72.32	72.48	0.00	-72.48	-100%
Installation of Fault Level Measurement Technology	5.75	5.75	5.77	0.00	-5.77	-100%
Installation of Fault Level Monitoring Technology	296.65	296.65	296.65	323.35	26.70	9%
Installation of Fault Level Mitigation Technology	445.10	313.38	313.38	313.38	0.00	0%
Installation of VCU Technology	148.11	0.00	0.00	0.00	0.00	0%
Capture, Analyse Data and performance	234.85	185.87	174.49	165.17	-9.32	-5%
Equipment	**9779.63**	**8162.65**	**8159.54**	**8155.89**	**-3.65**	**0%**
Procurement of Fault Level Measurement Technology	117.01	117.01	117.01	128.96	11.95	10%[2]
Installation of Fault Level Measurement Technology	9.58	9.58	8.26	8.52	0.26	3%
Procurement of Fault Level Monitoring Technology	1554.99	1554.99	1554.99	1494.85	-60.14	-4%
Installation of Fault Level Monitoring Technology	494.52	494.52	494.52	539.03	44.51	9%
Implementation of Real Time Modelling	3.76	3.76	3.25	3.13	-0.12	-4%
Procurement of Fault Level Mitigation Technology	5830.14	5214.14	5214.14	5214.14	0.00	0%
Installation of Fault Level Mitigation Technology	741.84	765.57	765.57	765.57	0.00	0%

Procurement of VCU technologies	777.86	0.00	0.00	0.00	0.00	0%[3]
Installation of VCU Technology	246.85	0.00	0.00	0.00	0.00	0%[3]
Equipment to enable modelling and technology installation	3.08	3.08	1.80	1.71	-0.09	-5%
Contractors	**1927.36**	**1927.36**	**1802.12**	**1795.73**	**-6.39**	**0%**
PB Project Support	340.94	340.94	322.00	317.00	-5.00	-2%
Detailed Investigation of Substation for Technology Inclusion	96.14	96.14	96.14	103.60	7.46	8%
Detailed Investigation of Technologies	102.89	102.89	102.89	107.98	5.09	5%
Detailed Design of Substation Modifications for Technology Inclusion	48.85	48.85	48.85	51.04	2.19	4%
Determine Enhanced Assessment Processes	64.85	64.85	64.81	65.88	1.07	2%
Create Advanced Network Model	51.38	51.38	51.20	52.00	0.80	2%
Implementation of Real Time Modelling	350.94	350.94	342.65	315.61	-27.04	-8%
Capture Monitored & Measured Data	49.61	49.61	47.15	48.18	1.03	2%
Analyse Monitored and Measured Data	157.49	157.49	147.29	146.64	-0.65	0%
Verify and Modify Advanced Network Models	253.89	253.89	250.00	251.32	1.32	1%
Gather Performance of Mitigation Technologies	50.07	50.07	47.58	48.69	1.11	2%
Knowledge Capture and Learning Dissemination	281.62	281.62	205.68	210.52	4.84	2%
Procurement & Installation Support	78.69	78.69	75.87	77.27	1.40	2%
IT	**57.73**	**57.73**	**57.65**	**43.15**	**-14.50**	**-25%**
IT Costs	57.73	57.73	57.65	43.15	-14.50	-25%[4]
IPR Costs	**3.29**	**3.29**	**1.96**	**1.94**	**-0.02**	**-1%**
IPR Costs	3.29	3.29	1.96	1.94	-0.02	-1%
Travel & Expenses	**465.62**	**465.62**	**442.41**	**400.53**	**-41.87**	**-9%**
Travel & Expenses	465.62	465.62	442.41	400.53	-41.87	-9%
Contingency	**1407.05**	**1030.24**	**1387.60**	**109.01**	**-1278.59**	**-92%**
Contingency	1407.05	1030.24	1387.60	109.01	-1278.59	-92%
Other	**27.21**	**27.21**	**17.89**	**17.45**	**-0.44**	**-2%**
Other	27.21	27.21	17.89	17.45	-0.44	-2%
TOTAL	**15477**	**13154.78**	**13319.08**	**11617.83**	**-1701.25**	**-13%**

Note 1 - *All Labour costs to date are underspent due to previously documented change in split of activities between WPD internal staff and Parsons Brinckerhoff*
Note 2 – *Additional features were provided with the technology to ensure they were transferrable between substation sites*
Note 3 – *Due to the FLMT designs VCUs are no longer required*
Note 4 – *Existing WPD IT has been used to date minimising the projected expenditure*

5 Successful Delivery Reward Criteria (SDRC)

During this eighth reporting period there has been three further SDRCs completed.

All 10 completed SDRCs are available on WPD's Innovation website.

5.1 Future SDRCs

Table 5-1 captures the remaining SDRCs for completion during the project life cycle.

Table 5-1 - SDRCs to be completed

SDRC	Status	Due Date	Comments
SDRC-11 Novel commercial aggs	Green	31/03/2017	On track

Status Key:	
Red	Major issues – unlikely to be completed by due date
Amber	Minor issues – expected to be completed by due date
Green	On track – expected to be completed by due date

6 Learning Outcomes

Learning outcomes have been detailed in all 10 SDRCs submitted to date (SDRC1-10).

Significant learning is being generated now all 10 FLMs are providing real-time fault level values. This data has specifically informed the continuing work looking to propose revised fault level general load infeed values based on types of load connected to a specific substation. Section 2.3 has provided further significant learning concerning this and will be further developed throughout the remainder of the project.

Learning surrounding the operation of the FLMTs is captured in Section 2.4. This learning has focussed on the initial operational experience and the maintenance requirements of the FLMTs. To date there has been no significant faults on the networks that they are connected to.

Moving in to the final reporting period of this project the learning will focus on the transition of the equipment, operational practises and modelling requirements through to main business operation.

7 Intellectual Property Rights

A complete list of all background IPR from all project partners has been compiled. The IP register is reviewed on a quarterly basis.

No relevant foreground IP has been identified and recorded in this reporting period.

8 Risk Management

Our risk management objectives are to:

- Ensure that risk management is clearly and consistently integrated into the project management activities and evidenced through the project documentation;
- Comply with WPDs risk management processes and any governance requirements as specified by Ofgem; and
- Anticipate and respond to changing project requirements.

These objectives will be achieved by:

- ✓ Defining the roles, responsibilities and reporting lines within the Project Delivery Team for risk management
- ✓ Including risk management issues when writing reports and considering decisions
- ✓ Maintaining a risk register
- ✓ Communicating risks and ensuring suitable training and supervision is provided
- ✓ Preparing mitigation action plans
- ✓ Preparing contingency action plans
- ✓ Monitoring and updating of risks and the risk controls.

8.1 Current Risks

The FlexDGrid risk register is a live document and is updated regularly. There are currently 38 live project related risks. Mitigation action plans are identified when raising a risk and the appropriate steps then taken to ensure risks do not become issues wherever possible. In Table 8-1, we give details of our top five current risks by category. For each of these risks, a mitigation action plan has been identified and the progress of these are tracked and reported.

Table 8-1 - Top five current risks (by rating)

Risk	Risk Rating	Mitigation Action Plan	Progress
FCL Fails and needs attention / repair	Moderate	Robust installation and repair process documented in policies	Failures have happened and maintenance Experience of devices has progressed
FLM data cannot be used to revise G74 data	Moderate	Significant analysis of the data in a structured and recorded manner	Data analysis shows that data can be used
Changes to key personnel	Minor	Rigorous and robust documentation of work. Induction Package to aid new starters	All work and learning is robustly captured to ensure changes to personnel would cause minimal disruption
Operation of the FLMTs cannot be validated on the network	Minor	Rigorous testing of the devices has happened in a controlled laboratory environment	The operation of the devices and any faults are being closely monitored
Maloperation of an FLM	Minor	Operation and Maintenance documents to manage the devices	FLMs are maintenance and operated as required

Table 8-2 provides a snapshot of the risk register, detailed graphically, to provide an on-going understanding of the projects' risks.

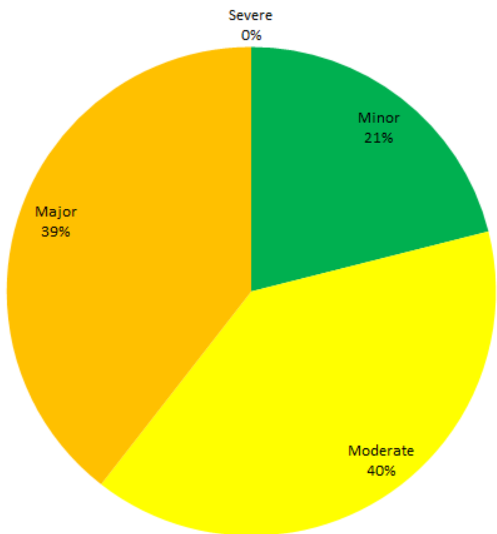
Table 8-2 - Graphical view of Risk Register

Likelihood = Probability x Proximity						
	Certain/Imminent (21-25)	0	2	0	0	0
	More likely to occur than not/Likely to be near future (16-20)	3	0	1	0	0
	50/50 chance of occuring/ Mid to short term (11-15)	0	0	2	2	0
	Less likely to occur/Mid to long term (6-10)	0	1	5	8	0
	Very unlikely to occur/Far in the future (1-5)	1	0	6	6	1
		1. Insignificant changes, re-planning may be required	2. Small Delay, small increased cost but absorbable	3. Delay, increased cost in excess of tolerance	4. Substantial Delay, key deliverables not met, significant increase in time/cost	5. Inability to deliver, business case/objective not viable
		Impact				

	Minor	Moderate	Major	Severe	
Legend	8	15	15	0	**No of instances**
Total	38				No of live risks

Table 8-3 provides an overview of the risks by category, minor, moderate, major and severe. This information is used to understand the complete risk level of FlexDGrid.

Table 8-3 - Percentage of Risk by category



8.2 Update for risks previously identified

Descriptions of the most significant risks, identified in the previous six monthly progress report are provided in Table 8-4 with updates on their current risk status.

Table 8-4 - Top five risks identified in previous six monthly report

Risk	Previous Risk Rating	Current Risk Rating	Comments
Suppliers can't meet agreed functional specifications	Severe	Closed	Element of the project has been de-scoped following a change request
GE AFD is not ready for KEMA type testing	Severe	Closed	Element of the project has been de-scoped following a change request
FLM fails and needs attention at one or more sites	Major	Minor	Reduced based on continuing learning and maintenance of the FLMs
Current system for data capture is unsuitable to provide closed loop operation	Major	Closed	Closed loop system operation of FLMs is now on-going
Changes to Key Personnel	Moderate	Minor	All work and learning is robustly captured to ensure changes to personnel would cause minimal disruption

Descriptions of the most prominent risks, identified at the project bid phase, are provided in Table 8-5 with updates on their current risk status.

Table 8-5 - Top five risks identified at the project bid phase

Risk	Previous Risk Rating	Current Risk Rating	Comments
Insufficient WPD resource for project delivery	Minor	Minor	Specific WPD staff have been assigned to manage and deliver the construction aspects of the project
Partners and supporter perception of the project changes	Moderate	Moderate	University of Warwick's worked has been scaled down in order for them to focus on a specific element to produce useful output
Cost of high costs items are significantly higher than expected	Closed	Closed	Closed as per previous 6 monthly reports
No suitable FLMTs will be available	Closed	Closed	Closed as per previous 6 monthly report
No suitable FLMs will be available	Closed	Closed	Closed as per previous 6 monthly report
The overall project scope and costs could creep	Minor	Minor	The scope of the project has been well defined in the initial delivery phase of FlexDGrid, which has been represented and documented in the SoWs with each party. This has significantly controlled this risk and therefore the cost of delivery. All potential scope creep is managed at project management level, where a decision is made as to the viability of inclusion and/or recommendation for future work
A partner may withdraw from the project or have oversold their solution	Moderate	Minor	All SDRCs to date have been delivered on time and to the required content and quality
The project delivery team does not have the knowledge required to deliver the project	Minor	Minor	Project partners have provided personnel with significant experience in all project areas. A review of individual's CVs takes place prior to their engagement with the project. Construction also have significant experience in the activities to be undertaken as part of the project

9 Consistency with Full Submission

During this reporting period the same core team from both WPD and WSP|PB have been used, which has ensured that there has been consistency and robust capturing of learning from the previous reporting period. This has ensured that the information provided at the full submission stage is still consistent with the work being undertaken in the project phase.

The scale of the project has remained consistent for the first two methods; however, following the change request Method Gamma has reduced from five FLMTs to three:

- **Alpha** – Build advanced network model of FlexDGrid network;
- **Beta** – Install ten Fault Level Monitors at Birmingham Primary Substations; and
- **Gamma** – Install three Fault Level Mitigation Technologies at Birmingham Primary Substations.

Each of the 10 completed SDRCs to date has been completed on, or before, schedule, ensuring that the proposed delivery plan at the full submission stage is still applicable in project delivery.

10 Accuracy Assurance Statement

This report has been prepared by the FlexDGrid Project Manager (Jonathan Berry), reviewed by the Future Networks Manager (Roger Hey), recommended by the Network Strategy and Innovation Manager (Nigel Turvey) and approved by the Operations Director (Philip Swift).

All efforts have been made to ensure that the information contained within this report is accurate. WPD confirms that this report has been produced, reviewed and approved following our quality assurance process for external documents and reports.

<THIS PAGE IS INTENTIONALLY BLANK>