WESTERN POWER DISTRIBUTION

FLEXDGRID

HEAT AND POWER FOR BIRMINGHAM

SDRC-10

Analysis of Test Results, Evaluating and Quantifying the Benefits of the Solution and Applicability to GB HV Electricity Networks

December 2016

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

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Contents

Glossary

Abbreviation	Term
AFD	Active Fault Decoupler
CHP	Combined Heat and Power
DNO	Distribution Network Operator
EFLA	Enhanced Fault Level Assessment
EHV	Extra High Voltage
ENA	Engineering Networks Association
FCL	Fault Current Limiter
FLM	Fault Level Monitor
GB	Great Britain
GW	Giga Watts
HUBNET	The Supergen Energy Networks Hub
HV	High Voltage
LCNF	Low Carbon Networks Fund
LCNI	Low Carbon Networks Innovation
LV	Low Voltage
MVA	Mega Voltage Ampere
PSCFCL	Pre-Saturated Core Fault Current Limiter
RMS	Root Mean Square
RSFCL	Resistive Superconducting Fault Current Limiter
SDRC	Successful Delivery Reward Criteria
SHE	Safety, Health and Environment
ST	Standard Technique
WPD	Western Power Distribution

1 Introduction

FlexDGrid offers an improved solution to the problem of the timely and cost-effective integration of customers' generation and demand within urban high voltage (HV) electricity networks. The project seeks to explore the potential benefits arising from trials of three complementary methods: (Alpha) Enhanced Fault Level Assessment; (Beta) Real-time Management of Fault Level; and (Gamma) Fault Level Mitigation Technologies. The project location is Birmingham and aims to deliver a highly transferrable system-level solution, using real-time knowledge of the fault level status of the electricity network and application of fault level mitigation technologies, to manage multiple generation and demand connections. The learning will be transferrable to all Great Britain (GB) networks. The FlexDGrid solution has the potential to deliver £1Bn savings across GB through the avoidance of network reinforcement and safeguarding of electricity network assets. This could facilitate 6 GW of generation connections and offset 5.05 $MtCO_2$ / year.

This Successful Delivery Reward Criterion (SDRC), 10, focuses on the knowledge dissemination, publication of reports and the generation of new policies borne through the delivery of FlexDGrid. The SDRC provides the details of specific knowledge dissemination in the form of:

- Network data and policies made available;
- Six-monthly progress reports submitted to Ofgem throughout the project;
- Eight industry conferences attended and presented;
- LCNF/I conference presentations; and
- Publication of other SDRC reports.

As well as the knowledge dissemination described above, which has described the analytical approach of the test results, evaluated and quantified the benefits of each project solution along with demonstrating the applicability to GB HV electricity networks, in the form of new policies, knowledge has also been disseminated in a variety of other formats, such as DNO Workshops and industry visits.

This SDRC document will detail the format of each key element of project knowledge dissemination and its significant area of dissemination.

2 Network Data and Policies Made Available

2.1 Network Data

A key part of the project has been the generation of new data, which has been in the form of:

- Fully integrated system models from National Grid's infeed to the remote end of the 11kV system; and
- Real-time Fault Level Monitor (FLM) data.

2.1.1 Model Data

Throughout the project's first method, Enhanced Fault Level Assessment (EFLA), a significant amount of knowledge has been generated in the form of modelling practice and procedures. This has been robustly captured in various forms of documentation, principally SDRC-1 (Development of EFLA Processes) and SDRC-4 (Simulating and Applying EFLA Processes). Other knowledge has been captured and disseminated at CIRED Workshop 2014, in the form of a technical paper, "Sensitivity Analysis of Fault Level Assessments in HV Networks".

This data has played a key role for internal WPD knowledge dissemination. This dissemination has been focussed on facilitating more accurate fault level principles and providing detailed fault level data to staff that previously haven't had access to such data, in the form of a Distribution Fault Level Report. This was based on the standard WPD production of a Fault Level for EHV assets, whilst also encompassing the facility for engineers to quickly assess the capability of a generator to be connected, based on accurate and up to date fault level data.

2.1.2 Real-time FLM Data

The project's second method focussed on the fault level monitoring and management in the form of the installation of 10 FLMs. Following the installation of these 10 devices, as reported in SDRC-7 (Installation and Open-Loop Tests of FLM Equipment) a significant amount of data has been produced and captured. This data is fault level at specific points in time, both Make (peak at 10ms) and Break (RMS at 90ms).

Throughout the project this data has been used in a number of ways, most pertinently to review and refine the accuracy of the models generated as part of the EFLA method and to inform the technical assumption as part of G74 [1] that aggregated LV load on the 11kV network should be represented, in terms of fault level, as 1MVA per MVA of connected load. This was formed through the analysis of all 10 FLMs Make and Break data, the types of load connected at each and the amount of load at the point of fault level measurement. This data has shown that substations with differing load types, such as domestic, commercial and industrial should have specific fault level infeed values based on this. This is robustly captured in SDRC-9. A significant amount of FLM data has also been made available for independent review and analysis of results in the FlexDGrid FLM Data Hub, as shown in Figure 2-1; this is contained within Appendix 6.

[1] G74 – Procedure to Meet the Requirements on IEC 909 for Calculation of Short-Circuit Currents in Three-Phase AC Power Systems

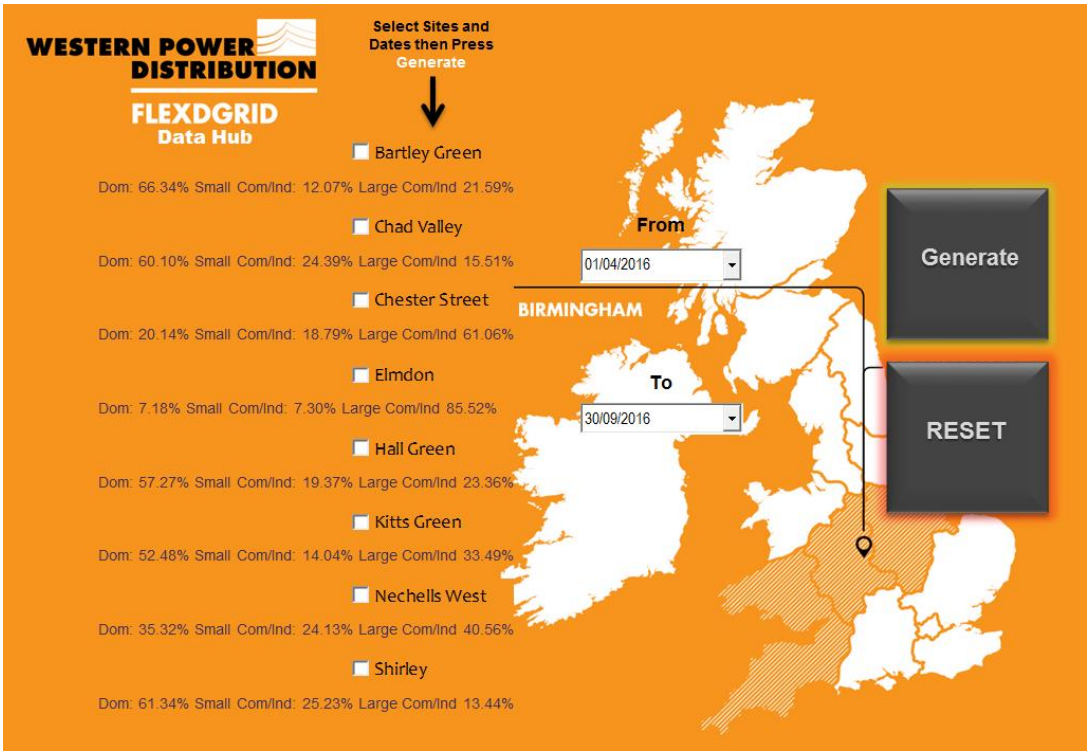

Figure 2-1: FlexDGrid FLM Data Hub

2.2 Policies

WPD's principle is to ensure that a device connected to the system has the policies required to ensure it can be suitably operated, controlled, maintained and inspected, prior to it being energised. This is of fundamental importance when considering a new technology and therefore the following suite of policy documents, as part of FlexDGrid have been produced and released:

EE SPEC: 201 - Fault Level Monitor (FLM) Devices for use on the 11kV Network (FlexDGrid)

This specification covers Western Power Distribution's requirements for the installation of Fault Level Monitor (FLM) devices on the 11kV network as part of the Low Carbon Networks Fund (LCNF) Tier-2 Project, FlexDGrid.

EE SPEC: 202 - Fault Current Limiter (FCL) Devices for use on the 11kV Network (FlexDGrid)

This specification covers Western Power Distribution's requirements for the installation of Fault Current Limiters (FCL) devices on the 11kV network as part of the Low Carbon Networks Fund (LCNF) Tier-2 Project, FlexDGrid.

ST: OC1V - Operation and Control of 11kV Network Fault Level Monitors (FLMs) for use on the FlexDGrid project

This document describes the standard operation and control procedure for fault level monitors (FLMs) on WPD's 11kV network, as part of FlexDGrid.

ST: OC1W - Operation and Control of GridON 11kV Pre-Saturated Core Fault Current Limiter installed at Castle Bromwich Primary Substation for use on the FlexDGrid project

This document covers Western Power Distribution's requirements for the operation and control of the GridON 11kV Pre-Saturated Core Fault Current Limiter (PSCFCL) as part of the Low Carbon Networks Fund (LCNF) tier-2 Project, FlexDGrid.

ST: OC1Y - Operation and Control of Nexans 11kV Resistive Superconducting Fault Current Limiter (FlexDGrid)

This document covers Western Power Distribution's requirements for the operation and control of the Nexans 11kV Superconducting Fault Current Limiter (RSFCL) as part of the Low Carbon Networks Fund (LCNF) Tier-2 Project, FlexDGrid.

ST: SD4R - Application and Connection of 11kV Fault Level Monitors (FLM) devices for FlexDGrid

This standard technique sets out the requirements for the application and connection of fault level monitor (FLM) devices on WPD's 11kV network. This policy is intended for the Low Carbon Networks Fund (LCNF) project, FlexDGrid and will be reviewed following the successful completion of the project.

ST: SD4S - Application and Connection of 11kV Fault Current Limiters (FCLs) for FlexDGrid

This policy sets out requirements for the application and connection of Fault Current Limiter Devices on WPD's 11kV network. This policy is intended for the Low Carbon Networks Fund (LCNF) project, FlexDGrid and will be reviewed following the successful completion of this project.

ST: SP2CAA - Inspection and Maintenance of GridON 11kV Pre-Saturated Core Fault Current Limiter installed at Castle Bromwich Primary Substation for use on the FlexDGrid project

This document covers Western Power Distribution's requirements for the inspection and maintenance of the GridON 11kV Pre-Saturated Core Fault Current Limiter (PSCFCL) as part of the Low Carbon Networks Fund (LCNF) tier-2 Project, FlexDGrid.

ST: SP2CAB - Inspection and Maintenance of 11kV Network Fault Level Monitors (FLMs) for use on the FlexDGrid project

This document describes the standard inspection and maintenance procedure for fault level monitors (FLMs) on WPDs 11kV network, as part of FlexDGrid.

ST: SP2CAC - Inspection and Maintenance of Nexans 11kV Resistive Superconducting Fault Current Limiter (FlexDGrid)

This document covers Western Power Distribution's requirements for the inspection and maintenance of the Nexans Resistive Superconducting Fault Current Limiter (RSFCL) as part of the Low Carbon Networks Fund (LCNF) Tier-2 Project, FlexDGrid.

These policies are now part of WPD's wider portfolio and are updated at a regular interval, or as required with the learning from the operation of new technologies.

All policies created as part of the project have been made available to all other DNOs via the ENACT portal[2].

As well as the new policies created as a direct result of the project's activities the learning generated from FlexDGrid has fed in to several other associated policies. These have ranged from the requirements for inspecting suppliers manufacturing facilities and procedures for new equipment testing to the further development of WPD's 11kV fault level network modelling policy. Learning will continue to be generated and further positively influence WPD's suite of policies.

3 Six-Monthly Progress Reports Submitted to Ofgem

Throughout the delivery of the project the regular reporting to Ofgem has been in the form of Six-Monthly Progress Reports (6MPR). These documents have contained key project management detail, risks, actions and cost profile and forecasting. As well as the direct project management detail a robust commentary on the project delivery activities over the six month reporting period were captured. This focussed on the design, installation and operational activities of the three project methods with significant focus on the learning and dissemination activities.

The 6MPRs submitted as part of FlexDGrid have been:

- December 2012 to May 2013;
- June 2013 to November 2013;
- December 2013 to May 2014;
- June 2014 to November 2014;
- December 2014 to May 2015;
- June 2015 to November 2015;
- December 2015 to May 2016; and
- June 2016 to December 2016.

All these reports are available on the ENA's Smarter Networks Portal and WPD's Innovation website[3].

[2] http://enact.energynetworks.org
[3] www.westernpowerinnovation.co.uk

4 Eight Industry Conferences Attended and Presented

As well as documenting the learning of the project in the 6MPRs and the SDRC submissions a vital part of the knowledge capture and dissemination activities has been through the active sharing of project learning through industry conferences. Throughout the project lifetime a vast number of conferences and dissemination events have been attended by members of the FlexDGrid project team, where project knowledge and learning has both been formally and informally shared with the industry. Below is a summary of the key eight industry conferences that have contained formal FlexDGrid presentations.

4.1 International Conference on Electricity Distribution (CIRED)

CIRED is widely considered to be the largest technical international conference focussed on distribution electrical networks. At the outset it was considered paramount to ensure that the FlexDGrid learning was to be captured and disseminated at each of the CIRED events, to enable appropriate peer review, comparison with international projects and information on the latest product developments from leading manufacturers, as soon as prominent learning was being gathered. Throughout 2013 the project focussed heavily on the design element of all three methods, where significant learning was gathered, therefore 2014 was the first opportunity to share learning at CIRED. The sections below describe the learning shared at each CIRED event to date.

All the CIRED papers and presentations are captured in Appendix 2.

4.1.1 CIRED Workshop – Rome, 11-12 June 2014

"SENSITIVITY ANALYSIS OF FAULT LEVEL ASSESSMENTS IN HV NETWORKS"

In this paper, the effects of the accuracy of HV network parameters on calculated make and break fault levels are investigated. Fault level calculations, using computer models, are an approximation to the behaviour of the actual distribution network and, due to assumed parameter values, include a level of inaccuracy. The results of the fault level sensitivity analysis studies show that the network parameters which have a greater impact on pre-fault voltage levels need to be modelled more accurately. In addition, the fault level sensitivity to general load fault in-feed assumptions given in engineering recommendations is studied. Based on the sensitivity analysis results, recommendations for modelling the HV networks and architecture of a fault level active management system are proposed.

4.1.2 CIRED – Lyon, 15-18 June 2015

"STANDARDISED CONNECTIONS AND THE ECONOMIC BENEFITS OF FAULT CURRENT LIMITERS ON DISTRIBUTION NETWORKS"

This paper discusses the advantages of standardised connections of fault current limiters (FCL) on the 11kV distribution network and the economic benefits of these installations against traditional network solutions. This paper is based on learning to date from FlexDGrid, and other FCL installations.

4.1.3 CIRED Workshop – Helsinki, 14-15 June 2016

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

This paper discusses the process of generating and the advantages of utilising real-time fault level values to produce MVA per MVA general load fault infeed templates for 11kV distribution network modelling. This paper is based on learning to date from FlexDGrid.

4.1.4 CIRED – Glasgow, 12-15 June 2017 (*Post Project*)

A significant amount of learning has been generated in the time since the CIRED event, 2016, and as such five technical papers have been submitted and accepted for 2017's event. These papers' titles are as below and will be full constructed in the early part of 2017:

- The Impact of Low Carbon Technologies on Short Circuit Levels at Medium Voltage Networks;
- Distributed generation connections under a fault level active network management scheme;
- Steady State Modelling of Fault Current Limiter Technologies;
- Developing Testing Procedures for High Voltage Innovation Technologies; and
- Characterisation of 11kV Fault Level contributions based on Substation Load Profile.

As the titles demonstrate there is a mix of analysis and learning being disseminated in these papers from all three project methods, Alpha, Beta and Gamma. The focus has been on providing the industry clear and transferable knowledge that has been gained throughout the project, that are useful to both fault level related work and wider distribution network development, such as the development of High Voltage (HV) testing procedures for innovation technologies.

4.2 ENA SHE Management Conference – Bristol, 15-17 April 2015

This conference is organised by the Energy Networks Association (ENA) and is the energy industry's Safety, Health and Environment (SHE) Management Conference. The conference provides a forum for all stakeholders – employees, employers, trade unions and regulators – to network, share best practice and review SHE challenges and concerns. It aims to foster co-operation and improve contact between and within the organisations and companies that comprise the energy industry.

The presentation focussed on the project's substantial work in creating operational, control, inspection and maintenance for FCLs and new, innovative, technologies in general. The key learning shared was the development of technologies, construction through to energisation on a live and operational electricity network – focussing on the documentation and procedural activities implemented.

4.3 Balancing Act – London, 8 September 2016

The Balancing Act conference was organised by WPD and focussed on how the changing nature of the electricity grid is transforming the role of DNOs, demanding intelligent ways of controlling power flows and voltages, a higher level of interaction with customers and more advanced methods of network management and planning.

The presentation centred on the development and changing nature of fault level on the distribution network borne by the changing elements connecting to and utilising the network. It demonstrated the value of the three methods' learning; including the value of more integrated and granular fault level power system analysis modelling, understanding the changing fault level contribution on a network by considering the type of load connected and the value of FLMTs in an environment both where fault level from National Grid's network decreases or remains constant.

4.4 Energy Saving Convention – Birmingham, 24 November 2016

Climate KIC and the University of Wolverhampton organise the Energy Saving Convention, which is part funded by the European Regional Development Fund, and focusses on how smart technology can help designers, manufacturers and users of buildings to deploy sustainable energy solutions to deliver low carbon, low cost and highly desirable buildings.

The theme of the presentation focussed on the value of the project, along with others in WPD's innovation portfolio, to end users in terms of the central focus of releasing generation capacity, specifically Combined Heat and Power (CHP), and how this can be utilised most effectively.

4.5 Power Electronics in Distribution Networks – London, 30 November 2016

HUBNET[4] and UKPN developed this conference, which looks at the use of Power Electronic devices in distribution networks. It focussed on the evolution of the distribution network and the requirements for innovative methods to control power flow and voltages in order to integrate new loads and increase the density of distributed generation. The event was attended by academics, equipment vendors and network operators to discuss the lessons learned from LCNF projects that have deployed power electronic solutions.

This presentation focussed on the learning and knowledge generated around the development of the GE Active Fault Decoupler (AFD). How the network would be designed to enable the inclusion of a power electronic device and the wider considerations of a power electronic device in the system were the principal dissemination elements. What else was shared was the process of developing an alternative technology to be used on the distribution network and the requirements to enable the technology to be installed on such a system.

4.6 Euro TechCon – Bristol, 1 December 2016

This three day conference focused on Primary Asset Management. It looked across the HV field to discuss new ideas, new techniques, case studies and new technology.

This presentation focussed on the operation and asset management of the two technologies installed as part of the project, FLMs and FLMTs. Key to this knowledge sharing was activity was the learning generated on the maintenance and operational requirements of both elements as well as the availability to modify the asset management of other elements of the distribution network. This particular element was focussed on how understanding fault level in real-time and limiting fault level at the point of fault can dramatically increase the utilisation of existing assets, such as switchgear and transformers.

All the industry conference presentations are captured within Appendix 3.

[4] http://www.hubnet.org.uk/

5 DNO Workshops

As part of the successful delivery of the project it has been critical to engage other DNOs' staff to ensure that the solutions provided are fit, not only for WPD's distribution network but also throughout the UK. As part of this there have been five workshops held. This section describes the workshops run as part of the project and main objectives and learning outcomes.

The presentations from all five DNO workshops are documented in Appendix 4.

5.1 Advanced Fault Level Management – 2 May 2013

This workshop provided a detailed introduction for the DNOs in to the FlexDGrid project and focused on the first method, Enhanced Fault Level Assessment. As part of this workshop the details of how all DNOs model fault level on their 11kV networks was discussed. The data gathered centred on the modelling tools used and their respective interpretation of G74. This enabled the project team to ensure that the modelling developments carried out as part of this method, whilst focussing on WPD's 11kV network in Birmingham would be able to be used on any other GB 11kV network. This learning was fundamental in the learning shared as part of SDRC-1 and 4.

5.2 Fault Level Mitigation Technologies – 4 September 2013

This workshop was designed to provide the other DNOs the background of the FLMTs and the design philosophy generated as part of SDRC-2, Detailed Design, and was reported in SDRC-3. It was also to ensure that the technical designs, to include the FLMTs, along with the specification of the FLMTs themselves were ratified as suitable and acceptable by each and all the other DNOs to ensure that they will provide the anticipated learning. This was formally documented as letters of support that accompanied SDRC-6.

5.3 Implementation of EFLA Processes – 23 October 2013

As part of SDRC-4, Simulating and Applying EFLA processes it was felt critical to ensure that, prior to publication, that all other DNOs had the opportunity to review and comment on the work carried out to date. This enabled the final submission to be suitably updated reflecting DNOs' comments at this workshop. The workshop focussed on the process followed to more granularly understand fault level on the 11kV network, which included greater detail within the modelling tool and the understanding of key elements connected to this model, such as load and generation capability. SDRC-4 was submitted on the 28th November 2013 with the other DNOs' comments and suggestions suitably incorporated.

5.4 Fault Level Mitigation Technologies – 14 May 2014

Building on the previous FLMT workshop, this provided all DNOs an update on the specification and particular details of each of the three FLMT devices. Knowledge related to the system, performance criteria, size and mass as well as the connection and protection philosophy of each. Similarly an update on the modelling performance of each of the FLMTs was provided, which is essential for the investigation of the suitability of a particular device to be connected to the network.

5.5 FLMT Dissemination Event – 14 September 2016

Following the installation, connection and energisation of the GridON and two Nexans FLMTs a dissemination event was held to share what the project team has learnt. Significant learning was generated on the design, construction, testing activity and installation and commissioning of each of the devices. whilst this has been robustly captured in SDRCs-8 and 9, taking the opportunity to share this learning in a workshop environment was seen as extremely valuable. This learning generated culminated in the production of all the FlexDGrid policies, as discussed in Section 2.2, which has been shared with each DNO. As well as the workshop activity both the GridON installation and a Nexans

installation were visited to afford the DNOs the opportunity to examine the installation of the FLMTs and the accompanying works required.

Figure 5-1 - DNOs at Nexans FLMT

Figure 5-2 - DNOs at GridON FLMT

6 LCNF/I Conference Presentations

Since the inception of the project, December 2013, it has been presented at each of the LCNF/I Conferences. There have been four conferences, 2013, 2014, 2015 and 2016. At these conferences the progress and learning of each of the project methods was shared. This learning started with the design principles of the project's methods and moved to the installation of technologies and through to the operational learning through the three methods. Each presentation has been delivered by the Project Manager, Jonathan Berry, in order to ensure that consistency in the learning dissemination is kept.

Appendix 5 documents all the LCNF/I presentations relating to FlexDGrid.

7 Publication of other SDRC Reports

To date 10 of the 11 SDRCs have been submitted, either on time or early, as set out in the Project Direction document. The last SDRC is due in March 2017 at the end of the project. These SDRCs have provided valuable learning throughout all aspects of the project and importantly have documented the clear decision making and optioneering for all elements of the project.

8 Conclusion

Throughout the delivery of FlexDGrid there has been a significant amount of learning generated and this has been robustly captured and disseminated in a number of formats, as discussed in this document.

This learning is captured in such a way that all other GB DNOs have access to the data and information they need, in order to determine the suitability and viability of any of the project's solutions to their networks. It also enables other parties, such as product suppliers and customers to understand the project's aim, process and outputs.

This learning and future learning will continue to be captured robustly and disseminated as applicable through to the end of the project and beyond where appropriate.

9 Appendices

Appendix 1 – Policies (CONFIDENTIAL)
Appendix 2 – CIRED Papers and Presentations
Appendix 3 – Industry Presentations
Appendix 4 – DNO Workshop Presentations
Appendix 5 – LCNF/I Presentations
Appendix 6 – FLM Network Data