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FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

PROJECT PROGRESS REPORT
REPORTING PERIOD:
DECEMBER 2015 – MAY 2016

LCN Fund Low Carbon Networks THE UNIVERSITY OF WARWICK PARSONS BRINCKERHOFF

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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
RIIO-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, December 2015 to May 2016.

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.

1.2 Project Progress

During this report period FlexDGrid remainsin the construction phase. The second Nexans Resistive Superconducting Fault Level Mitigation Technology (FLMT) has been installed at Bournville Primary Substation. This takes the total number of FLMTs installed as part of the project to three. This reporting period has also seen twelve months operation of the first FLMT installed, GridON's Pre-Saturated Core device at Castle Bromwich Primary Substation. As documented in the previous reporting period there have been significant issues with the design and build of GE's active fault de-coupler; during this reporting period this has been revised, be-baselined and the commercial terms updated with the aim of having two devices delivered within the required timescales.

Following the installation of the final four Fault Level Monitors (FLM) during the last reporting period the focus of this reporting period has been to analyse the output of the 10 FLMs and support the closed-loop operation of the data. This analysis and learning has focussed on three key elements in this reporting period:

- Updating MVA per MVA general load infeed to support enhanced network modelling;
- Provision of real-time Make and Break fault level data to network Control Engineers; and
- Pro-active control and connection of existing and future 11kV generation.

During this reporting period (December 2015 – May 2016) FlexDGrid has made significant progress in working towards the delivery of the final four successful delivery reward criteria (SDRC) 8 to 11.

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 issue resolution of the GE active fault de-coupler (AFD) design and the re-baselining of delivery plan.

1.3.2 Resourcing

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

Contracted construction staff continue to be employed on a site by site basis to support WPD with the delivery of the technology installation activities.

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 expected installation dates is provided below in Table 1-1.

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

Table 1-1 - FlexDGrid Technology Contracts

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	October 2016 October 2016

1.5 Installation

All 10 FLMs are now installed, commissioned and operational.

Three of the five FLMTs are now fully operational with the third FLMT being commissioned and energised in this reporting period on the 17th February 2016.

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.

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 WPD policy documents.

Building on the learning generated to date from the 10 FLMs providing real-time Make and Break fault level values an engineering paper has been produced in this reporting period, focussing on updated MVA per MVA general load infeed modelling values, that will be presented at the CIRED Workshop in June 2016.

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 Distributed Generation (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 seventh project report. The period covered in this report is further focussed on construction, data analysis and model updating activities as well as the implementation of customer control and alternative connection schemes based on the availability of real-time fault level values. Within this reporting period the construction activities have continued. The energisation of the third FLMT has been achieved. The fourth and fifth FLMT, following significant issues in the previous reporting period, have been re-baselined for successful design, build, testing and delivery within the previously agreed timescales. Following the successful energisation of all 10 FLMs a significant amount of data continues to be analysed to understand the variable nature of fault levels and to enable updates to modelling practices to be applied.

2.3 Substation Selection Update

The design phase for FlexDGrid selected 10 and 5 sites for the installation of FLMs and FLMTs respectively, from 18 sites originally identified as part of the detailed design phase of the project.

As discussed previously Perry Barr substation has been replaced with Nechells West and Sparkbrook with Bartley Green. No further substation alterations are expected.

2.4 Fault Level Monitors - Method Beta

2.4.1 FLM Operation

Following the successful delivery of all 10 FLMs in the last reporting period work this period has focused on validating the accuracy of operation of the devices. Work has been on-going solving minor engineering issues at various sites, testing the reliability of the FLMs performance and looking to increase the granularity of the data via the increase in FLM operations.

Engineering Issues

Since the last reporting period the following issues have occurred with a number of FLMs:

- Re-initialisation due to loss of communications at Shirley and Nechells West FLMs;
- Parallel Detection PM7000 has stopped operating at Elmdon; and
- Operation of Castle Bromwich FLM was stopped due to incorrect pole position indicator.

The loss of communications at Shirley and Nechells West was investigated at the time and a reset of the device carried out. Initial system checks have identified the reason for the loss being the mobile data connection being disconnected and not successfully connecting again due to the volume of data.

Investigation of the Elmdon Parallel Detection PM7000 showed that the device was not charging from either the 240V supply or the back-up 110V dc supply. Opening the device on site and discussing the issues with the manufacturer the issue was identified as a blown fuse that is soldered to the main circuit board that is not user replaceable. Therefore the device was removed from site and sent for repair.

At Castle Bromwich, an internal pole position incorrect error within the IntelliRupter caused a lockout of the FLM. A diagnostic file was downloaded from the IntelliRupter and sent to the manufacturer for detailed analysis. At this time the analysis indicates that this is a spurious fault that would be unlikely to re-occur. Discussions are on-going as to the best way to robustly test the IntelliRupter before the FLM is reenergised.

Reliability

The reliability of the FLM is measured as the number of results recorded by the FLM over a given period versus the number of results expected. For an FLM operating four times a day a total of 112 results are expected for any four week period. Table 2-1 below gives an average reliability figure for each of the 10 FLM substations for the first four months of this calendar year.

Table 2-1: % Reliability for January to April 2016 at each FLM Substation

Substation	Reliability %
Bartley Green	72.98%
Bournville	0.00%
Castle Bromwich	85.28%
Chad Valley	95.62%
Chester Street	92.44%
Elmdon	97.11%
Hall Green	90.71%
Kitts Green	68.57%
Nechells West	80.10%
Shirley	66.32%

Since the last reporting period, Bournville FLM has been out of service due to the requirement for structural support modifications. This was an outcome of the last intensive structural survey carried out at Bournville. Design work is on-going to identify the most suitable least cost solution to enable the FLM to be re-energised in the shortest possible time.

Further work is required to identify the low reliability seen at some of the remaining sites. Initial theories include the disturbance waveforms not being “seen” by the PM7000s due to other load changes at the time of operation causing noise on some recording channels.

Operation Increase

Following 18 months of successful operation of the FLM at Elmdon with no adverse impact on customers or the network, it was decided to increase the number of operations from four to eight operations a day. The network and customers will continue to be monitored for any adverse effects, however, so far none have been identified. Figure 2-1 and Figure 2-2 below show the seven day week averages for the Peak (Make) and RMS (Break) fault levels respectively at Elmdon for the four weeks of April 2016 following the increase to eight operations per day.

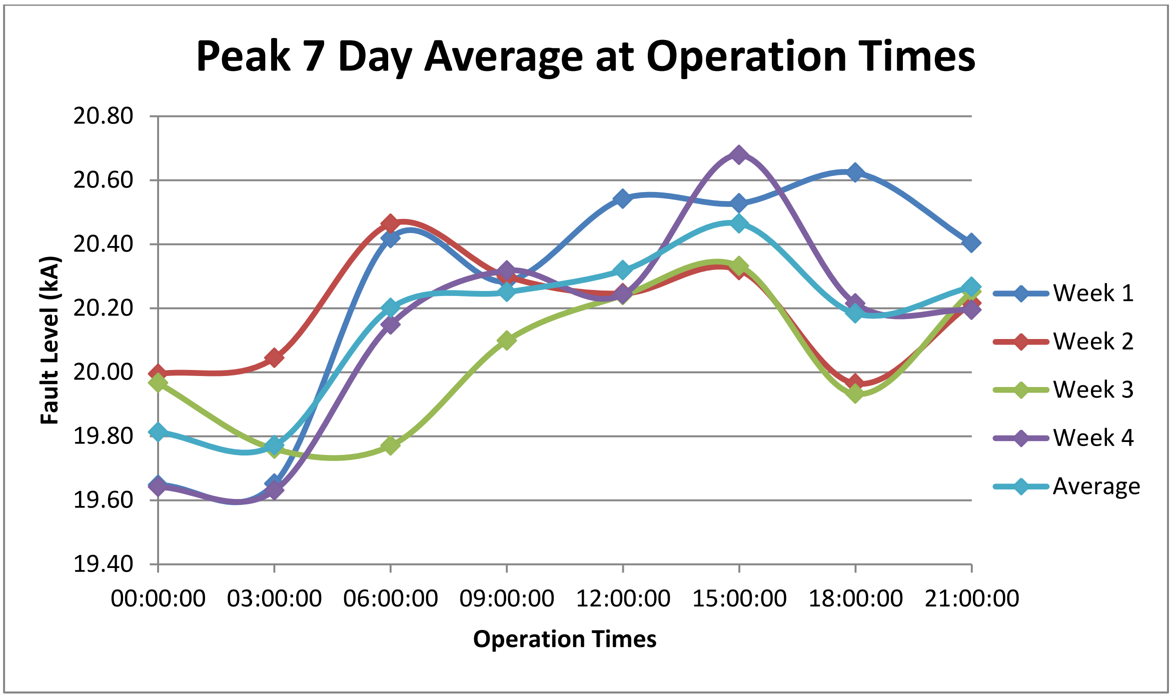


Figure 2-1: Peak 7 Day Average for April 2016 at Elmdon

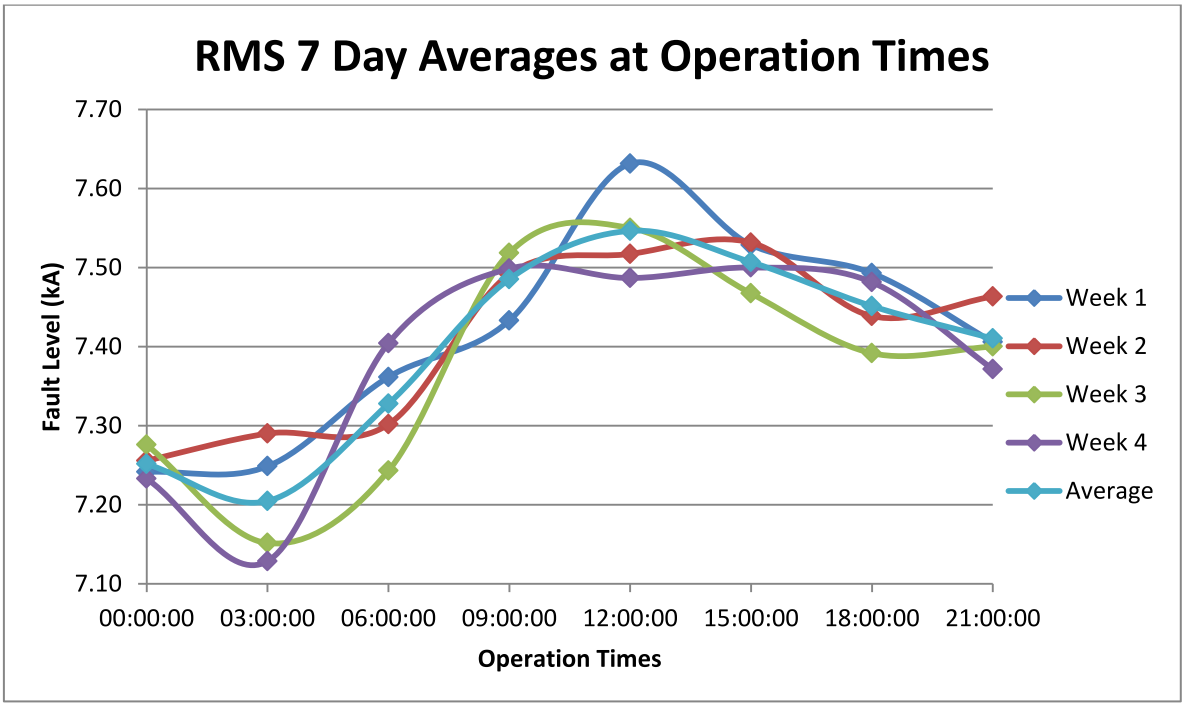


Figure 2-2: RMS 7 Day Averages for April 2016 at Elmdon

Compared to the results provided in the previous reporting period, the graphs above show that an increase in the number of operations has provided a better understanding of the changes in fault level throughout the day. Following the so far successful test at Elmdon, over the next reporting period the changes will be rolled out to all remaining FLMs.

2.4.2 MVA per MVA Update

Since the last reporting period work has been continuing to calculate the MVA per MVA (MVA/MVA) fault infeed at each FLM substation and comparing this to the substation's load mix. An engineering paper presenting the results so far has been accepted to the CIRED Workshop in June 2016. Figure 2-3 below shows the MVA/MVA infeed based on the percentage of domestic load at each substation. The results are for FLM fault levels calculated between June 2015 and January 2016.

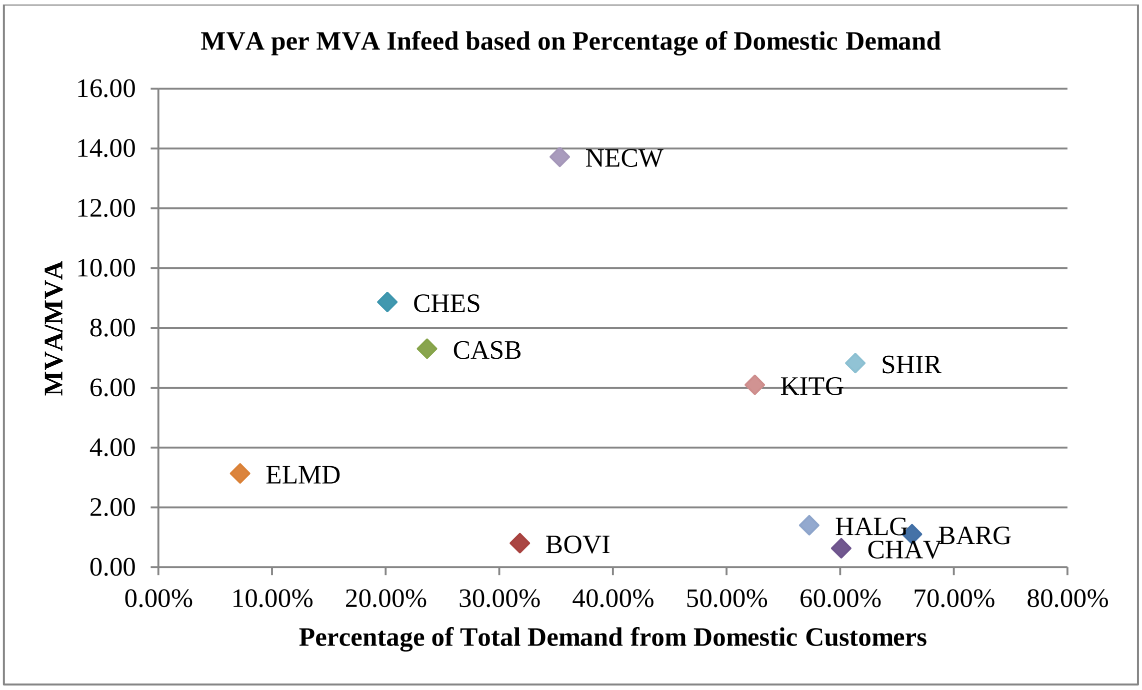


Figure 2-3: MVA per MVA Load Infeed based on % Domestic Demand at each Substation

From these results it can be seen that three of the substations, Bartley Green, Hall Green and Chad Valley, generally follow the G74 recommendation of 1 MVA/MVA infeed for 11kV connected loads. These substations all have a high level of domestic load with very few large commercial or industrial customers connected.

Chester Street and Castle Bromwich have a lower Domestic demand and a high percentage of large commercial and industrial loads connected. The average MVA/MVA infeed for these substations is 8.1 MVA/MVA. Kitts Green with a high level of both domestic and large commercial and industrial loads connected has a fault infeed value between the two extremes of 6.1 MVA/MVA.

At this stage the remaining four substations, Bournville, Elmdon, Nechells West and Shirley, are treated as anomalous. Further analysis of the loads at each of the substations has shown that the large commercial and industrial load at Bournville and Elmdon are mainly mixed use with a lower than usual amount of large industrial load. Investigations at both Nechells and Shirley show that the majority of the industrial and commercial loads are situated close to the substations. This is likely to be causing an increased impact on the calculated fault levels due to the minimal impedance between load and substation.

Throughout the next reporting period the loads at each substation will be further analysed to attempt to break the load types into further categories. At the moment the data appears to be trending towards a generic hysteresis curve and it is believed that by breaking the loads types down further it may be possible to show that the current anomalous data points will follow this trend.

2.4.3 FLM data in to WPD's NMS

During the period of this report, work has been on-going to make the FLM data available through WPD's Network Management System (NMS), PowerOn. Discussions have taken place with Control personnel as to the data they want to be made available and the required internal and external resources required to facilitate the real time import of data. By placing the data into the NMS, this can then be accessed by both control engineers to help inform their network operation procedures an also network planning staff who can access historical data for use with any network studies. Currently the FLM data is held and analysed externally. In order to display the values on the NMS the data must be held on an internal server. To achieve this a number of steps are required:

- On-Site SIM card replacement;
- External data provider software updates; and
- Internal server upgrades.

Provided the external data provider's software updates are complete the first site should be transferred on to the internal system at the start of the next period, with a view to transfer the remaining nine shortly after.

2.4.4 Using the Data to Connect a Customer

During this period efforts were made to identify a customer site at which we could use the FLM data to facilitate a connection around fault level restrictions. The intention was to find an outstanding connection offer that contained significant fault level reinforcement, which could be reduced through the innovative use of the FLM.

In order to be trialled the customer needed to be electrically supplied from one of the 10 Primary Substations that contains an FLM and specifically from the bus section at which the FLM is connected; limiting the trial to approximately 60 feeders. Furthermore the customer needed to be actively pursuing a connection with build and connection planned before the end of October 2016.

Two routes to identify customers were taken; the first used the existing Active Network Management (ANM) mailing list to mail out details of the trial and requested potential interested parties to get in touch. Whilst a number of replies were received no potential sites were identified which met the necessary requirements. The second route was via engagement with design engineers using their local knowledge to identify potential sites. Again, no new sites were identified which met the stretching requirements; however a site with existing fault level issues was identified and pursued further.

Trial Customer

A customer has been identified that is an existing 11kV connected customer fed from Nechells West Primary Substation on GT1B, which corresponds with the location of the FLM, See Figure 2-4.

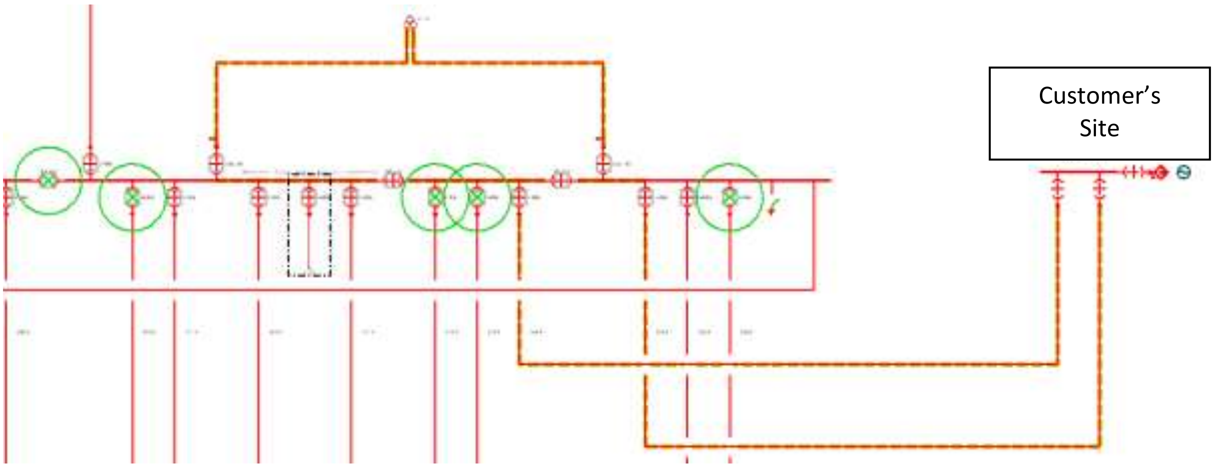


Figure 2-4: Customer 11kV Location

The customer is a well-established manufacturing company. Their Nechells site has a 10MVA Import/Export allowance with a number of restrictions in place depending on the current running arrangement as detailed in their connection agreement. The most relevant restriction, for the purposes of this trial, is the historic requirements placed on the site to install a fault current limiter (Is Limiter) at the time when the company installed two Combined Heat and Power (CHP) units (4.7MVA and 6.3MVA) to provide both steam and electrical power to site.

In early 2015, as the existing Is Limiter was approaching the end of its useful working life the customer began understanding the requirements for replacement. WPD, at the time, confirmed that the Is limiter was still required at which point the company ordered their new device which is yet to be installed. However, after meeting with the customer's Energy Manager and Site Electrician to discuss the issues and operating regime it was agreed that WPD would present an innovative FLM proposal for review and potential implementation.

Fault Level Soft-Intertrip Proposal

In order to produce a proposal the network conditions under which the customer operated first needed to be understood. It was found that the conditions under which WPD's primary system design team make decisions sometimes differed from the conditions that occurred in reality on the network. Primary system design in some instances model for a full transformer parallel, whereas in reality control engineers would first split the windings before any parallels were made. This opening of the bus-section greatly reduces the Fault Levels; however, through detailed studies as part of FlexDGrid, it was found that there were still conditions which caused the Fault Level to exceed the equipment ratings.

An initial proposal focussed around developing the existing ANM offering to include Fault Level capabilities, and as such two of the existing ANM providers were approach to produce a proposal. On review of the proposals it was felt that the costs involved to pursue were too high and subsequently other options were investigated.

After detailed analysis of a number of other options a final proposal has been developed utilising many of the existing Soft-Intertrip Alternative Connections concepts.

The final proposal enables the Control Engineers to utilise the FLM data to inform escalating mitigating actions to reduce fault levels to a safe value. Prior to making 'suspect' parallels it is proposed that the control engineers initiate an artificial disturbance to produce up-to-date Fault Levels. This data then informs the following mitigating actions:

Table 2-2 - ANM FLM Provision Detail

FLM Value (kA)	Mitigating Actions
≥12.705	No Acceptable Mitigating Actions Available
12.190 to 12.704	800kVA Gas Generator Disconnected 4.7MVA CHP Disconnected Bus-Section Z-Y Open
10.675 to 12.189	4.7MVA CHP Disconnected Bus-Section Z-Y Open
≤10.674	Bus-Section Z-Y Open

Mitigating Action	Av. No. of Actions per Year	Av. Length of Action (Minutes)	Typical Times When Action May be Required	
800kVA Gas Generator Disconnected	1.16	3	9:30am	2:30pm to 4:30pm
4.7MVA CHP Disconnected	2.52			
Bus-Section Z-Y Open	2.80			

Using historic switching data it has been found that a 'suspect' parallel only occurs during planned maintenances. Generally at Nechells Primary Substation the connection of parallels (Either GT1B with one winding of GT3C or one winding of GT3C with on winding of GT1B) occur twice a year.

The above data can be used within the offer document in line with the existing Soft-Intertrip offering.

It is proposed that in order to curtail the customer's generators a standard issue Generator Constraint Panel will be installed at each of the customer's generators (4.7MW CHP and Gas Generator). Stage 1 will initiate a disconnection of generator via the customers control system. It is not anticipated that Stage 2 functionality shall be utilised due to the potential impact on the customer's operation. However failure to comply shall be flagged to the control engineer. The generator constraint panel is already configured on Power-On, greatly simplifying system integration.

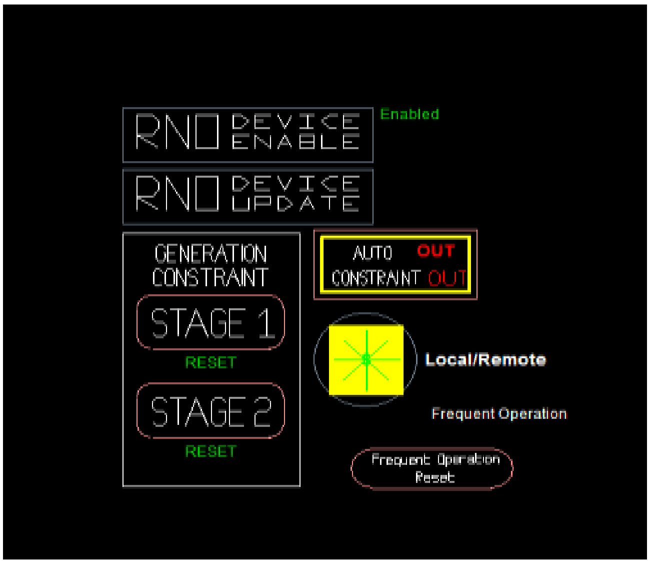


Figure 2-5 - Generator Constraint Panel Scheme

Next Steps

Over the next period the proposal will be issued to the customer for review and comment. Following this, and in-line with the Power-On installation, we will be in a position to undertake installation of Generator Constraint panels for demonstration.

In parallel with the above and using the learning from the customer case study the connection agreements, offer letters and control policies shall be amended to include provision for Soft-Intertrip FLM operation.

2.4.5 Development of modelling tools and operational philosophies

As part of the deliverables of FlexDGrid, to ensure learning from FlexDGrid is transitioned successfully from the project to the main business, various tools have been developed that enable planning engineers to access the learning generated on the project. After feedback on the use of the tools by the main business and following the significant amount of learning over the last period, updates are currently being carried out on the tools to ensure they remain relevant. Internal training seminars will also take place towards the end of the next period to transfer ownership of the tools to the main business. This is an essential part of ensuring the closed loop operation of the FLM to be reported on in SDRC 9.

2.5 Fault Level Mitigation Technologies – Method Gamma

2.5.1 GridON Pre-Saturated Core FCL

Overview

The GridON FCL was successfully energised on 8th April 2015. The device has not seen any 11kV network faults and hence the fault limiting performance of the FCL could not be analysed during this reporting period.

The GridON FCL suffered an issue with the DC sensing circuit in September 2015 which is described in detail in the last six monthly report. The DC sensor was incorrectly reading 0A which causes the protection system to trip the circuit breakers feeding the FCL. The FCL was disconnected from the network while GridON carried out a full investigation into the entire dc sensing circuit.

The investigation was undertaken on the sensor, sensor circuit, system software and any interference from adjacent ancillary systems. Through various tests and simulations it was found that the dc sensor was faulty which meant that the system was incorrectly detecting 0A for transient periods. The sensor was subsequently replaced and the dc sensing circuit was tested and re-commissioned successfully.

During the original commissioning of the UPS feeding the FCL DC supplies, it was found that the firmware required an upgrade. Rather than perform this during commissioning and causing delays to the energisation date it was decided that this update would be postponed. In early May 2016, GT1 at Castle Bromwich was due for scheduled maintenance during which the FCL was disconnected from the system and the opportunity was taken to upgrade the firmware. Thereafter the FCL was successfully re-connected onto the network on 6th May 2016.

2.5.2 Nexans Resistive Superconducting FCL

Chester Street

Overview

The Chester Street FCL was successfully energised and connected to the 11kV network at the end of the last reporting period, on the 25th November 2015. However, an issue with the substation AVC scheme meant that the FCL had to be disconnected from the network until it could be resolved. The FCL was successfully switched back into the network on 5th January 2016 after the AVC scheme modifications were installed. The issues experienced with the AVC are explained in greater detail below.

The Nexans FCL has been connected to the network and operating continuously for the last four months of this reporting period. The FCL has not seen any 11kV network faults and hence the fault limiting performance of the FCL could not be analysed. During this period of operation the FCL issued an alarm event warning of a malfunction in its cooling system. This issue did not require the disconnection of the device and work is on-going to resolve the issue. The issues experienced with this alarm event are explained in greater detail below.

AVC Scheme

During the design phase it was identified that the transformers GT2 and GT3 at Chester Street substation would be connected in parallel when the FCL is switched into the network. The existing automatic voltage control (AVC) scheme was investigated to identify whether there was the possibility of adapting it for parallel transformer operation through the use of a circulating current scheme. The GT2 relay panel housed a relay unsuitable for this application. Modifications were made to replace the GT2 AVC relay with a type suitable for the new scheme.

The FCL was successfully energised on the 25th November 2015 with the AVC modifications in place. However, after energisation it was found that the existing settings had not been changed to accommodate the new parallel operation. As such, the FCL was removed from the system until new parallel settings were applied. Whilst reviewing the AVC settings it was decided to replace the planned circulating current scheme with a negative reactance scheme to avoid the need for additional parallel detection logic. The FCL was switched into the network successfully on 5th January 2016.

Cooling System Alarm

Following a routine site inspection of the Chester Street FCL a number of alarms were found on the local HMI and an auxiliary alarm flag on the remote FCL protection panel. Figure 2-6 shows the alarms present on the local HMI. The alarms were indicating 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 are able to maintain stable cooling of the cryogenic material due to the redundancy built into the system. This has allowed the FCL to remain connected to the network during this period. An investigation was launched into the cause of the alarms by the manufacturer, Nexans. They indicated that the cause was likely to be air present in the cooling circuit reducing the cooling circuit efficiency. Nexans have proposed a procedure to resolve this issue by opening a valve on the cooling circuit to release the trapped air. This solution is currently being implemented at site.

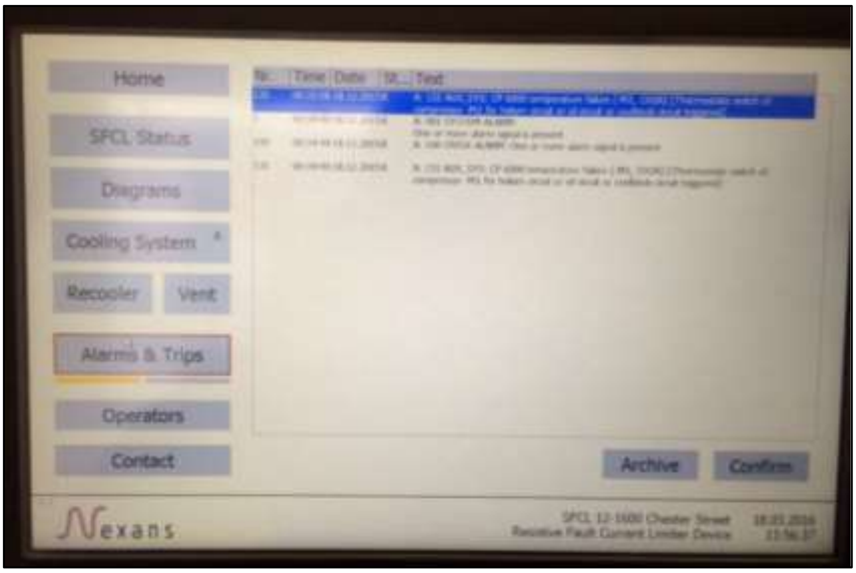


Figure 2-6 - Screenshot from FCL HMI showing cooling system alarms

Bournville

Testing

In the last reporting period the Bournville device was in the process of undergoing modifications to resolve the issue of higher than expected electrical losses in the device. The modifications consisted of the installation of a further two cold heads to the device to increase the available cooling power to allow the device to operate at its continuous rating of 1050A. The cold heads and additional cooling equipment were successfully installed by Nexans. Refer to the previous six monthly progress report for detailed information on the root cause of the high electrical losses and the modifications that were proposed.

The modified Bournville device underwent Factory Acceptance Testing between 30th November and 2nd December 2015 in Hanover, Germany. The device successfully passed all functional and high voltage testing. The tests performed were as follows:

1. Insulation resistance measurement (before and after each test sequence)
2. Temperature rise test
3. Acoustic sound level test
4. Withstand voltage test
5. Lightning impulse voltage test
6. Partial discharge measurement test

Refer to Figure 2-7 showing photos of the device undergoing testing at the Nexans factory in Hanover.

Figure 2-7: Photograph of Bournville FCL during FAT in Hanover, Germany

Figure 2-8: Photograph of Bournville FCL during short circuit testing in KEMA lab, Arnhem, Netherlands

Following the successful completion of the Factory Acceptance Testing the FCL went through a 'warm-up' process and was then transported to the KEMA test laboratory in Arnhem, Netherlands for the short circuit testing. The FCL was subject to test on the 7th December 2015 in the high current laboratory. The test set-up was the same as the circuit used to test the Chester Street device. Refer to Figure 2-9 for a connection diagram of the test set-up.

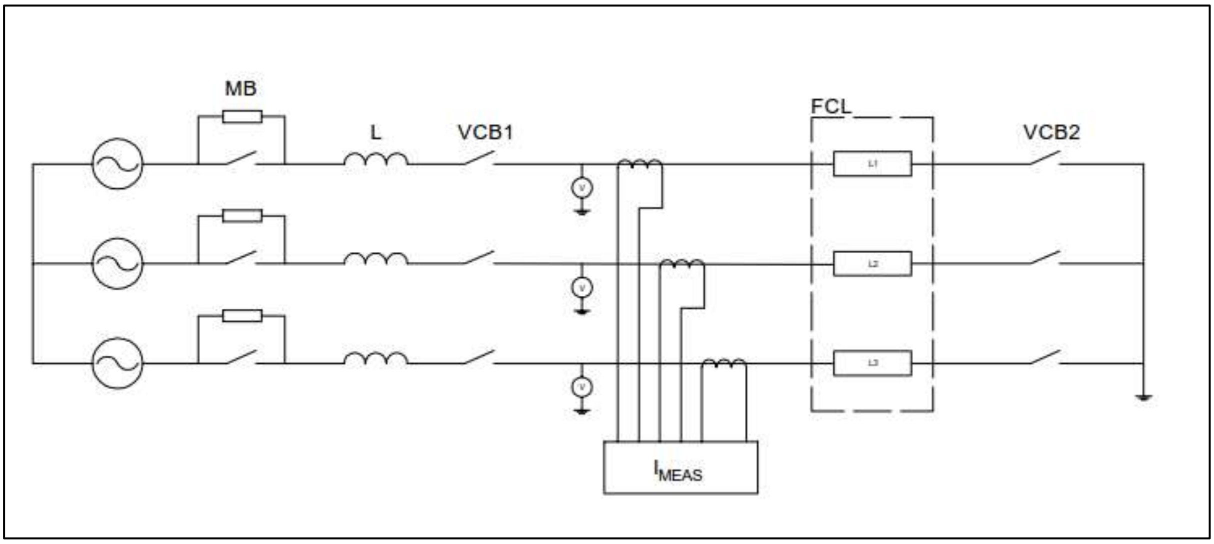


Figure 2-9: Connection diagram showing the KEMA short circuit test set-up for Chester Street FCL

Voltage was applied to the FCL by closing the Main Breaker (MB) and VCB1 before application of the short circuit. The short circuit was applied by closing VCB2. The short circuit duration was set to 100ms to avoid damage to the superconducting tape inside the cryostats. This is the maximum time that a fault current is allowed to flow through the FCL.

The KEMA test engineers carried out several shots of short circuit current without the FCL in the circuit. Measurements were taken and circuit parameters adjusted to ensure that the prospective peak current and RMS break current was as close as possible to the contractually specified values (21.97kA, 7.66kA respectively).

The FCL was then placed in the circuit and the short circuit limitation test was performed. The short circuit was applied with the peak prospective current applied to each phase in turn beginning with phase L1. The FCL successfully passed the test. The device limited the peak prospective current to 6.64kA and the RMS break current to <3kA for all current shots, below the contractual values of 7.70kA and 3.05kA respectively.

The next test to be performed was the short circuit current withstand test. The KEMA test engineers removed the FCL from the test circuit and carried out further test shots. Measurements were taken and circuit parameters adjusted to ensure that the prospective peak current as close as possible to the contractually specified value of 33.4kA.

The FCL was then placed in the test circuit and the short circuit withstand current applied. The prospective peak current was applied to phase L3. The FCL successfully passed the test. The device limited the peak prospective current to 6.45kA.

The FCL quench detection system was tested in parallel to the short circuit limitation tests and short circuit withstand test. The quench detector system was required to send a signal to the KEMA test equipment a maximum of 20ms after the applied short circuit. The test was passed successfully.

Installation

After the high current tests were completed successfully the FCL was disassembled and transported to Bournville Substation. The FCL consists of three cryostat vessels. Each vessel was lifted from the ground floor to its final position on the first floor of the substation building via an existing equipment lifting hatch at the gable end of the switchroom.

Due to the complexity of the substation and the lifting procedures it was tendered that the main contractor would be best placed to lift the cryostat vessels from the ground to the first floor. It was originally planned that the existing lifting beam above the hatch was to be used to lift the vessels. However, the main contractor decided to use a portable steel frame above the hatch instead (Refer to Figure 2-10). This had the advantage of allowing the cryostat vessels to be lifted and moved to their final position in one action making the lifting process both safer and more efficient. Refer to Figure 2-11 for a photograph of the L2 cryostat vessel being positioned at Bournville.

The weight of each cryostat vessel was approximately 1600kg (including liquid Nitrogen), giving a total weight of 4900kg. Instructions were given to the installation team to ensure that the weight loading of the cryostat vessels was kept as close to the under floor structural beams during temporary storage and movement to their final positions. This was to avoid unnecessary stress to the concrete slab.

Figure 2-10: Portable lifting frame used to lift the cryostat vessels to the first floor

Figure 2-11: Placement of L2 cryostat vessel in its final position on the first floor

AVC Scheme

The transformers GT1 and GT3 are connected in parallel when the FCL is switched into the network. The existing AVC scheme was investigated to identify whether there was the possibility of adapting it for parallel transformer operation. Both GT1 and GT3 AVC relay panels were capable of both circulating current and negative reactance schemes to achieve voltage regulation.

The Bournville AVC scheme was configured with a negative reactance scheme to be consistent with the approach at Chester Street.

Energisation

The Bournville FCL was successfully energised on Wednesday 17th February 2016. However, over the proceeding days GT1 and GT3 tap positions began to diverge. It was decided to remove the FCL from service on 23rd February 2016 to avoid excessive circulating currents in the transformers. Subsequent investigations found that the CT and VT connections to the AVC panels did not provide the correct phasing to ensure correct operation of the negative reactance scheme. To solve the problem the correct voltage and current signals were taken from the substation metering panel. The Bournville FCL was successfully reconnected on Wednesday 16th March 2016.

2.5.3 GE Power Electronic FLMT

In the last reporting period GE completed the build of the Active Fault Decoupler (AFD) in preparation for testing in December 2015. GE made an initial visit to the KEMA test laboratory in Arnhem, Netherlands on 3rd November 2015 to discuss the technical characteristics of the AFD and the test circuit configuration prior to the short circuit testing scheduled on 16th November 2015. KEMA communicated a number of serious design concerns associated with the AFD during the meeting with GE. This prompted GE to carry out a thorough review of the design. A summary of the design issues identified by GE during their review are detailed below along with the mitigating items taken.

Insulation Level

The AFD was found to have insufficient levels of insulation to enable the device to pass the functional and contractual requirements of the device, which require the dielectric design to withstand 28kV (rms) and 95kV lightning impulse (peak).

A number of fundamental design changes have since been implemented by GE to ensure insulation level requirements are met. The main change is the complete redesign of the cooling system to enable the use of de-ionised water in the coolant circuit. A bespoke modular cooling plant has been procured by GE. In addition, the IGBT devices have been stood off the racks with insulator posts to provide the adequate insulation to earth. GE is currently undertaking a complete redesign of the busbar arrangement from the 11kV switchgear panels to the IGBT racks.

Current Interruption

The AFD is designed to “switch-off” high levels of current in around 20µs to limit the fault current before it reaches the first peak. When the current is suddenly interrupted, the stored energy in the circuit 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 have been subject to unacceptable levels of over voltage.

GE has had to completely redesign the device to cope with the overvoltage condition generated by the operation of the AFD. GE have specified additional surge arresters that now have the appropriate electrical characteristics to clamp the transient overvoltage to the desired level, whilst also ensuring the energy generated in the surge arrester is within its energy rating. A transient overvoltage study was commissioned to ensure the proposed surge arresters produced the desired results. The study involved the simulation of the AFD device in operation at Kitts Green which is the ‘worst case’ site with the highest X/R ratio i.e. the site with the most stored energy to dissipate during the AFD operation.

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. GE discovered that the AFD design did not include measures to ensure the voltage across the device was shared equally between the IGBT banks. This would mean that some IGBTs would be subject to greater stress than other units.

GE redesigned the IGBT circuits with the addition of a resistor and capacitor in parallel across the collector and emitter of each IGBT bank to ensure that any stresses are constrained across each IGBT.

Status

WPD insisted that a major change to GE's engineering approach following the discovery of the fundamental design issues with the AFD. GE's previous engineering team was replaced with appropriate GE resource assigned to addressing each element of the re-design of the device.

The device has been re-engineered to address the issues relating to the current interruption and voltage sharing. The cooling system has been re-designed with an external third party company brought in to provide a modular cooling plant. GE is now in the position of ordering key components and submitting detailed design drawings for WPD review and approval. However, significant work is still required to re-design the arrangement of the internal 11kV connections from the switchgear panels to the IGBT racks, the control system for the AFD and the design/arrangement of the device's auxiliary systems.

The re-design of the AFD has caused significant delays to the project programme. The programme key milestones for the redesigned AFDs are shown in Table 2-3. As much of the previous AFD units is being salvaged to reduce the overall project timescales; for example, the shipping container housing is being retained and modified as required to avoid the need to order a new device enclosure.

A key update is that WPD and GE have worked proactively to agree a re-working of the contractual payments. In order to demonstrate GE's commitment to the project they have increased their financial contribution to the project as well as receiving the final payment for the device after six months successful operation of both AFD devices on the live 11kV network.

Table 2-3 - Key milestones for GE Power Electronic FCL

Activity	Forecast Date	
	Kitts Green	Bartley Green
Device Build	July 2016	August 2016
Successful Testing	August 2016	September 2016
Delivery to Site	September 2016	September 2016
Energisation	October 2016	October 2016

2.5.4 Comparison of Chester Street and Bournville Installations

The two Nexans Resistive Superconducting FCL installations at Chester Street and Bournville highlight two different approaches to the installation of FLMTs. The Chester Street device was housed in an outdoor bespoke concrete enclosure within its own compound inside the substation. The Bournville device was installed in the first floor of an existing substation building in a disused switchroom.

There were different challenges associated with the different types of installation. The benefit of the enclosure installation is the modular nature of the device. The device is installed and tested at the factory as a complete unit which allows most of the site works to be completed prior to the offloading of the device, after which it is mainly a case of terminating the HV, LV and signal cables and then performing the site testing and commissioning. The disadvantage is that the unit requires a large amount of space to be available within the substation compound due to the physical size of the enclosure. When designing the layout of the enclosure, the key design considerations were to make the layout as compact as possible whilst maintaining sufficient clearances and access for the new and existing substation compounds. Delivery and offloading is an important consideration for the choice of installation type. The enclosure was approximately 36 tonnes in weight which meant that the unit had to be offloaded and positioned on its foundation by a crane from the adjacent street, requiring a road closure.

The first floor installation had the benefit that the device was not fixed in one unit. This meant that the device could easily be dismantled and the discrete pieces of equipment shipped separately, which meant delivery and offloading at site was much simpler. In contrast to the enclosure installation, the device required more site installation works (e.g. to run signal and control cables, pipework etc.) before the device was ready for site testing and commissioning. However, the HV cabling and terminations onto the device was much simpler due to the extra space afforded to the cable jointers compared to the enclosure installation. The termination of the HV cables to the cryostat vessels proved particularly difficult in the enclosure due to lack of space. This is an aspect of the design that could be improved upon in a future installation.

2.6 Policy Documents – All Methods

2.6.1 Devices

During this reporting period no new policies have been produced, however, both FLMT Operation and Control policies have been updated, following site training of operational staff to ensure that the procedures, specifically concerned with the FLMT operation under outage conditions, are clear, transparent and easily understood.

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

Table 4-1 - Progress against budget

	Total Budget	Expected Spend to Date May 2016	Actual Expenditure to date	Variance £	Variance %
Labour	**1809.49**	**1666.16**	**1038.18**	**-627.98**	**-38%[1]**
WPD Project management	320.00	271.02	213.90	-57.12	-21%
Detailed Investigation of Substation for Technology Inclusion	71.26	71.26	29.44	-41.82	-59%
Detailed Investigation of Technologies	71.14	71.14	29.43	-41.71	-59%
Detailed design of substation modifications for Technology Inclusion	72.43	72.43	0.00	-72.43	-100%
Determine Enhanced Assessment Processes	71.88	71.88	0.00	-71.88	-100%
Create Advanced Network Model	72.32	72.32	0.00	-72.32	-100%
Installation of Fault Level Measurement Technology	5.75	5.75	0.00	-5.75	-100%
Installation of Fault Level Monitoring Technology	296.65	296.65	323.35	26.70	9%
Installation of Fault Level Mitigation Technology	445.10	403.88	393.83	-10.05	-2%
Installation of VCU Technology	148.11	134.39	0.00	-134.39	-100%
Capture, Analyse Data and performance	234.85	195.44	48.24	-147.21	-75%

Equipment	**9779.63**	**9053.27**	**8057.69**	**-995.59**	**-11%**
Procurement of Fault Level Measurement Technology	117.01	117.01	128.96	11.95	10%[2]
Installation of Fault Level Measurement Technology	9.58	8.26	8.52	0.26	3%
Procurement of Fault Level Monitoring Technology	1554.99	1554.99	1494.85	-60.14	-4%
Installation of Fault Level Monitoring Technology	494.52	494.52	539.03	44.51	9%
Implementation of Real Time Modelling	3.76	1.98	1.80	-0.18	-9%
Procurement of Fault Level Mitigation Technology	5830.14	5200.00	5153.33	-46.67	-1%
Installation of Fault Level Mitigation Technology	741.84	673.13	729.71	56.58	8%
Procurement of VCU technologies	777.86	777.81	0.00	-777.81	-100%[3]
Installation of VCU Technology	246.85	223.98	0.00	-223.98	-100%[3]
Equipment to enable modelling and technology installation	3.08	1.59	1.50	-0.09	-6%
Contractors	**1927.36**	**1597.41**	**1540.23**	**-57.19**	**-4%**
PB Project Support	340.94	267.29	247.28	-20.01	-7%
Detailed Investigation of Substation for Technology Inclusion	96.14	96.14	103.60	7.46	8%
Detailed Investigation of Technologies	102.89	102.89	107.98	5.09	5%
Detailed Design of Substation Modifications for Technology Inclusion	48.85	48.85	51.04	2.19	4%
Determine Enhanced Assessment Processes	64.85	64.85	65.88	1.03	2%
Create Advanced Network Model	51.38	51.38	52.00	0.62	1%
Implementation of Real Time Modelling	350.94	310.56	299.65	-10.91	-4%
Capture Monitored & Measured Data	49.61	39.36	36.56	-2.80	-7%
Analyse Monitored and Measured Data	157.49	115.65	110.78	-4.87	-4%
Verify and Modify Advanced Network Models	253.89	196.59	182.62	-13.97	-7%
Gather Performance of Mitigation Technologies	50.07	41.30	36.98	-4.32	-9%

Knowledge Capture and Learning Dissemination	281.62	201.32	190.23	-11.09	-6%
Procurement & Installation Support	78.69	61.23	55.63	-5.60	-9%
IT	**57.73**	**57.45**	**38.26**	**-19.19**	**-33%**
IT Costs	57.73	57.45	38.26	-19.19	-33%[4]
IPR Costs	**3.29**	**1.50**	**1.44**	**-0.06**	**-4%**
IPR Costs	3.29	1.50	1.44	-0.06	-4%
Travel & Expenses	**465.62**	**375.15**	**366.46**	**-8.69**	**-2%**
Travel & Expenses	465.62	375.15	366.46	-8.69	-2%
Contingency	**1407.05**	**1358.44**	**62.61**	**-1295.84**	**-95%**
Contingency	1407.05	1358.44	62.61	-1295.84	-95%
Other	**27.21**	**13.52**	**12.83**	**-0.69**	**-5%**
Other	27.21	13.52	12.83	-0.69	-5%
TOTAL	**15477**	**14123**	**11118**	**-3005**	**-21%**

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 not currently required*

Note 4 – *Existing WPD IT has been used to date – as technologies are installed additional IT will be required*

5 Successful Delivery Reward Criteria (SDRC)

During this seventh reporting period there has been no further SDRCs completed.

All seven 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-8 Open-loop test of FLMTs	Amber	31/12/2016	Risk due to GE AFD delays
SDRC-9 Closed-loop test of FLMs & FLMTs	Amber	31/12/2016	Risk due to GE AFD delays
SDRC-10 Analysis & Benefits	Green	31/12/2016	On track
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 seven SDRCs submitted and approved to date (SDRC1-7).

Learning continues to be generated and disseminated through the production of WPD policies in relation to the Inspection and Maintenance and Operation and Control of all devices connected as part of the project. These are detailed in Section 2.6.

Significant learning is being generated now all 10 FLMs are providing real-time fault level values. This data has specifically informed the recent work looking to propose revised fault level general load infeed values based on types of load connected to a specific substation. This learning will be further developed to propose MVA/MVA templates per substation type in the next reporting period.

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 50 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
Suppliers can't meet agreed functional specifications	Severe	Early engagement and rigorous tendering process	GE device is currently undergoing complete re-design
GE AFD is not ready for KEMA type testing	Severe	Proactive design and build required from GE	Device is now planned for testing in September. Risk will be reduced on completion of device re-design
FLM fails and needs attention at one or more sites	Major	Robust design and testing prior to the installation	An FLM is currently disconnected due to a mechanical operation issue and communications from the system is below required reliability
Current system for data capture is unsuitable to provide closed loop operation	Major	Early planning with NMS integration team to understand restrictions and requirements	Work is on-going to develop the data capture system to enable presentation of data in to NMS system
Changes to Key Personnel	Major	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

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

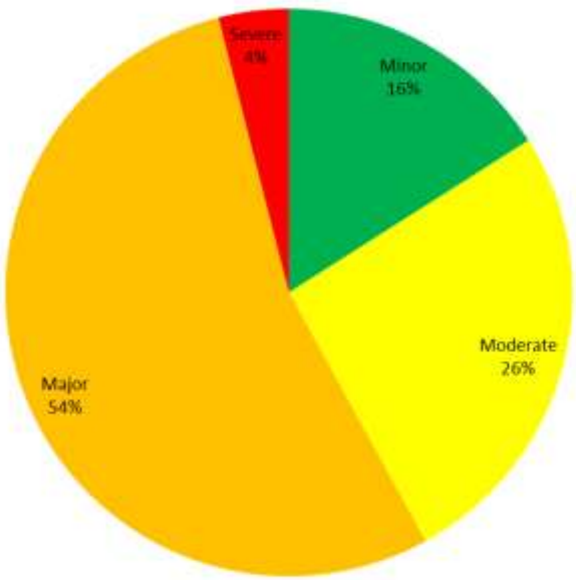
Table 8-2 - Graphical view of Risk Register

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)	0	1	5	0	1
	50/50 chance of occuring/ Mid to short term (11-15)	0	0	2	6	1
	Less likely to occur/Mid to long term (6-10)	0	1	6	10	1
	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	13	27	2	**No of instances**
Total	50				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	Severe	GE device has now been re-baselined and re-design is close to being finalised
GE AFD is not ready for KEMA type testing	Severe	Severe	Device re-planning is now complete and KEMA testing is planned for early September
FCL fails and needs attention at one or more sites	Severe	Major	GridON device is now fully repair however issues on Nexans device have been encountered
Unforeseen issues relating to Bournville FCL and FLM installation being on the 1st Floor	Major	Moderate	FCL work has been completed and device is fully operational. FLM requires some remedial work to enable re-energisation of device
Changes to Key Personnel	Major	Moderate	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	Moderate	Whilst seven SDRCs have been delivered on time and to the specification set out in the Project Direction the UoW Engineering department have, to date, not delivered fully their requirements
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 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 all three methods:

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

Each of the six 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.