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SUCCESSFUL DELIVERY REWARD CRITERIA REPORT
DEVELOPMENT OF ENHANCED FAULT LEVEL ASSESSMENT PROCESSES

LCN Fund Low Carbon Networks

THE UNIVERSITY OF WARWICK

PARSONS BRINCKERHOFF

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Contents

Glossary of Terms

Abbreviation	Term
BaU	Business as Usual
CI	Customer interruption
CML	Customer minutes lost
DFIG	Doubly-fed induction generator
DNO	Distribution Network Operator
EHV	Extra High Voltage (voltages above 22,000V)
ENA	Energy Networks Association
ER	Engineering Recommendation
ETR	Engineering Technical Report
HV	High voltage (voltages above 1,000V but below 22,000V)
PV	Photovoltaic
R	Resistance
SDRC	Successful Delivery Reward Criteria
SGT	Supergrid Transformer
STATCOM	Static Compensator
X	Impedance

Executive Summary

This document fulfils the first Successful Delivery Reward Criterion of FlexDGrid "Develop an enhanced fault level assessment process" (SDRC-1). The purpose of this document is to identify and define a number of possible processes that will be trialled within FlexDGrid and could be used to demonstrate how DNOs' knowledge of fault level could be enhanced. The processes, which have been developed in the initial design stage (Phase 1) of FlexDGrid and which will be trialled throughout the project, are outlined below:

1. Baseline the consistency of application of present fault level assessment methods;
2. Explore assumptions and parametric sensitivity analysis of present fault level standard calculation methods;
3. Increasing the frequency of fault level assessments and granularity of fault levels within HV electricity networks;
4. Network design and deployment of fault level monitoring technologies;
5. Network design and deployment of fault level mitigation technologies;
6. Connection offers based on novel commercial frameworks.

The first FlexDGrid DNO consultation workshop was held as part of the base-lining process and a questionnaire was submitted to all GB DNOs. The workshop provided a welcome opportunity for DNOs to collaborate and share best practice, as well as voicing concerns and challenges that are currently experienced by DNOs regarding the assessment of fault level within HV electricity networks. Building on questionnaire responses from DNOs the following conclusions were reached:

1. Clarifications on the application of ER G74 to HV electricity networks would be beneficial to the DNO community;
2. A comprehensive sensitivity analysis of HV electricity network fault levels to input parameters would provide useful learning for DNOs;
3. An open source database of generation / motor plant types would be beneficial for dealing with missing / inconsistent data from customers;
4. The development of open source fault level mitigation technology models would be of benefit to the DNO community and could allow the capacity to accommodate customers' connections to be readily assessed;
5. At present, single snapshots are used to calculate worst-case fault level values for credible network operating conditions (for example the parallel and split operating configurations of primary substation transformers). The increase in frequency of fault level assessments would be useful for assessing the potential gains from fault level monitoring in FlexDGrid. However, the potential benefits resulting from fault level monitoring would need to be quantified and outweigh the increased modelling effort required, if this process were to be adopted by other DNOs.
6. Due to the Electricity, Safety, Quality and Continuity Regulations (ESQCR) and health and safety implications, a move towards probabilistic fault level assessments was not deemed to be feasible at this point in time. However, the various DNO representatives saw the potential in introducing 'connect and manage' options for generation and demand customers so long as fault levels at no point violate switchgear ratings.
7. The need was identified for the present fault level assessment training processes within DNOs to be documented so that staff are given consistent guidance on how to conduct HV fault level

assessments. In addition, any enhancements to the HV fault level assessment methodology should be process-driven and easily adopted by the user of the methodology.

The scope of work within the SDRC-1 work package has been to develop the Birmingham HV electricity network in order to create the test bed for trialling the enhanced fault level assessment processes. The 11kV network model is currently fit-for-purpose. However, a more detailed electricity network model allows the future complexities associated with the integration of low carbon technologies to be more fully understood. The results of enhanced fault level assessment trials will be reported within future FlexDGrid SDRCs.

The following recommendations have resulted from the work conducted to fulfil this Successful Delivery Reward Criterion:

1. The processes identified and detailed in this SDRC report should be followed to inform the development of enhanced fault level assessments.
2. A follow-on workshop should be organised to report back the findings from base-lining the consistency of HV fault level assessment processes and sensitivity analysis studies. The implementation of this recommendation is within the scope of the FlexDGrid project.
3. It is not clear how the values reported in ER G74 for modelling the fault contribution of asynchronous motors forming part of the general load were originally derived and if these values are still representative of the present distribution network load demand mix. ER G74 reports these values as ‘indicative allowances’ where measured values are not available. In order to address this issue it is recommended that:

    a. Load mixes (demand types) and associated fault level in-feed values should be investigated in more detail to understand the variation of fault in-feed with different combinations of load. An initial implementation of this recommendation is within the scope of the FlexDGrid project;
    b. In situations where calculated fault levels are approaching switchgear ratings, the deployment of fault level monitoring equipment should be considered by DNOs.

4. An industry-wide review of ER G74 would be of benefit to the DNO community with clarifications and guidance on the consistent application of ER G74 to HV distribution networks. Whilst FlexDGrid will aim to inform recommended changes to ETR 120 (the application guide to ER G74), the industry-wide review of ER G74 is outside of the scope of the FlexDGrid project.
5. Traditionally, DNOs have trained staff to carry out connection studies ‘on-the-job’ and through supervised instruction. It is recommended that DNOs formally document their connection study process so that HV fault level assessments are conducted consistently, assumptions are well-understood and engineering judgements can be made more confidently.
6. DNOs should consider the development of integrated electricity network models, whereby both EHV and HV networks are modelled within the same power system analysis software package. This removes the need for equivalent models, which have the potential to introduce sources of error and uncertainty.
7. DNOs should confirm whether or not there is a need to de-rate HV switchgear in line with the CIGRE 304 recommendation. The confirmation of the need to de-rate HV switchgear by other GB DNOs is outside the scope of the FlexDGrid project.

1 Introduction

1.1 Aims, objectives and scope

This document fulfils the first Successful Delivery Reward Criterion of FlexDGrid "Develop an enhanced fault level assessment process" (SDRC-1). The purpose of this document is to identify and define a number of possible assessment processes that will be trialled within FlexDGrid and will inform the development of enhanced fault level assessments. A full list of FlexDGrid's SDRCs are given in Appendix A, based on the FlexDGrid Project Direction from Ofgem [1]. This SDRC defines the processes, the trialling and results of which will be reported in a number of other SDRCs, as listed below:

1. SDRC-2: Confirmation of project detailed design (1 June 2013);
2. SDRC-3: Hold a workshop, inviting all GB DNOs and other interested parties to provide input on the methodology of Method Gamma (31 October 2013);
3. SDRC-4: Simulation and application of the enhanced fault level assessment process to demonstrate what can be achieved with customer connections (1 December 2013);
4. SDRC-10: Analysis of test results, evaluating and quantifying benefits of the solution and applicability to GB HV electricity networks (31 December 2016);
5. SDRC-11: Development of novel commercial frameworks with generation and demand customers (31 March 2017).

The scope of this SDRC is to develop processes to enhance DNOs' knowledge of fault level and, in doing so, propose various methodologies that could be adopted by DNOs as fault level issues become more prevalent. The trialling and application of the enhanced fault level assessment processes will take place throughout FlexDGrid and be reported as outputs from the other SDRCs.
FlexDGrid is focused on calculation, modelling and simulation methods that are used by DNOs to assess HV (11kV and 6.6kV) distribution network fault levels. FlexDGrid is particularly focused on fault levels within urban environments where synchronous generation is currently connected or expected to be connected in the future as electricity and heating systems are decarbonised.

1.2 SDRC Definition

The defined Successful Delivery Reward Criterion, as agreed with Ofgem in the FlexDGrid Project Direction [1], is given in Table 1.

1.2.1 SDRC Interpretation

This SDRC aims to develop processes to inform how fault level assessments could be enhanced. The report summarises the high-level design architecture of the FlexDGrid project in terms of processes that will be trialled to model, monitor and mitigate HV electricity network fault levels. Six modelling and simulation processes have been developed as part of FlexDGrid's initial design phase and will be trialled throughout the project. The developed processes include an assessment of the consistency of application of present fault level standards by DNOs, an exploration of the assumptions that underpin standard fault level calculations and an assessment of the benefits that can be gained from an increase in the granularity of fault levels along HV feeders. The developed processes also encompass trials to compare the simulated and actual performance of fault level measurement, monitoring and mitigation technologies. These processes will be trialled in FlexDGrid and are expected to deliver valuable

outputs, generating knowledge and learning that could be used by DNO planning engineers to respond to generation and demand connection applications more quickly and cost effectively.
The measureable criteria, agreed with Ofgem for the delivery of this SDRC, were to (i) demonstrate how the Birmingham HV electricity network will be used throughout FlexDGrid to trial the processes (Sections 3 and 4); (ii) hold a workshop with other DNOs to discuss the Enhanced Fault Level Assessment processes (Section 5); and (iii) to produce a report on the processes to be shared with other DNOs (this report and follow-on SDRC reports).

Successful Delivery Reward Criteria	Evidence
Specific: Develop an Enhanced Fault Level Assessment process.	Using the Birmingham HV electricity network to trial the Enhanced Fault Level Assessment process.
Measurable: Workshop and report on the Enhanced Fault Level Assessment process.	A workshop with other DNOs to discuss the Enhanced Fault Level Assessment process.
Achievable: An initial Enhanced Fault Level Assessment process has been developed as part of the bid from the Initial Screening Process to Full Submission Pro-forma.	A publication on the Enhanced Fault Level Assessment process to be shared with other DNOs.
Relevant: This criterion corresponds to the delivery of Method Alpha (Enhanced Fault Level Assessment).	
Timely: The Enhanced Fault Level Assessment process will be developed by 1 June 2013, with the publication being available to other DNOs interested parties thereafter.	

1.3 Overview of proposed processes

The processes, which have been developed in the initial design stage (Phase 1) of FlexDGrid and which will be trialled throughout the project, are outlined below and discussed in more detail in Sections 3 and 4.

1. Baseline the consistency of application of present fault level assessment methods (an initial assessment is reported in this SRDC);
2. Explore assumptions and parametric sensitivity analysis of present fault level standard calculation methods (the outputs of which will be reported in SDRC-4);
3. Increasing the frequency and granularity of fault level assessments (the outputs of which will be reported in SDRC-4);
4. Network design and deployment of fault level monitoring technologies (the outputs of which will be reported in SDRC-2 and SDRC-10);
5. Network design and deployment of fault level mitigation technologies (the outputs of which will be reported in SDRC-2, SDRC-4 and SDRC-10);
6. Connection offers based on novel commercial frameworks (to be reported in SDRC-11).

1.4 Report Overview

This report is structured in the following way: Section 2 provides background to FlexDGrid and a project-level definition of fault level. Section 3 defines the processes that are proposed for trialling within FlexDGrid. Section 4 explains the methodology that has been used to develop WPD's 11kV electricity network model for Birmingham and how the HV electricity network model will be used to trial enhanced fault level assessment processes. Section 5 provides details of the questionnaire, and workshop with other GB DNOs, to gather views to inform the enhanced fault level assessment processes. Section 6 draws conclusions and provides DNOs and other interested parties with recommendations regarding the fault level assessment processes.

2 Background

2.1 Overview of FlexDGrid

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. This project 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.

FlexDGrid is being delivered by Western Power Distribution, in collaboration with Parsons Brinckerhoff and the University of Warwick, and supported by Cofely District Energy and Birmingham City Council.

2.2 Fault level definition

Various definitions of fault level have been produced by industrial, academic and regulatory stakeholders. For the purpose of the FlexDGrid project, fault level has been defined in the following way:

Fault level is a measure of electrical stress when an unintentional conducting path (fault) causes a short circuit. This causes high "fault currents" to flow in the electricity lines, cables and substation equipment. The amount of fault current varies from location to location, depending on how close it is to the energy source (for example a transformer or generator).

A fault (short circuit) occurs when one electrical components contacts another, intended to be at a different voltage level. This allows an electrical current to flow along an undesired, often negligible, impedance path.

The short circuit currents can be orders of magnitude larger than the normal operating current. For example HV fault currents can typically be 10kA – 15kA, whilst load current may be 0.1kA – 0.6kA. Examples of unintentional conducting paths (faults) in a 3-phase system are given in Figure 1. Common sources of faults include lightning strikes, manufacturing defects, a tree branch falling on to an overhead line or a digger cutting through a cable.

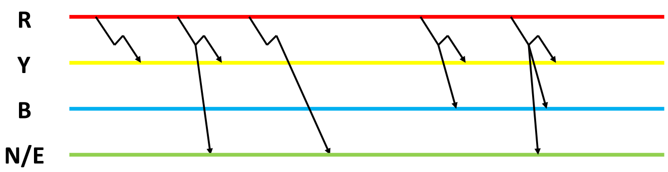

Figure 1 - Examples of unintentional conducting paths (faults) in a 3-phase system

3 Defining enhanced fault level assessment processes

This section of the report defines enhanced fault level assessment processes. A series of questions are proposed, which will be answered through FlexDGrid's trials and which aim to demonstrate how fault level assessments could be enhanced for the benefit of DNOs and distribution customers.

3.1 Baseline the consistency of application of present fault level assessment methods

Justification: It is important to understand the issues and challenges that are currently faced by the DNO community so that FlexDGrid can deliver meaningful and relevant outputs.

This process seeks to baseline the consistency of application of present fault level assessment methods (IEC 60909 [2], ER G74 [3] and ETR 120 [4]) used by DNOs to calculate fault level. During this process, answers to the following questions will be sought:

1. Are fault level standards being interpreted and consistently applied by DNOs?
2. Should ER G74 and ETR 120 be reviewed and, potentially, refined with clarifications?
3. Does each DNO licence area model the 11kV network from primary substations to distribution substations?
4. Is the model maintained and updated with 'as-built' data? (How often does this maintenance take place?)
5. What limitations are there with software packages for power system simulation of fault level?
6. What training materials exist and how are staff trained to conduct fault level analysis?

This process has been initiated as part of FlexDGrid's detailed design activities (Phase 1) and will provide the starting point from which enhanced fault level assessments can be developed.

3.2 Exploration of assumptions and sensitivity analysis

Justification: It is important to understand the accuracy and confidence of fault level assessments, so that FlexDGrid can deliver meaningful and relevant outputs.

This process seeks to explore the present assumptions that are used by DNOs to conduct fault level assessments:

1. Are the original assumptions that underpin IEC 60909, G74 and ETR 120 still valid?
2. To which parameters is fault level most sensitive, how certain are we of the value of these parameters?
3. What are the merits in increasing the level of granularity of fault level assessments?
4. Which different types of faults should be investigated, modelled and monitored?

This process informs the development of enhanced fault level assessments by identifying the key parameters to which fault level calculations are most sensitive, and which should be explored in more detail to reduce uncertainties.

3.3 Increasing the granularity of fault level assessments

Justification: Increasing the granularity of fault level assessments along 11kV feeders, by more detailed modelling of the HV network, allows DNOs to confirm that fault levels are within switchgear ratings downstream of primary substations. It also allows the decrement of fault level along feeders to be assessed. For DNOs that do not already model HV systems in detail, a more detailed HV network model to calculate fault level could provide customers with connection offers more quickly and more cost effectively due to the increased accuracy. Increasing the time granularity (frequency) of fault level assessments (due to daily, weekly and seasonal variations) allows the benefits of fault level monitoring to be assessed and quantified. During this process, answers to the following questions will be sought:

1. What does the 'real-time' fault level profile of the network look like?
2. How does fault level change with distance from the primary substation?
3. What are the merits of reactive and proactive fault level assessments?

This process informs the development of enhanced fault level assessments by allowing the decrement of fault level along feeders to be assessed and by increasing the time granularity (frequency) of fault level assessments to allow comparisons of modelled and monitored fault levels to take place.

3.4 Trialling of fault level measurement and monitoring technologies

Justification for measurement technologies: DNOs make key investment decisions based on simulated fault level values. This process seeks to explore the variation between short circuit currents that are simulated and measured during an actual HV fault. During this process, answers to the following questions will be sought:

1. How does a DNO decide on the number of measurement units required?
2. Where should measurement equipment be located? What factors influence the decision?
3. How is the performance of measurement equipment evaluated?

Justification for monitoring: DNOs make key investment decisions based on simulated fault level values. This process seeks to compare real-time fault level simulations to HV fault levels arising from the use of fault level monitoring equipment and not requiring the measurement of actual fault currents. During this process, answers to the following questions will be sought:

1. How does a DNO decide on the number of monitoring units required?
2. Where should monitoring equipment be located? What factors influence the decision?
3. How is the performance of monitoring equipment evaluated?
4. What refinements should be made to fault level assessment calculations?

These processes inform the development of enhanced fault level assessments by allowing measured and monitored fault level data to be gathered from the HV electricity network and compared with simulated measurement and monitoring values (from HV electricity network model).

3.5 Trialling of fault level mitigation technologies

Justification: The deployment of fault level mitigation technologies is expected to facilitate quicker and more cost-effective connections, whilst increasing the security of supply to customers by allowing transformers to be run in parallel operation. In order to facilitate this, fault level mitigation technology models need to be developed so that the simulated performance of the technology can be compared with the actual performance of the technology for planning purposes. During this process, answers to the following questions will be sought:

1. Where should fault level mitigation technologies be located? (For example in a substation or at strategic locations within the 11kV network).
2. If substations are the most viable option, where in the substation should fault level mitigation technologies be located? (For example, across windings of same transformer; across two busbars (interconnection); in series with transformer ‘incomers’).
3. If strategic network locations are preferable, where in the network should fault level mitigation technologies be located?
4. What are the benefits that result from the modelling and simulation of fault level mitigation technologies?

This process informs the development of enhanced fault level assessments by allowing fault level mitigation data to be gathered from the HV electricity network and compared with simulated fault level mitigation values (from HV electricity network model).

3.6 Connection offers based on novel commercial frameworks

Justification: This process aims to provide generation and demand customers with options to connect to the network more quickly and cost-effectively through ‘connect and manage’ contracts. (This process assumes that generation and demand customers could have the control systems in place to manage their connection to the network so that fault levels remain within switchgear ratings). Questions related to connection offers, based on novel commercial frameworks, are given below:

1. How should fault level investment decisions be made?
2. How are the benefits realised? (For example, quantification of increased capacity for DG connections, quicker connection times, impact on network losses, potential CML and CI reductions resulting from the parallel operation of transformers).
3. How should costs be apportioned to customers, DNOs and other relevant parties in ‘connect and manage’ scenarios?

This process informs the development of enhanced fault level assessments by creating the novel commercial frameworks, based on enhancements to modelled, monitored and mitigated fault levels, which will provide generation and demand customers with options to connect to the network more quickly and cost-effectively.

4 How the Birmingham HV network will be used to trial the processes

4.1 Development of the Birmingham HV network

The scope of work within the SDRC-1 work package has been to develop the Birmingham HV electricity network in order to create the test bed for trialling the enhanced fault level assessment processes. The results of these trials will be reported within other FlexDGrid SDRCs, as outlined in Section 1. The existing model for the Birmingham 11 kV network is updated on a limited basis and is not directly integrated with the EHV model at present. Moreover, there are a number of different data sources that are used by design and planning engineers to conduct fault level assessments. The 11kV network model is currently fit-for-purpose. However, a more detailed electricity network model allows the future complexities associated with the integration of low carbon technologies to be more fully understood. This work also delivers additional potential benefits to the WPD business by bringing together the information from multiple data sources into a single power system analysis model. These benefits will be passed on to distribution customers through greater efficiencies in the 11kV connection assessment processes. The methodology for integrating the EHV and HV networks is described in Appendix E.

The use of these various data sources to develop the integrated network model is demonstrated in Figure 2. Descriptions of the data sources are given in Appendix E.

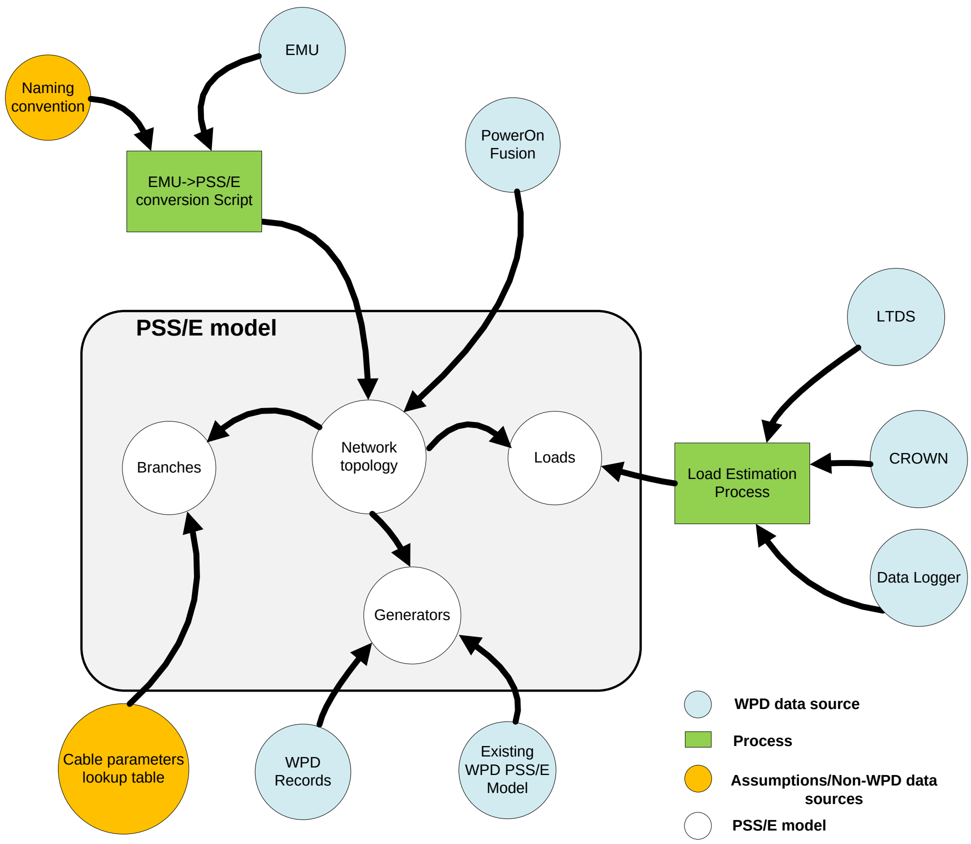

Figure 2: The data sources used to develop an integrated network model

The implementation of the modelling methodology is illustrated for an example primary substation within the trial network area. Figure 3 represents the business as usual (BaU) EHV / HV network model prior to FlexDGrid. Figure 4 represents the schematic diagram of the 11kV network which, in BaU, is not integrated with the EHV network in the same power system analysis package. Figure 5 represents tangible output of FlexDGrid in terms of delivering to WPD an integrated network model that can be used by the project to test the enhanced fault level assessment processes throughout the project trials. In addition, the increased granularity of fault level assessments along HV feeders could, potentially, allow network planning engineers to assess connection applications more quickly.

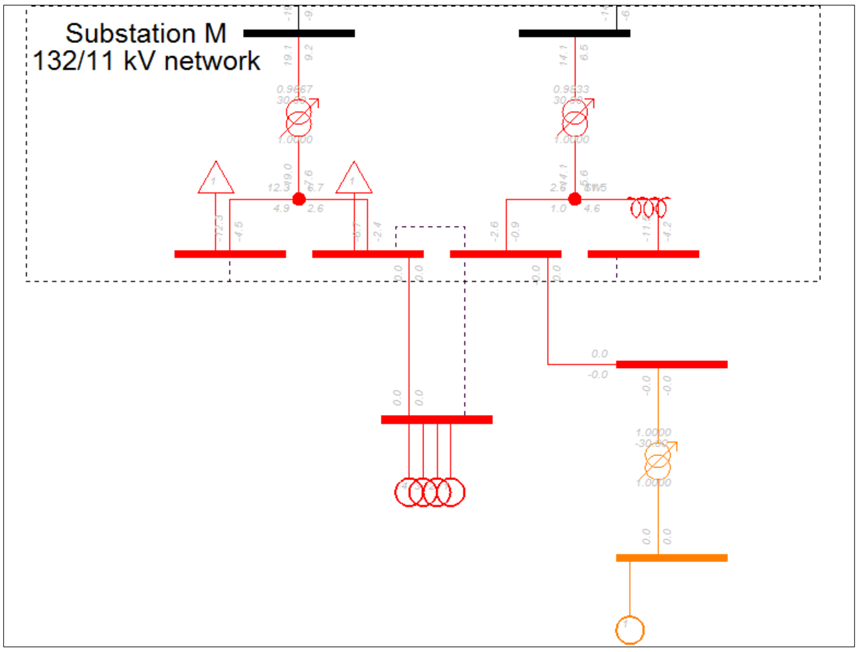

Figure 3: Representation of the EHV / HV network (BaU pre-FlexDGrid) within the power system analysis package PSS/E

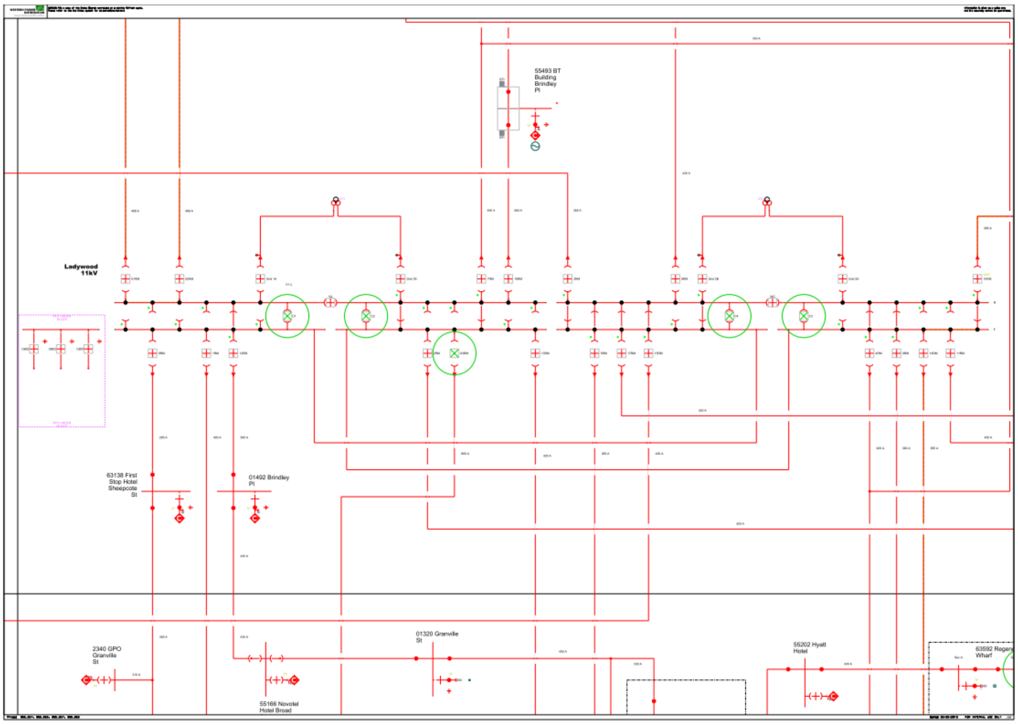

Figure 4: Schematic representation of the HV network (BaU pre-FlexDGrid) within EMU

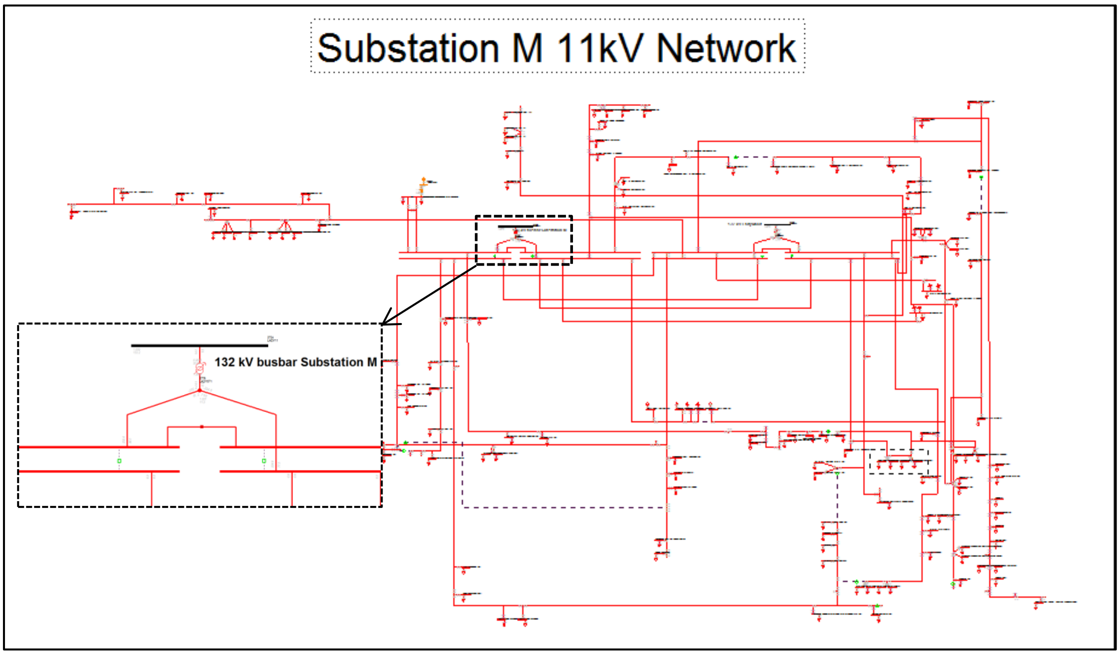

Figure 5: Representation of the integrated EHV / HV network model within the power system analysis package PSS/E as a result of FlexDGrid

4.2 How the DNO base-lining process will be trialled

4.2.1 Description of the trialling process

The following process has been proposed in order to base-line the processes that DNOs presently use to assess HV network fault levels:

1. Disseminate a questionnaire to all GB DNOs to understand: (i) the consistency of application of fault level calculation standards at 11kV or 6.6kV and associated upstream / downstream voltages (IEC 60909, ER G74 and ETR 120); (ii) the assumptions used by DNOs in applying fault level calculation standards; (iii) the validity of applying these assumptions, both now and in the future (for example with the anticipated increase in levels of synchronous generation and LV-connected heat pumps); (iv) the merit in proposing an industry-wide review of fault level calculation standards.
2. Organise a GB DNO consultation workshop to discuss the questionnaire responses and the proposed processes to enhance DNOs' knowledge of fault level.
3. Conduct literature surveys to understand the reviews and discussions regarding fault level standards that have taken place to date.

Steps 1 and 2 of this process have been completed within the scope of this SDRC and are reported in Section 5.

4.2.2 Knowledge capture and learning dissemination methods

The following methods will be used to capture the knowledge and disseminate the learning from trialling this process:

1. The base-lining questionnaire, compiled responses from DNOs and an analysis report based on the questionnaire responses (see Section 5).
2. A summary of the DNO workshop outputs, conclusions and recommendations (see Section 5).
3. Literature surveys that analyse the work that has been done to date regarding reviews and discussions of fault level standards (to be reported in SDRC-4).

4.3 How fault level assumptions will be explored

4.3.1 Description of trialling process

Building on the DNO questionnaire and workshop, fault level assumptions will be explored through a sensitivity analysis process. This process will quantify the change in calculated fault level values due to changes in calculation input parameters.

The following steps will be used to trial this process:

1. Quantification of make and break fault level indices for each primary substation (two transformers in parallel) within the Birmingham trial network in order to identify fault level 'hot spots' and areas of the network that would benefit from any reduced uncertainty in fault level calculations that may be delivered by FlexDGrid;
2. Break down make and break fault levels at ten primary substations into their constituent fault in-feed parts: (i) Upstream fault contribution; (ii) general load contribution; (iii) motor contribution; and (iv) generation contribution. Illustrative examples of the fault level break down are given in Figures 6 and 7 respectively.
3. The relative proportions of the fault level in-feed will be used to direct efforts in exploring assumptions. A sensitivity analysis will be conducted to explore the variation in calculated fault level values due to the variation in parameters input to the calculation.

4.3.2 Knowledge capture and learning dissemination methods

A record of assumptions and sensitivity analysis report will be delivered as an output of SDRC-4.

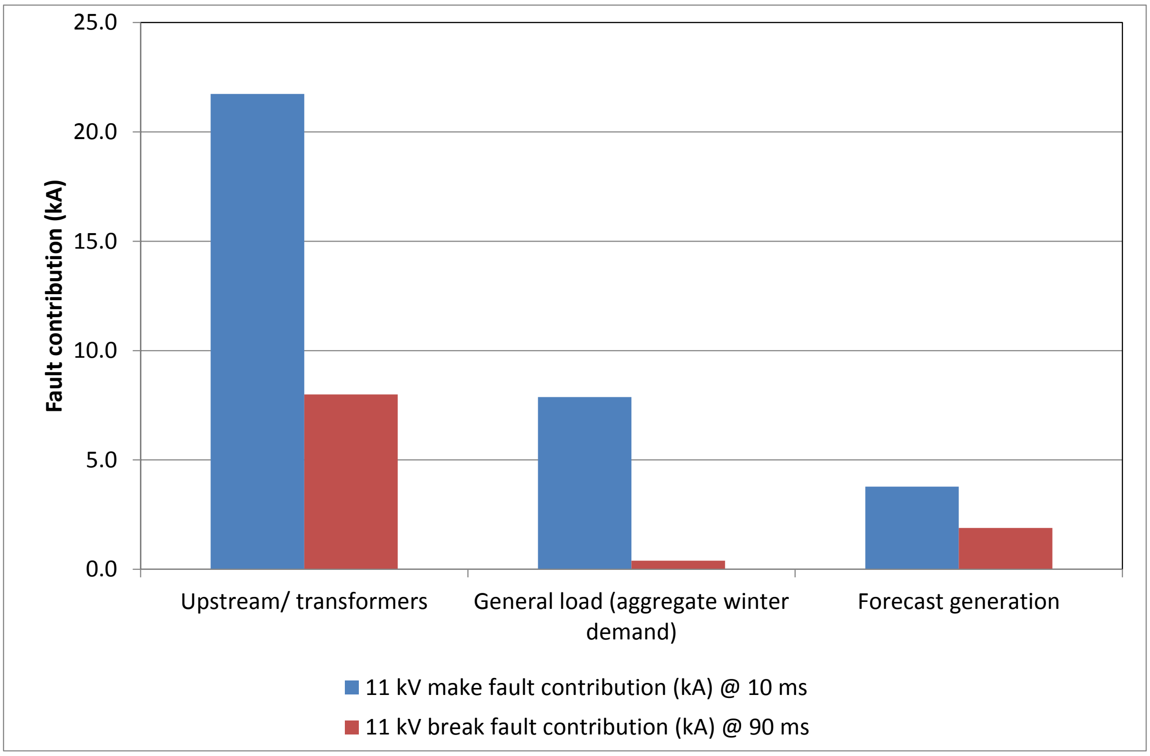

Figure 6: 11kV fault level separated into constituent parts for a substation within the trial area

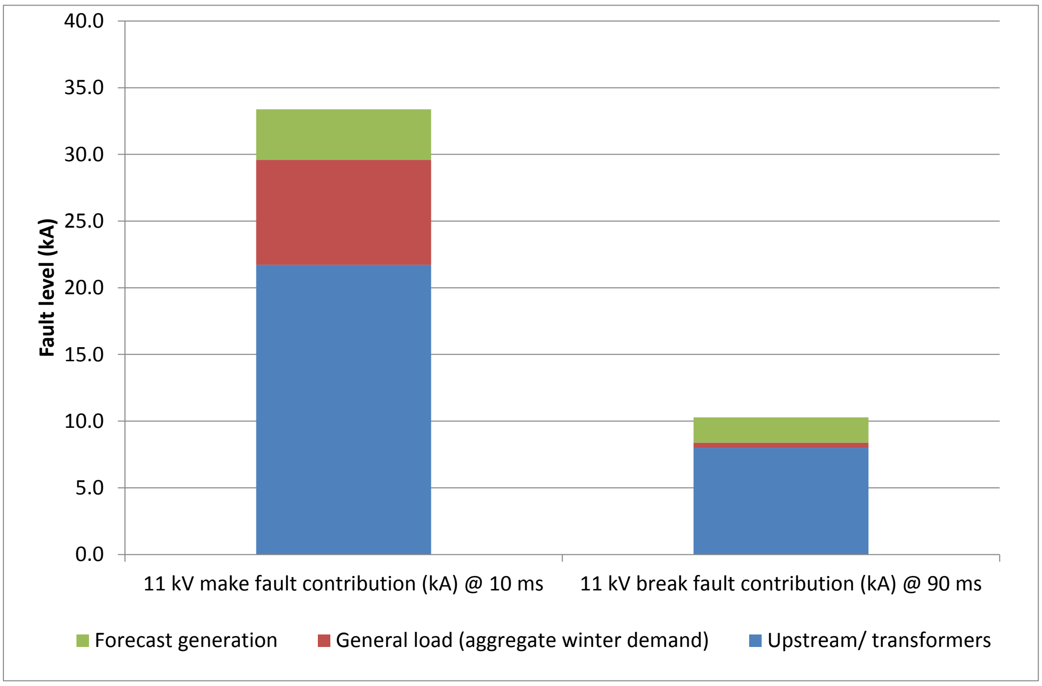

Figure 7: 11kV fault current constituent components for a substation within the FlexDGrid project trial area

4.4 How the granularity of fault level assessments will be increased

4.4.1 Description of the feeder fault level granularity trialling process

1. The HV network will be developed using the methodology as described in Section 4.1 to integrate the 11kV network infrastructure into the PSS/E master file for fault level studies.
2. In order to understand the change of fault level with distance from the primary substation, a range of standard cable types within the trial area will be selected, artificial nodes will be introduced at 100m intervals along the feeders and fault level studies will be used to quantify the change in fault level with distance.
3. The connection application process will be trialled as follows:
    a. Historical connection applications for the 12-month period prior to the start of FlexDGrid, which have triggered network reinforcement as a result of fault level issues, will be identified. These connection applications will be used as the basis for trialling connection studies with fault level mitigation technologies integrated into the HV network model (see Section 4.6).
    b. In line with the Full Submission Pro-Forma for FlexDGrid, every connection application received for a six-month period after the validation of the trial area HV network model will be assessed using the old and new HV network models to quantify the difference in fault level values.

Future generation connection scenarios, based on DECC Pathways 2050, will be simulated using probabilistic approaches to determine the size and location of future generation connection applications. Once the size and location of each generation application has been determined, standard calculations (based on ER G74) will be used to quantify the fault level.

4.4.2 Description of the time granularity fault level assessment trialling process

1. Assessment of the time-variance of fault level at substations with differing operating configurations:
    a. A table of substation operating configurations will be created for each of the ten substations within the trial area;
    b. The duration of substation operational configurations will be assessed for the year prior to the start of FlexDGrid;
    c. The corresponding make and break fault levels for the different operational configurations will be calculated.
    d. Variation of fault level with time and fault level duration curves will be generated and the potential additional capacity to connect generation through ‘connect and manage’ connection agreements will be quantified.

2. Depending on the output of the sensitivity analysis work, the time-variance of other parameters, to which fault level calculations are particularly sensitive, will be investigated. This work will underpin the comparison of monitored and modelled fault level values.

4.4.3 Knowledge capture and learning dissemination methods

A report on the benefits delivered through the increase in granularity of fault levels along HV feeders will be given in SRDC-4. In addition, this report will consider the time granularity (frequency) of fault level assessments through daily, weekly and seasonal variations. This report aims to record fault level assessment metrics (fault level values and study times) and to evaluate the relationship between fault level along the 11kV distribution feeders and distance from the primary substation.

4.5 How fault level will be measured and monitored

4.5.1 Description of the fault level measurement trialling process

In order to explore the practical measurement of fault level and compare the measured and modelled fault level results, the following process has been developed:

1. Gather fault location data for the trial area from the three years previous to the start of FlexDGrid;
2. Analyse the data to establish where, in the network, faults are statistically most likely to occur;
3. Conduct surveys to assess where fault level measurement equipment should be located (this is likely to be within primary substations);
4. Install measurement equipment and gather measurement data to determine the type, magnitude and location of faults within the trial area;
5. Simulate the type, location and magnitude of the fault;
6. Compare measured and modelled fault level values.

4.5.2 The following trialling process has been proposed

In order to explore the practical monitoring of fault level and compare the monitored and modelled fault level results, the following process has been developed:

1. Determine where fault level ‘hotspots’ occur in the network;
2. Characterise the network by conducting site surveys, installing background monitoring equipment and determining the need for ‘active’ monitoring and substation suitability;
3. Implement ‘active’ monitoring systems if required;
4. Comparison of ‘actual’ fault level with calculated fault levels from network model.

4.5.3 Knowledge capture and learning dissemination methods

The site survey and detailed design outputs of this process are reported in SDRC-2. The results of the trials of this process will be reported in SRDC-10.

4.6 How fault level issues will be mitigated

4.6.1 Description of trialling process:

The following process has been proposed in order to trial the performance and effectiveness of fault level mitigation technologies:

1. Determine where fault level 'hotspots' occur in the network through fault level indices and fault level heat maps;
2. Conduct substation surveys and suitability assessments;
3. Model fault level mitigation technologies based on requests for information from manufacturers and typical fault level mitigation technologies that will be installed within the scope of FlexDGrid;
4. Determine the most appropriate fault level mitigation technologies for deployment at different substations within the trial area, the results of which will be reported within SDRC-3;
5. System-wide implementation and use of voltage conditioning units to control voltage excursions;
6. Implement mitigation technologies as specified in SDRC-2 and SDRC-3;
7. Monitor performance of mitigation technologies against the original specification and compare the performance with simulated network models.

4.6.2 Knowledge capture and learning dissemination methods

The site survey and detailed design outputs of this process are reported in SDRC-2. The methodology to determine the most appropriate fault level mitigation technologies will be reported in SDRC-3 and results of the trials of this process will be reported in SRDC-10.

4.7 How novel commercial frameworks will be developed

4.7.1 Description of trialling process:

It is proposed that novel commercial frameworks are trialled using the following process:

1. Base-line the number and capacity of DG connections that could trigger network reinforcement due to fault level issues, quantify case study connection costs and the time to connect DG to the network, quantify the projected energy production associated with different types of connection, quantify the change in losses associated with different types of connection, quantify the potential carbon reductions that could be achieved, quantify the expected change in CIs and CMLs;
2. Use the metrics defined in step 1 to determine the types of connection offers based on modelling of fault levels;
3. Use the metrics defined in step 1 to determine the types of connection offers based on monitoring of fault levels;
4. Use the metrics defined in step 1 to determine the types of connection offers based on mitigation of fault levels;
5. Use the metrics defined in step 1 to determine the types of connection offers based on a combination of modelling, monitoring and mitigation.

4.7.2 Knowledge capture and learning dissemination methods

A report on the trialling of novel commercial frameworks will be developed in SDRC-11.

5 Workshop on EFLA processes

5.1 Questionnaire

A pre-workshop questionnaire was submitted to all GB DNOs, as given in Appendix B-1. The objective of the questionnaire was to gain an understanding of:

- Consistency of application of fault level calculation standards at 11kV or 6.6kV and associated upstream / downstream voltages (IEC 60909, ER G74 and ETR 120);
- The assumptions used by DNOs in applying fault level calculation standards;
- The validity of applying these assumptions, both now and in the future (for example with the anticipated increase in levels of synchronous generation and LV-connected heat pumps);
- The merit in proposing an industry-wide review of fault level calculation standards.

Questionnaire responses were received from DNOs representing eight GB licence areas. The collated questionnaire responses are given in Appendix B-2.

5.2 Analysis of initial questionnaire responses

All respondents agreed that there is merit in an industry-wide review of fault level standards, in particular ER G74. This is because ER G74 is over 20 years old and generator technologies have changed since the standard was developed (DFIGs, generators with fully-rated converters). Therefore, a common methodology for modelling new generation types would be useful. Fault level is a growing concern with in-house approaches now being developed to incorporate embedded generation within ER G74 / IEC 60909 calculations. Thus a consistent approach in applying the standards could help to connect generation and demand customers more quickly and cost-effectively to the distribution network. It was also highlighted that it would be beneficial to assess results and present connection assessment processes from other DNOs.

Work has already been done in the ASG / OSG X/R group of the ENA to produce a test network. This work was carried out a number of years ago and some of the findings may have been implemented. However, the output of this work may not have been widely disseminated within the various DNO organisations.

The following potential limitations have been encountered with ER G74:

1. The different methods available for calculating fault level can give very different results, for example depending on the X/R ratio selected;
2. ER G74 provides a general consistent approach for voltage levels at 33kV and above. However, difficulties are encountered when applying ER G74 at HV levels;
3. Elements of ER G74 and ETR 120 may need updating and expanding to add further clarifications.

Computer simulations, based on ER G74, are predominantly used amongst DNOs to calculate HV fault levels. However, IEC 60909 hand calculations are used to support and supplement the computer simulation results.

A variety of software packages are used by DNOs to conduct fault level studies, including PSS/E, IPSA and DINIS. The extent of the EHV (132kV, 66kV, 33kV) and HV (11kV and 6.6kV) network models varies significantly between DNOs:

- In some licence areas, 33kV, 11kV and 6.6kV networks are modelled in detail with 132kV (slack busbar) connections;
- Separate models are used by some DNOs for the EHV network to HV primary busbars and from HV primary substation busbars to corresponding HV distribution networks;
- Some DNOs model the electricity network from the National Grid supergrid transformers (SGTs) to the 11kV / 6.6kV primary substation busbars;

Where there are interfaces between the different software packages used to model the electricity network, a mismatch in fault level values has been reported and represents a source of uncertainty in terms of 'actual' fault level values.

The following software limitations have been reported:

1. Some software packages do not allow the user to vary the time constants for the sub-transient and transient components of the fault level response;
2. Limited guidance is available for the modelling of power electronic devices: doubly-fed induction generators (DFIGs), photovoltaic generation (PV), static compensators (STATCOMs).
3. The A.C. decrement of fault level can lead to challenges with modelling plant with very short A.C. time constants.

In some DNO licence areas, two models are now being used to simulate the make fault levels and break fault levels respectively. This can lead to issues with switching between different models and ensuring that the correct generator / load models are selected.

The following assumptions are used for modelling distributed generation:

1. In general, devices with power electronic interfaces are currently modelled with a synchronous generator equivalent.
2. At 33kV, distributed generation is modelled within the 33kV network;
3. At 11kV / 6.6kV, some DNOs model the distributed generation within the 11kV network model, whilst some DNOs model the generation as an equivalent source in the EHV model;
4. At 0.4kV, some DNOs model distributed generation as an equivalent in the EHV model, some DNOs model the generation at a mixture of voltage levels and some DNOs do not model LV-connected generation.

Some DNOs expressed concern with the data for generation connection studies since it can be difficult to obtain detailed technical data from customers. Also, concern was expressed regarding the need to model some generation sources with an equivalent synchronous generator, rather than with a model of the generator type itself.

A variety of approaches are used by DNOs to model the fault level contribution of network general load. The views expressed by different DNOs, regarding the accuracy of the general load contribution to fault level, vary significantly: Some DNOs feel the values provided in ER G74[1] are still fit-for-purpose, some DNOs are unsure and some DNOs feel it is unclear whether the values are still representative of today's loads. There is an overall discrepancy in opinion amongst DNOs regarding this area of fault level modelling. In addition, the view was expressed that it is unclear at which point DNOs should move from HV to LV load modelling.

The safety margins between calculated fault levels and switchgear ratings vary significantly between DNO licence areas. From the questionnaire responses received, the safety margin range is 0% - 10%. Short-term paralleling, which potentially allows fault levels to exceed switchgear ratings, is tolerated by some DNOs under strictly controlled conditions.

The number of uneconomic connections due to fault level is generally unknown because, in most cases, DNOs do not find out why customers choose not to proceed with developing projects.

5.3 Workshop overview

A DNO consultation workshop took place on Thursday 2 May 2013 at the IET Birmingham. The aims of the workshop were to raise awareness of FlexDGrid, to develop networks amongst the DNO community, to provide the forum for knowledge sharing and to assess the merits of processes to enhance DNOs' knowledge of fault level through collaboration. The various workshop preparation documents are given in Appendix C, including the letter of invitation sent to all GB DNOs, the workshop agenda and the workshop facilitation plan. The presentations that were delivered at the workshop to introduce the FlexDGrid project and disseminate initial findings from the DNO questionnaire are given in Appendix D. Photographs of the workshop in action are given in Figures 8a and 8b.

Figures 8a and 8b – The first FlexDGrid workshop in action, delivering a collaborative forum for DNO discussion and knowledge sharing

[1] ER G74: "Where measured values are not available, the following indicative allowances can be used for calculating the initial three-phase symmetrical RMS short-circuit current contribution at 33kV busbar from the asynchronous motors in the general load supplied from that busbar: For load connected to the supply network at (i) low voltage, allow 1.0 MVA per MVA of aggregate low voltage network substation winter demand; (ii) high voltage allow 2.6 MVA per MVA of aggregate winter demand. These contributions relate to a complete loss of supply voltage to the motors.

5.4 Workshop conclusions

The first FlexDGrid DNO consultation workshop provided the forum for DNOs to collaborate and share best practice, as well as voicing concerns and challenges that are currently experienced by DNOs regarding the assessment of fault level within HV electricity networks. Building on the questionnaire responses the following conclusions were reached:

1. Clarifications on the application of ER G74 to HV electricity networks would be beneficial to the DNO community;
2. A comprehensive sensitivity analysis of HV electricity network fault levels to input parameters would provide useful learning for DNOs;
3. An open source database of generation / motor plant types would be beneficial for dealing with missing / inconsistent data from customers;
4. The development of open source fault level mitigation technology models would be of benefit to the DNO community and could allow the capacity to accommodate customers' connections to be readily assessed;
5. At present, single snapshots are used to calculate worst-case fault level values for credible network operating conditions (for example the parallel and split operating configurations of primary substation transformers). The increase in time granularity of fault level assessments would be useful for assessing the potential gains from fault level monitoring in FlexDGrid. However, the potential benefits resulting from fault level monitoring would need to be quantified and outweigh the increased modelling effort required, if this process were to be adopted by other DNOs.
6. Due to the Electricity, Safety, Quality and Continuity Regulations (ESQCR) and health and safety implications, a move towards probabilistic fault level assessments was not deemed to be feasible at this point in time. However, the various DNO representatives saw the potential in introducing 'connect and manage' options for generation and demand customers, on the condition that fault level values would at no point violate switchgear ratings.
7. The need was identified for the present fault level assessment training processes within DNOs to be documented so that staff are given consistent guidance on how to conduct HV fault level assessments. In addition, any enhancements to the HV fault level assessment methodology should be process-driven and readily accessible to the user of the methodology.

5.5 Feedback and evaluation of workshop

5.5.1 What worked well?

The feedback from the workshop attendees was that the workshop succeeded in its knowledge-sharing aims and provided an opportunity, much-welcomed by the DNO representatives, to collaborate. The workshop provided valuable learning by allowing the DNO community to share best practice, raise concerns and express challenges that are currently experienced by DNOs when dealing with HV fault level assessments. Conclusions were drawn from the workshop, which support FlexDGrid's aims in delivering outputs that are relevant and transferrable to other GB DNOs. A dedicated scribe documented the discussions throughout the day and ensured that key discussions, learning points and conclusions were robustly captured.

5.5.2 What lessons were learnt?

Whilst the questionnaire and workshop invitation was disseminated to DNOs six weeks prior to the event, a particular challenge faced at this early stage in FlexDGrid was the engagement with the whole DNO community. This has been analysed and attributed to the following reasons: (i) the delay in the timely receipt of the invitation by the most appropriate representatives within the various DNO organisations; (ii) some DNOs were unable to provide representatives due to prior 'Business as Usual' commitments.

These challenges will be addressed in future workshops by bringing forwards the DNO engagement process and refining the stakeholder mapping process to identify the most appropriate representatives within the various DNO organisations and the route by which these representatives could be approached more directly.

6 Conclusions and recommendations

6.1 Conclusions

6.1.1 Enhanced fault level assessment processes

Six processes have been defined within the initial six-month design period of FlexDGrid:

1. Baseline the consistency of application of present fault level assessment methods;
2. Explore assumptions and parametric sensitivity analysis of present fault level standard calculation methods;
3. Increasing granularity of fault level assessments;
4. Network design and deployment of fault level monitoring technologies;
5. Network design and deployment of fault level mitigation technologies;
6. Connection offers based on novel commercial frameworks.

These processes will be trialled during the course of the FlexDGrid project and the knowledge and learning generated will be reported as the output from the other SDRC deliverables.

6.1.2 How the Birmingham HV electricity network will be used to trial the processes

The scope of work within the SDRC-1 work package has been to develop the Birmingham HV electricity network in order to create the test bed for trialling the enhanced fault level assessment processes. The results of these trials will be reported within future FlexDGrid SDRCs.

The Birmingham HV network model has been developed in PSS/E and integrates the electricity network from the National Grid / WPD electricity network interface to distribution customers connected into the HV / LV electricity networks. The HV networks associated with three primary substations within Birmingham's city centre have been modelled, which increases the granularity of fault level assessments and has potential to introduce time and cost savings into the connection assessment process when future customers' connections are considered. These savings will be quantified as an output of FlexDGrid in SDRC-10.

The development of an integrated electricity network model overcomes some of the challenges expressed by the DNO community in terms of fault level mismatch between different modelling tools at different voltage levels. The selection of the PSS/E modelling package delivers functionality which (i) makes the transition towards the electricity network data being stored in a single database, reducing the maintenance requirements associated with data stored in multiple databases; (ii) allows the user to vary fault level assessment times for make and break calculations; (iii) allows models of fault level mitigation technologies (for example fault current limiters) to be readily integrated; and (iv) supports the development of models that more accurately represent new types of generation and demand connections.

The Birmingham HV electricity network model will be used in the following ways in FlexDGrid:

1. To explore the assumptions associated with fault level calculations and the sensitivity of fault level calculations to input parameters;
2. To quantify the decrement of fault level along HV feeders;

3. To increase the time granularity (frequency) of fault level assessments due to daily, weekly and seasonal variations;
4. To compare actual measured and monitored fault level values with simulated values;
5. To compare mitigated fault level values with data simulated from fault level mitigation technology models; and
6. To quantify the metrics (for example, simulated DG energy production, simulated impact on losses) that will underpin novel commercial frameworks for generation and demand customers.

6.1.3 DNO fault level questionnaire and consultation workshop

A questionnaire was distributed to each GB DNO to base-line the current fault level assessment processes. Based on the initial responses received, representing eight DNO licence areas, there is growing concern regarding the application of fault level standards to HV electricity networks and a general level of inconsistency in approaches for modelling fault level within HV distribution networks at present. Particular areas of concern were identified as (i) the mismatch in fault levels that can occur at the interface between different power system analysis tools and voltage levels; (ii) the representation of new types of generation and demand connection; (iii) the modelling of the contribution of general load to fault level; and (iv) the reporting of the status of electricity network fault levels to Ofgem for consistent evaluation.

A particular challenge faced at this early stage in FlexDGrid was the engagement with the whole DNO community in the consultation workshop. This challenge will be addressed in future workshops by bringing forwards the DNO engagement process and refining the stakeholder mapping process to identify the most appropriate representatives within the various DNO organisations and the route by which these representatives should be approached.

The first FlexDGrid DNO consultation workshop provided a welcome opportunity for DNOs to collaborate and share best practice, as well as voicing concerns and challenges that are currently experienced by DNOs regarding the assessment of fault level within HV electricity networks. Building on the questionnaire responses the following conclusions were reached:

1. Clarifications on the application of ER G74 to HV electricity networks would be beneficial to the DNO community;
2. A comprehensive sensitivity analysis of HV electricity network fault levels to input parameters would provide useful learning for DNOs;
3. An open source database of generation / motor plant types would be beneficial for dealing with missing / inconsistent data from customers;
4. The development of open source fault level mitigation technology models would be of benefit to the DNO community and could allow the capacity to accommodate customers' connections to be readily assessed;
5. At present, single snapshots are used to calculate worst-case fault level values for credible network operating conditions (for example the parallel and split operating configurations of primary substation transformers). The increase in time granularity of fault level assessments would be useful for assessing the potential gains from fault level monitoring in FlexDGrid. However, the potential benefits resulting from fault level monitoring would need to be

quantified and outweigh the increased modelling effort required, if this process were to be adopted by other DNOs.

6. Due to the Electricity, Safety, Quality and Continuity Regulations (ESQCR) and health and safety implications, a move towards probabilistic fault level assessments was not deemed to be feasible at this point in time. However, the various DNO representatives saw the potential in introducing 'connect and manage' options for generation and demand customers so long as fault levels at no point violate switchgear ratings.
7. The need was identified for the present fault level assessment training processes within DNOs to be documented so that staff are given consistent guidance on how to conduct HV fault level assessments. In addition, any enhancements to the HV fault level assessment methodology should be process-driven and readily accessible to the user of the methodology.

6.2 Recommendations

The following recommendations have resulted from the work conducted to fulfil this Successful Delivery Reward Criterion:

1. The processes identified and detailed in this SDRC report should be followed to inform the development of enhanced fault level assessments.
2. A follow-on workshop should be organised to report back the findings from base-lining the HV fault level assessment processes and sensitivity analysis studies. The implementation of this recommendation is within the scope of the FlexDGrid project.
3. It is not clear how the values reported in ER G74 for modelling the fault contribution of asynchronous motors forming part of the general load were originally derived and if these values are still representative of the present distribution network load demand mix. ER G74 reports these values as 'indicative allowances' where measured values are not available. In order to address this issue it is recommended that:

    a. Load mixes (demand types) and associated fault level in-feed values should be investigated in more detail to understand the variation of fault in-feed with different combinations of load. An initial implementation of this recommendation is within the scope of the FlexDGrid project;
    b. In situations where calculated fault levels are approaching switchgear ratings, the deployment of fault level monitoring equipment should be considered.

4. An industry-wide review of ER G74 would be of benefit to the DNO community with clarifications and guidance on the consistent application of ER G74 to HV distribution networks. Whilst FlexDGrid will aim to inform recommended changes to EA ETR 120 (the application guide to ER G74), the industry-wide review of ER G74 is outside of the scope of the FlexDGrid project.
5. Traditionally, DNOs have trained staff to carry out connection studies 'on-the-job' and through supervised instruction. It is recommended that DNOs formally document their connection study process so that HV fault level assessments are conducted consistently, assumptions are well-understood and engineering judgements can be made more confidently.

6. DNOs should consider the development of integrated electricity network models, whereby both EHV and HV networks are modelled within the same power system analysis software package. This removes the need for equivalent models, which have the potential to introduce sources of error and uncertainty.
7. DNOs should confirm whether or not there is a need to de-rate HV switchgear in line with the CIGRE 304 recommendation. The confirmation of the need to de-rate HV switchgear by other GB DNOs is outside the scope of the FlexDGrid project.

7 References

[1] Ofgem, *Project Direction ref WPD/FlexDGrid – Advanced fault level management in Birmingham*, [on-line], 21 December 2012.

[2] International Electrotechnical Commission, *International Standard 60909 "Short-circuit currents in three-phase a.c. systems"*, Switzerland, July 2001.

[3] Energy Networks Association, *Engineering Recommendation G74 "Procedure to meet the requirements of IEC 909 for the calculation of short-circuit currents in three phase AC power systems"*, 1992.

[4] Energy Networks Association, *Engineering Technical Report 120 "Calculation of fault currents in three-phase AC power systems (Application Guide to Engineering Recommendation G74)*, 1995.

Appendices

Appendix A - Successful Delivery Reward Criteria Memo

Appendix B - DNO pre-workshop questionnaire

- B1 - Pre-workshop questionnaire
- B2 - Collated questionnaire responses

Appendix C - FlexDGrid DNO consultation workshop preparation documents

- C1 - Workshop letter of invitation
- C2 - Workshop agenda

Appendix D - FlexDGrid DNO consultation workshop presentations

- D1 - FlexDGrid Advanced Fault Level Management in Birmingham
- D2 - FlexDGrid Initial survey results
- D3 - Workshop feedback form

Appendix E - Modelling methodology for integrating EHV and HV network models

Appendix A – Successful Delivery Reward Criteria Memo

WESTERN POWER DISTRIBUTION
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MEMO

Date:	**24.03.2013**
Version:	**V001**
To:	**FlexDGrid Project Staff**
Copy to:	**Steering Committee**
From:	**Samuel Jupe, Parsons Brinckerhoff**
Title:	**FlexDGrid Successful Delivery Reward Criteria**
Purpose:	**Update and clarify the FlexDGrid SDRC based on Ofgem's Project Direction**

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1. Introduction

This briefing note defines the Successful Delivery Reward Criteria (SDRC) for the FlexDGrid project, based on the FlexDGrid Full Submission Pro-forma (FSP) and Ofgem's Project Direction [1]. The 11 SDRCs (detailed in Section 2) represent key milestones within the FlexDGrid project and each criterion has associated deliverables for WPD, Ofgem and other GB DNOs.

2. Successful Delivery Reward Criteria

Successful Delivery Reward Criteria	**Evidence**
SDRC-1	
<u>Specific:</u> Develop an Enhanced Fault Level Assessment process. **<u>Measurable:</u>** Workshop and report on the Enhanced Fault Level Assessment process. **<u>Achievable:</u>** An initial Enhanced Fault Level Assessment process has been developed as part of the bid from the Initial Screening Process to Full Submission Pro-forma. **<u>Relevant:</u>** This criterion corresponds to the delivery of Method Alpha (Enhanced Fault Level Assessment). **<u>Timely:</u>** The Enhanced Fault Level Assessment process will be developed by 1 June 2013, with the publication being available to other DNOs interested parties thereafter.	1. Using the Birmingham HV electricity network to trial the Enhanced Fault Level Assessment process. 2. A workshop with other DNOs to discuss the Enhanced Fault Level Assessment process. 3. A publication on the Enhanced Fault Level Assessment process to be shared with other DNOs.

SDRC-2	
Specific: Confirmation of the project detailed design. **Measurable:** Lead to the confirmation of five substation sites for the inclusion of Fault Level mitigation technologies and ten sites for Fault Level monitoring. **Achievable:** Design developed with partners. Builds on the outputs of Criteria 1 and 2. **Relevant:** Delivery of Method Beta and Method Gamma. Design will confirm the capability of equipment being installed, the connection requirements, location and any modifications needed to the HV network to allow the equipment to be connected. **Timely:** The project detailed design will be developed by 1 June 2013.	1. Confirmation and justification of the five substation sites selected for Fault Level mitigation and ten substation sites selected for Fault Level monitoring. 2. Availability of detailed design documents to other DNOs.

SDRC-3	
Specific: Hold a workshop, inviting all GB DNOs and other interested parties. **Measurable:** The workshop will (i) provide details of the emerging learning of Method Alpha and Method Beta and the proposed methodology for Method Gamma; and (ii) provide GB DNOs and other interested parties the opportunity to provide feedback on the proposed methodology for Method Gamma, based on the emerging learning of Method Alpha and Method Beta. **Achievable:** Date of workshop set to allow time for sufficient planning and for learning to be emerging from Method Alpha and Method Beta. **Relevant:** Workshop will provide outputs feeding into all three project Methods **Timely:** Workshop will take place by 31 October 2013.	1. Hold a workshop with other GB DNOs by 31 October 2013. 2. Written responses to the consultation from each GB DNO submitted with the report that is required to fulfil Condition Precedent 3(A) "Methodology of Method Gamma" (See Section 3 for further details) of 3.

MEMO

SDRC-4	
Specific: Simulation and application of the Enhanced Fault Level Assessment process to demonstrate what can be achieved with customers' connections. **Measurable:** Quicker response to customers' connections applications. **Achievable:** Simulation and application of Enhanced Fault Level Assessment process to Birmingham Primary Substations carried out as part of the bid from ISP to FSP. **Relevant:** Delivery of Method Alpha (Enhanced Fault Level Assessment). **Timely:** The Enhanced Fault Level Assessment process will be applied by 1 December 2013, with potential adoption into BaU by the end of the project.	1. A developed and tested Enhanced Fault Level Assessment process with endorsement from WPD planning and design engineers. 2. Quicker response to customers' connections applications. 3. Characterisation of the substations to determine the suitability of potential Fault Level Mitigation Technologies. 4. Open source fault Level Mitigation Technology models. 5. Quantification of additional capacity that will be unlocked to accommodate future customers' connections.

SDRC-5	
Specific: Delivery and Authority approval of report before issuing Invitation to Tender for fault level mitigation technologies. **Measurable:** Production of report to fulfil Condition Precedent 3(B) “Value for Money” (See Section 3 for further details). **Achievable:** Demonstration to Ofgem of procurement processes that WPD already has in place. **Relevant:** Deliverable associated with Method Gamma. **Timely:** Due by 31 December 2013.	1. Delivery of a report to the Authority to fulfil Condition Precedent 3(B) “Value for Money” (See Section 3 for further details). 2. Authority approval that the competitive procurement process will be undertaken in a way that will deliver best value for money for GB customers.

SDRC-6	
Specific: Delivery and Authority approval of report before signing contracts for fault level mitigation technologies. **Measurable:** Production of report to fulfil points (i) to (iv) of Condition Precedent 3(A) "Methodology of Method Gamma" (See Section 3 for further details). **Achievable:** Deliverable builds on Requests for Information (RfIs) developed at the bid stage of the FlexDGrid project. **Relevant:** Deliverable associated with Method Gamma. **Timely:** Due by 31 December 2013.	1. Delivery of a report to the Authority covering points (i) to (iv) of Condition Precedent 3(A) "Methodology of Method Gamma" (See Section 3 for further details). 2. Authority approval that there is sufficient evidence that GB DNOs consider that proceeding to Method Gamma would provide the learning outlined in the Full Submission pro-forma.

SDRC-7	
Specific: Installation and open-loop (non-network controlling) tests of Fault Level monitoring equipment. **Measurable:** Installation of equipment in ten Primary Substation sites with open-loop testing results being disseminated. **Achievable:** Positioning to deliver monitoring through successful testing in previous IFI and Tier-1 projects. Identification of alternative monitoring options through thorough design phase. **Relevant:** This criterion corresponds to the delivery of Method Beta. **Timely:** Installation and trialling of equipment by 31 December 2015.	1. Installation of equipment in ten Primary Substation sites. 2. Open-loop (non-network controlling) test results being disseminated.

SDRC-8	
Specific: Installation and open-loop (non-network controlling) tests of Fault Level mitigation equipment. **Measurable:** Installation of equipment in five Primary Substation sites with open-loop testing results being disseminated. **Achievable:** Positioning to deliver Fault Level mitigation technologies through successful testing in previous IFI, ETI and Tier-1 projects. Identification of alternative mitigation options through thorough design phase. **Relevant:** This criterion corresponds to the delivery of Method Gamma (Fault Level Mitigation Technologies). **Timely:** Installation and trialling of equipment by 31 December 2016.	1. Installation of equipment in five Primary Substation sites. 2. Dissemination of open-loop (non-network controlling) test results and system-level learning.

SDRC-9	
Specific: Closed-loop (network controlling) tests of Fault Level monitoring and mitigation equipment. **Measurable:** Control of network and quantification of gains (for example Fault Level reduction, security of supply, increased customer connection capacity). **Achievable:** Building through the learning of open loop testing. Valuable learning output, independent of customer connection applications. **Relevant:** Criterion corresponds to the delivery of Method Beta and Method Gamma. **Timely:** Installation and trialling of equipment by 31 December 2016.	1. Dissemination of closed-loop (network controlling) test results and system-level learning.

SDRC-10	
Specific: Analysis of test results, evaluating and quantifying the benefits of the Solution and applicability to GB HV electricity networks. **Measurable:** Knowledge dissemination, publication of reports, generation of new Policy documents. **Achievable:** Appropriate resource to deliver learning outcomes and Policy document development through WPD internal resource, PB and the University of Warwick. **Relevant:** Provides project output and the evaluation of Method Alpha, Method Beta and Method Gamma. **Timely:** Knowledge dissemination, publication of reports, generation of new Policy documents to be achieved by 31 December 2016.	1. Knowledge dissemination: a. Network data being made available. b. Six-monthly progress reports submitted to Ofgem throughout project. c. Eight industry conferences attended and presented by December 2016. d. LCNF Annual Conference. 2. Publication of reports.

SDRC-11	
Specific: Development of novel commercial frameworks with generation and demand customers **Measurable:** Enter into novel commercial contracts and inform policy changes through contract trials. **Achievable:** The novel commercial frameworks will be developed by WPD's Connections Policy Team in conjunction with Parsons Brinckerhoff. **Relevant:** The novel commercial contracts will deliver to customers the benefits of Method Alpha (Enhanced Fault Level Assessment process), Method Beta (Real-time Management) and Method Gamma (Fault Level Mitigation Technologies) **Timely:** Novel commercial frameworks will be developed, trialled and tested by the end of the project.	1. Novel commercial frameworks are readily available for use in customers' connection applications within the project trials. 2. Production a `Connections Options' document and dissemination to other DNOs, customers and other interested parties.

3. Condition Precedents

A) Methodology of Method Gamma

The Funding DNO must, prior to signing binding contractual agreements for the fault level mitigation technologies, as described in Section 2 (Project Description), provide a report including the following information:

i. The progress, including learning to date, of Method Alpha – Enhanced Fault Level Assessment and Method Beta – Real-time Management, as described in Section 2 (Project Description).
ii. A proposed methodology for Method Gamma – Fault Level Mitigation Technologies, as described in Section 2 (Project Description). This must include a functional description of the five proposed fault level mitigation technologies and five proposed substations. It must also include an explanation of why these technologies and substations have been chosen, based on the learning described in (i).
iii. A description of the process the Funding DNO has followed to consult with other GB DNOs on whether, based on the information provided in (i) and (ii), proceeding to Method Gamma – Fault Level Mitigation Technologies would provide the learning outlined in the Full Submission pro-forma. This must include a written consultation.
iv. The written responses received from other GB DNOs to the written consultation described in (iii) together with summaries of all other feedback received.

The Funding DNO may not access any funds from the Project Bank Account for the procurement process for the fault level mitigation technologies or for the fault level mitigation technologies until the Authority is satisfied that there is sufficient evidence provided through feedback in (iv) that GB DNOs consider that proceeding to Method Gamma would provide the learning outlined in the Full Submission pro-forma.

B) Value for money

Notwithstanding A) above, the Funding DNO may commence the procurement process for fault level mitigation technologies at its own cost.

The Funding DNO must, prior to issuing an Invitation to Tender for fault level mitigation technologies, provide a report to the Authority which demonstrates that the Funding DNO will procure fault level mitigation technologies in a way that will deliver best value for money.

The Funding DNO may not issue the Invitation to Tender for fault level mitigation technologies until the Authority is satisfied that the competitive procurement process will be undertaken in a way that will deliver best value for money.

4. References

[1] Project Direction ref: WPD/ FLEXDGRID – Advanced Fault Level Management in Birmingham, 21 December 2012. Available at: http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/stlcnp/year3/flexgrid/Documents1/FLEXDGRID%20Project%20Direction.pdf

Appendix B – DNO pre-workshop questionnaire

Appendix B1 – Pre-workshop questionnaire

DNO Questionnaire on the consistent application of fault level assessment standards

DNO name ....

DNO network area ....

DNO point of contact for this/further information:-

Name ....

Function/designation ....

Telephone number ....

Email address ....

Please complete and return your response to John Goodall (goodallj@pbworld.com) at PB by **Friday 19 April 2013**

No	Query	Response
1.1	**Is there merit in an industry-wide review of fault level calculation standards?**	**Yes/no/unsure**
1.2	**Please explain why / why not.**	
1.3	**Would the establishment of a simple but comprehensive test network be useful in order to gain confidence in software and /or methods employed?**	**Yes/no**
1.4	**Would you welcome clarifications to make the interpretation and application of ER G74 more consistent?**	**Yes/no**
1.5	**Please explain your answer to (1.4)**	

2.1	**Are you assessing 11 kV or 6.6 kV fault levels by applying computer simulations?**	**Yes/no/to some extent**
2.2	**If so, what software is used?**	
2.3	• **What is the extent of the model** **(e.g. 132 kV equivalent infeed to 11 or 6.6 kV primary substation busbars or** **132 kV equivalent infeed to 11 or 6.6 kV ring main units etc)**	
2.4	• **Does EA ER G74 (1982) [and/or EA ETR 120 (1995)] influence the simulation?**	**Yes/no/to some extent**

2.5	• **Briefly describe the influential factors**			
2.6	• **Please define any specific problems encountered with the application of aspects of ER G74 (and/or ETR 120)**			
2.7	• **Is the fault time a variable set by the software user (e.g. 10 ms make, 100 ms break)?**	**Yes (list make and break times)/no**		
2.8	• **Is distributed generation modelled?**	**At 33 kV** **Yes/no**	**At 11 or 6.6 kV** **Yes/no**	**At 0.4 kV** **Yes/no**
2.9	• **How is inverter-connected generation modelled?**			
2.10	• **Is load fault contribution modelled?**	**Yes/no**		
2.11	**If so,** ○ **How is section 9.5 of ER G74 applied at busbars other than 33 kV?**			
2.12	○ **Are significant numbers of HV-connected motors modelled (either individually or as groups)?**	**Yes/no**		
2.13	○ **Are you satisfied that load fault contribution is of acceptable accuracy?**	**Yes/no/unsure**		
2.14	• **What is the extent of modelling of circuit susceptance, e.g.33 kV cables, 33 kV lines, etc.**			
2.15	• **What is the extent of modelling of power factor correction, e.g. 33 kV SVC etc.**			
2.16	• **For circuit resistances (e.g. transformers, cables and overhead lines) are hot AC values applied or cold DC?**			
2.17	• **Are transformer off-nominal voltages and the associated effect on impedance modelled?**	**Yes/no**		
2.18	• **Are changes in transformer impedance with tap position modelled?**	**Yes/no**		
2.19	• **For generator modelling, is the saturated or the unsaturated impedance used?**	**Saturated/unsaturated**		
2.20	• **In pre-fault load flow studies, what demand condition is modelled?**	**Max/other**		
2.21	• **Does the DNO's Long Term Development Statement include the results of the above modelling /computer simulation / studies?**	**Yes/no**		

Questions continued overleaf

3.1	**Are you assessing fault levels by applying hand / spreadsheet calculations?**	**Yes/no**
3.2	**If so,** • **What is the extent of the system analysed in the calculation** **(e.g. 11 or 6.6 kV primary substation busbars to 11 or 6.6 kV ring main units or** **11 or 6.6 kV primary substation busbars to 0.4 kV busbars)**	
3.3	• **Does IEC 60909 influence the calculation**	**Yes/no/to some extent**
3.4	• **Briefly describe the influential factors**	
3.5	• **Please describe any specific problems encountered with the application of aspects IEC 60909**	
3.6	• **Does the DNO's Long Term Development Statement include the results of the above hand / spreadsheet calculations?**	**Yes/no**

4	**Do you allow a safety margin between calculated fault levels and switchgear fault rating (make and break)?**	**Yes (define margin)/no**

5	**Do you assess fault levels for abnormal operating scenarios e.g. short term paralleling of primary substations etc?**	**Yes (define scenarios)/no**

6	**Is it a requirement that fault levels must be acceptable under all operating scenarios (including short term paralleling)**	**Yes/no**

7.1	**Do you have any issues with data for generation connection studies?**	**Yes/no**
7.2	**Do you update models with as-built generator data after connection?**	**Yes/no**

8	**Is fault level currently or expected to be a constraint on the connection of distributed generation?**	**Yes/no**

9	**How many connections do you estimate have been uneconomic due to fault level reinforcement needs in the past 5 years?**	

Appendix B2 – Collated questionnaire responses

Number	Query	Response
1.1	**Is there merit in an industry-wide review of fault level calculation standards?**	**Yes/no/unsure**
		Yes (All respondents)
1.2	**Please explain why / why not.**	
		It will be beneficial for an engineer to assess results from other bodies. Consistency across DNOs and for regulatory reporting G74 was written some 20 years ago and generator technologies that exist now are quite different to those that existed then e.g. DFIGs, fully inverted generators. Some common methodology of modelling these new technologies could be useful. G74 was written some 20 years ago and generator technologies that exist now are quite different to those that existed then e.g. DFIGs, fully inverted generators. Some common methodology of modelling these new technologies could be useful. Consistent approach from DNOs will help demand and generation customers.
1.3	**Would the establishment of a simple but comprehensive test network be useful in order to gain confidence in software and /or methods employed?**	**Yes/no**
		Yes - worth noting that it's been done before in the ASG/OSG X/R sub-group (ENA). Any learning points from that exercise may have already been implemented.
1.4	**Would you welcome clarifications to make the interpretation and application of ER G74 more consistent?**	**Yes/no**
		Yes (All respondents)
1.5	**Please explain your answer to (1.4)**	
		The method options to calculate fault level could give very different answers e.g. X/R ratio. To ensure accurate modelling and consistency between analysis applications We're comfortable with the way that we apply G74, but we recognise that there may be elements that may need updating or expanding. General consistent approach for higher voltage networks (>=33kV) but G74 difficult to apply at secondary network level.
2.1	**Are you assessing 11 kV or 6.6 kV fault levels by applying computer simulations?**	**Yes/no/to some extent**
		Yes (All respondents)
2.2	**If so, what software is used?**	IPSA, PSS/E?
		DINIS for HV network simulations.
2.3	• **What is the extent of the model (e.g. 132 kV equivalent infeed to 11 or 6.6 kV primary substation busbars or 132 kV equivalent infeed to 11 or 6.6 kV ring main units etc)**	
		From National Grid SGTs to 11/6.6kV busbars. 33kV equivalent generator at the transmission – distribution interface. Separate models for EHV networks down to HV primary substation bars (IPSA) and HV primary substation bars and corresponding HV distribution networks (DINIS).For the EHV model: NGET week 42 equivalent infeeds used at a transmission voltage (i.e. GSPs – SGTs are modelled. Remaining networks modelled down to 11kV busbars at primaries.For the HV model: Infinite busbar with an impedance modelled on the primary side of primary substation transformers. Modelled through to 33kV, 11kV and 6.6kV networks modelled in detail. Each BSP connected to 132kV slack bar
2.4	• **Does EA ER G74 (1982) [and/or EA ETR 120 (1995)] influence the simulation?**	
		Yes We don't use the G74 package in DINIS.
2.5	• **Briefly describe the influential factors**	
		X/R ratio(DC decay), load fault infeed Takes account of estimated motor contribution therefore returns higher FL result. Based on full DQ axis machine models including saturation, saliency, sub-transient and transient decay and second harmonic effects (extract from IPSA Power website). We calculate sub-transient infeeds at time = 0. G74 equivalent induction motor infeed modelled at each primary substation 11kV or 6.6kV busbars.
2.6	• **Please define any specific problems encountered with the application of aspects of ER G74 (and/or ETR 120)**	
		It will also be helpful to provide guidance of modelling power electronics e.g. DFIG, PV, STATCOM It is only an estimate of possible motor connected load. Not aware of any with IPSA. We don't assume any decrement of the a.c. component of fault current. However, this leads to difficulty with plant with a very short a.c. time constant. None.
2.7	• **Is the fault time a variable set by the software user (e.g. 10 ms make, 100 ms break)?**	**Yes (list make and break times)/no**
		Yes Yes for the IPSA EHV model. For the Yorkshire EHV DINIS models only sub-transient fault-levels are used as a most onerous case. Yes Make --10ms and Break-100ms

Number	Query	At 33 kV	At 11 or 6.6 kV	At 0.4 kV
2.8	• **Is distributed generation modelled?**			
		Yes	Yes	Yes
		Yes	Yes	Yes
		Yes	**Yes as an equivalent in the EHV model**	**Yes, mix of equivalent & actual models.**
		Yes	**Yes as an equivalent in the EHV model**	**Yes as an equivalent in the EHV model**
		Yes	No	No

2.9	• **How is inverter-connected generation modelled?**	
		Obtain fault infeed current characteristics and mimic the fault current by a synchronous machine model. Not modelled accurately. Only model generators above 50kW Mixture – some are modelled as synchronous plant with an equivalent infeed resulting in errors to either make or break duty values. Others are modelled independently for make and break duties – manual switching by user required dependent upon study being undertaken i.e. make or break. Modelled as synchronous plant with an equivalent infeed resulting in errors to either make or As equivalent synchronous model
2.10	• **Is load fault contribution modelled?**	
		Yes Yes in IPSA. Not in the DINIS HV model. Not in DINIS itself, this is calculated in spreadsheet and added to the results.
2.11	**If so,** o **How is section 9.5 of ER G74 applied at busbars other than 33 kV?**	
		In IPSA, equivalent motor was attached to load bar in order to mimic fault infeed. In PSS/E, a DINIS allows the modelling of an equivalent motor representing G74 contribution. Modelled at The contribution is considered at the 33kV bar and inflated based upon an average primary transformer impedance and then added in to the IPSA model at the HV busbar. The contribution is applied at the 33kV bar and inflated based upon the actual impedance between it and the lower voltage busbar. Applied at the HV busbar with appropriate allowance is made for transformer impedance.
2.12	o **Are significant numbers of HV-connected motors modelled (either individually or as groups)?**	
		Yes – grouped based on peak 33/11kV site load Yes as groups No No – some but not many.
2.13	o **Are you satisfied that load fault contribution is of acceptable accuracy?**	
		Yes No, it's unclear whether the values calculated are still representative of the loads calculated today. It's unclear at what point we should move from HV to LV load modelling. unsure
2.14	• **What is the extent of modelling of circuit susceptance, e.g.33 kV cables, 33 kV lines, etc.**	132/66/33kV lines
		No Limited at 132kV, but no data at lower voltages. Included at 132kV, but limited data at lower voltages. Modelled for all circuits. Data forms part of the cable database
2.15	• **What is the extent of modelling of power factor correction, e.g. 33 kV SVC etc.**	
		None. Do not normally have SVC on system except GSP busbars. Modelled where it exists, but there are limited instances, it's also manually adjusted.
2.16	• **For circuit resistances (e.g. transformers, cables and overhead lines) are hot AC values applied or cold DC?**	
		Hot AC values used
2.17	• **Are transformer off-nominal voltages and the associated effect on impedance modelled?**	
		Off-nominal voltages included but fixed transformer impedance. Yes No
2.18	• **Are changes in transformer impedance with tap position modelled?**	
		No not sure
2.19	• **For generator modelling, is the saturated or the unsaturated impedance used?**	unsaturated
		Saturated (unsure) Saturated Saturated Saturated
2.2	• **In pre-fault load flow studies, what demand condition is modelled?**	Max/Min
		Max (All respondents)
2.21	• **Does the DNO's Long Term Development Statement include the results of the above modelling /computer simulation / studies?**	
		No Yes
3.1	**Are you assessing fault levels by applying hand / spreadsheet calculations?**	
		Yes – to compare against plant rating Yes for make duty component. No
3.2	**If so,** • **What is the extent of the system analysed in the calculation (e.g. 11 or 6.6 kV primary substation busbars to 11 or 6.6 kV ring main units or 11 or 6.6 kV primary substation busbars to 0.4 kV busbars)**	
		Assessment of load (inc latent demand) to calculate load related backfeed for make duty calculation. 33kV, 11kV & 6.6kV substation switchgear N/A

3.3	• Does IEC 60909 influence the calculation	
		Yes N/A No
3.4	• Briefly describe the influential factors	
		Unsure N/A G74 philosophy adopted for d.c. component decrement in make duty calculation.
3.5	• Please describe any specific problems encountered with the application of aspects IEC 60909	
		N/A (All respondents)
3.6	• Does the DNO's Long Term Development Statement include the results of the above hand / spreadsheet calculations?	
		No N/A Yes
4	Do you allow a safety margin between calculated fault levels and switchgear fault rating (make and break)?	
		Yes (10% margin) Yes (5% margin) No
5	Do you assess fault levels for abnormal operating scenarios e.g. short term paralleling of primary substations etc?	
		No Yes (outage/load transfer) Yes where required, but not included in LTDS. yes
6	Is it a requirement that fault levels must be acceptable under all operating scenarios (including short term paralleling)	
		Yes No
7.1	Do you have any issues with data for generation connection studies?	
		Yes – collecting accurate data, including generator transformers. Yes. In many cases, it is difficult to obtain detailed technical data from customers. Also, different software/standards give different fault level answers for generators. Yes, generally due to us needing an equivalent synchronous infeed. No
7.2	Do you update models with as-built generator data after connection?	
		Yes for big generations (>5mW). Generic model sometimes were used if risk is low or data was not available. Yes
8	Is fault level currently or expected to be a constraint on the connection of distributed generation?	
		Yes – run city centre 11kV & 6.6kV with bus-section open to limit fault level. Yes This is a standard consideration for connecting customers rather than an expected constraint. Yes – particularly in urban areas of the network.
9	How many connections do you estimate have been uneconomic due to fault level reinforcement needs in the past 5 years?	
		Haven't needed to reinforce network due to fault level. No idea Unknown as we don't find out why customers do not proceed with developing their projects. Not known.

Appendix C – FlexDGrid DNO consultation workshop preparation documents

Appendix C1 – Workshop letter of invitation

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6th Floor
Toll End Road
Tipton
West Midlands
DY4 0HH

Telephone: 0121 623 9459
Mobile: 07894 258 671
Email: jberry@westernpower.co.uk

Dear David,

FlexDGrid Workshop 1: Processes to enhance DNOs' knowledge of fault level
Thursday 2 May 2013, Telford Room, Austin Court, IET Birmingham

The FlexDGrid project kicked-off in January 2013, aiming to develop an improved solution to the problem of the timely and cost-effective integration of customers' generation and demand within urban high voltage (11 kV and 6.6 kV) electricity networks. FlexDGrid is financed through Ofgem's Low Carbon Networks Fund.

FlexDGrid seeks to explore the potential benefits arising from trials of three complementary methods: (Alpha) Enhanced fault level assessments; (Beta) Real-time management of fault level; and (Gamma) Fault level mitigation technologies. The project location is Birmingham.

We would like to invite you to an all-day workshop at the IET, Austin Court, Birmingham on Thursday 2 May 2013, focusing on Method Alpha: Processes to enhance DNOs' knowledge of fault level. Please find attached a provisional workshop agenda.

By **Friday 12 April 2013**, please email wpdinnovation@westernpower.co.uk to confirm your availability to attend the workshop. If you are unavailable, please nominate another person to represent your DNO licence area(s).

At the end of the workshop we expect to have a more in-depth awareness of the methods and assumptions DNOs presently apply to calculate fault levels. We would also like to invite the DNO community's input on processes that could be developed and tested to enhance knowledge of fault level.

Your engagement at the workshop is valuable to us and, by attending the workshop, we offer you the opportunity to meet representatives from other DNOs, sharing knowledge and fault level modelling best practice, in keeping with Low Carbon Networks Fund objectives.

To maximise the potential learning outcomes from the workshop, we would be grateful if you could arrange for the attached pre-workshop questionnaire to be completed by **Friday 19 April 2013**.

Yours sincerely,

Jonathan Berry
Innovation and Low Carbon Networks Engineer

Appendix C2 – Workshop agenda

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AGENDA

Date:	Thursday 2 May 2013
Venue:	Telford Room, Austin Court, IET Birmingham 80 Cambridge St, Birmingham, West Midlands B1 2NP
Project:	FlexDGrid
Meeting Title:	Processes to enhance DNOs' knowledge of fault level
Purpose:	Introduction to FlexDGrid project aims and discussion of processes to enhance DNOs' knowledge of fault level
Attendees:	Various DNO representatives (to be advised)

Provisional workshop agenda:

1.	Arrival and pre-workshop refreshments	10:00 – 10:30
2.	Introduction to FlexDGrid and the project aims / objectives Summary of initial survey results on fault level modelling	10:30 – 11:30
3.	Session 1 – Topic focus: Sharing best practice in modelling fault level	11:30 – 12:45
4.	Lunch	12:45 – 13:30
5.	Session 2 – Topic focus: Exploration of processes to enhance DNOs' knowledge of fault level	13:30 – 14:45
6.	Break	14:45 – 15:00
7.	Summary of workshop results and closure	15:00 – 15:30

DISTRIBUTION: Attendees + FlexDGrid Steering Committee

Appendix D – FlexDGrid DNO consultation workshop presentations

Appendix D1 – FlexDGrid Advanced Fault Level Management in Birmingham

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FlexDGrid

Advanced Fault Level Management in Birmingham

EFLA DNO Workshop
02.05.2013

Jonathan Berry
Innovation and Low Carbon Networks Engineer
FlexDGrid Project Manager

FlexDGrid – What and Why

What are we doing?

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

Why are we doing it?

Facilitating the early and cost effective integration of Low Carbon generation

Why are we doing it now?

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

Scenario	Total annual heat generation (TWh(h)/yr)	Total annual electricity generation (TWh(e)/yr)	Total electricity generation capacity (MW)	Number of homes connected to district heating	Annual carbon emission saving compared to the UK generation mix and gas boilers (kt)
Scenario 1: 10% of homes in Birmingham	0.6	0.4	71.2	41,000	60
Scenario 2: Trial Fault Level Mitigation Technology substations	1.95	1.22	214.5	123,379	180
Scenario 3: 50% of homes in Birmingham	3.3	2.0	356.4	205,000	300
Scenario 4: 50% of homes in the UK	210	131	23,051	13,258,500	19370
Scenario 5: 140 substations in the UK with Fault Level Mitigation Technologies	54.7	34.2	6,006	3,454,601	5050

FlexDGrid - Overview

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

Enhanced Assessment

- Enhanced network models
- Detailed understanding of network Fault Level

Management

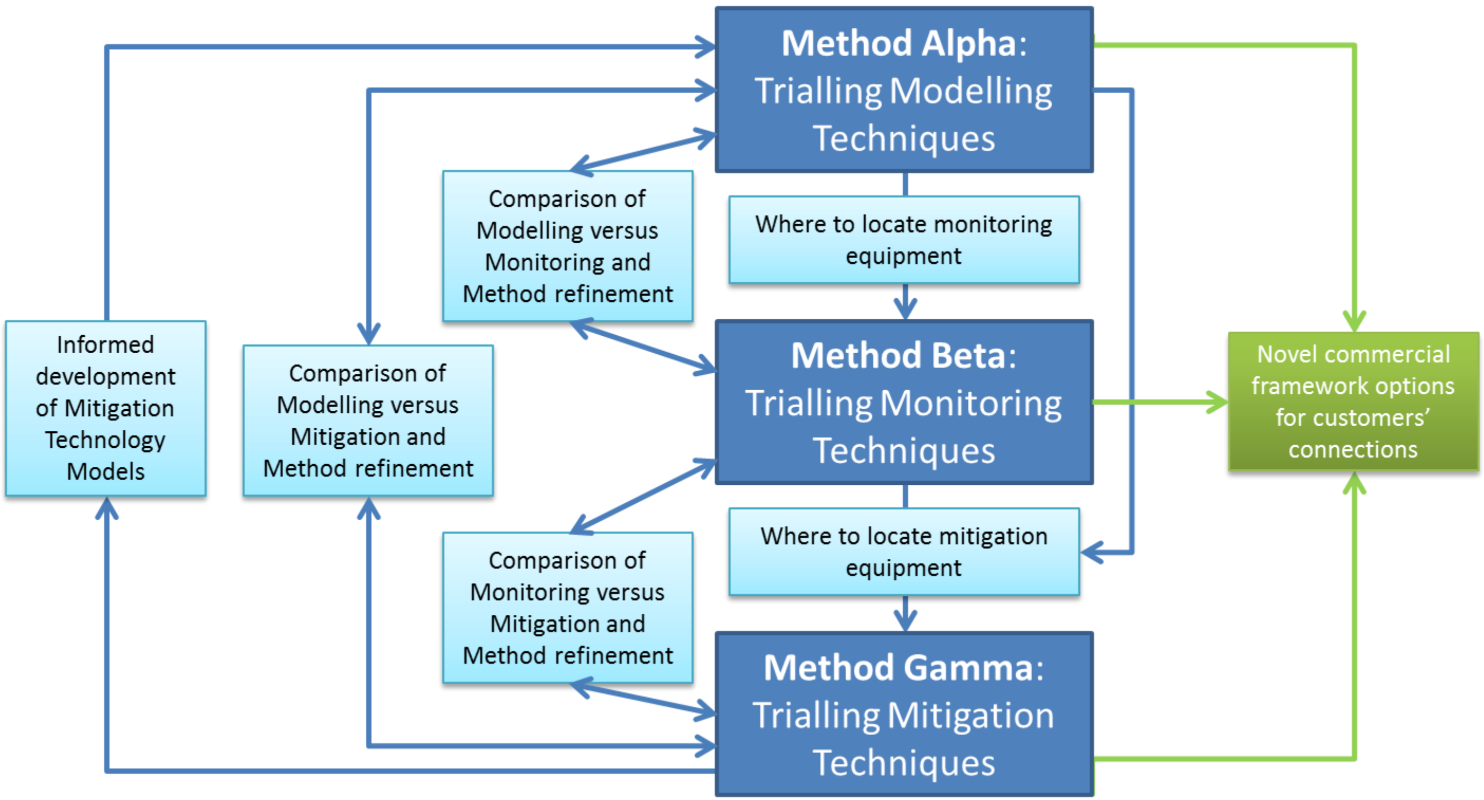
- Monitoring Fault Level (Steady-state)
- Measuring Fault Level (Faulted-state)
- Verify/Update network models

Mitigation

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

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

FlexDGrid Integrated Method Approach



Key:

- Output benefit of trialling all three Methods in one project (Technical)
- Output benefit of trialling all three Methods in one project (Commercial)

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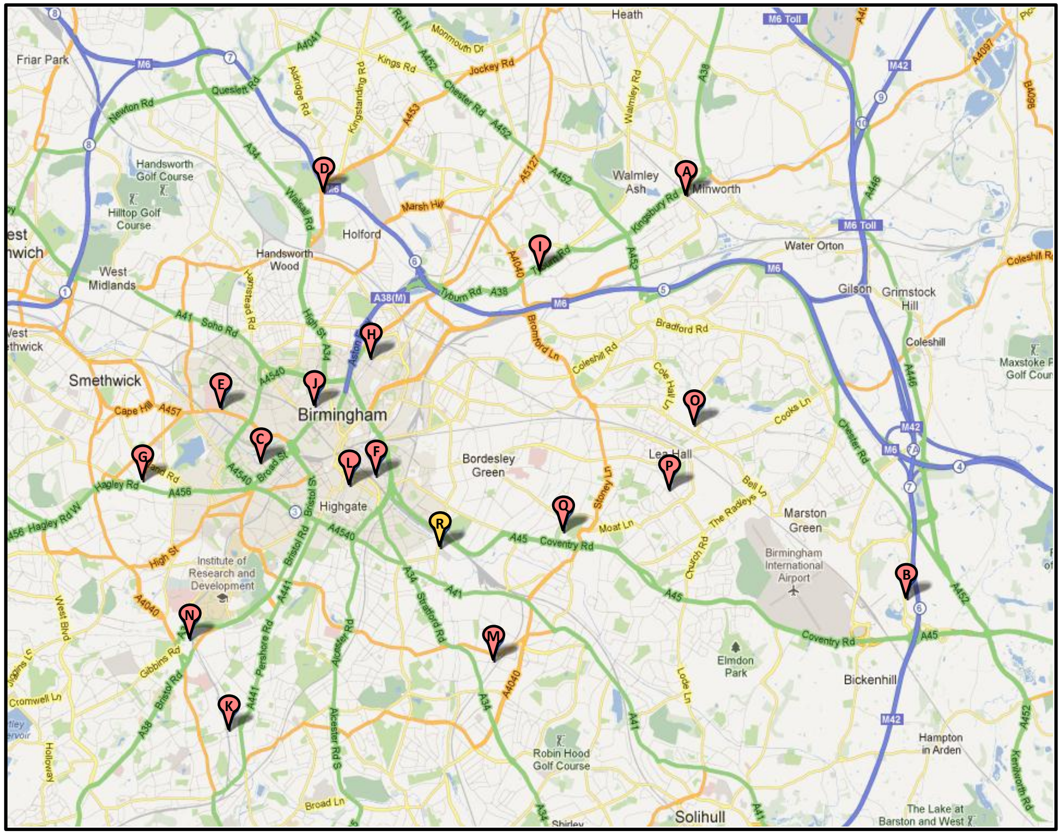
FlexDGrid – Where

Potential Primary Substations to be used in the Trials



map data © 2012 Google

Methods

Alpha – Develop enhanced network model for all of Birmingham

Beta – Install FL Monitoring and Measurement in 10 Substations

Gamma – Install FL Mitigation Technologies in 5 of the 10 (in Beta) Substations

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QUESTIONS

?

Appendix D2 – FlexDGrid Initial survey results

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FlexDGrid

Advanced Fault Level Management in Birmingham

Initial survey results

02.04.2013

Dr Samuel Jupe (Parsons Brinckerhoff)

Initial survey results on fault level modelling

- Survey sent out to each GB DNO
  - Responses received representing 6 DNO licence areas

- All respondents agree that there is merit in G74 review
  - G74 is over 20 years old
  - Generator technologies have changed (DFIGs, generators with fully-rated converters)
  - A common methodology for modelling new generation types would be useful
  - Fault level is a growing concern, in-house approaches are being developed to incorporate embedded generation within G74 / IEC60909 calculations
  - Consistent approach will help demand and generation customers
  - It will be beneficial to assess results and application processes from other DNOs

Initial survey results on fault level modelling

- Development of a simple but comprehensive test network
  - Work has already been done in ASG / OSG X/R group of ENA
  - May not be widely known about

- Potential limitations of G74
  - Method options to calculate fault level can give very different results (e.g. X/R ratio)
  - Provides a general consistent approach for voltage levels at 33kV and above, but difficult to apply at HV levels
  - Elements may need updating / expanding

Initial survey results on fault level modelling

- Both IEC60909 (hand calculations) and G74 standards (computer simulations) are used
  - DINIS
  - IPSA
  - PSS/E

- Extent of HV network model
  - 33kV, 11kV and 6.6kV networks modelled in detail with 132kV (slack busbar) connections
  - Separate model for EHV network to HV primary busbars and HV primary substation busbars to corresponding HV distribution networks
  - From National Grid SGTs to 11kV / 6.6kV busbars

Initial survey results on fault level modelling

- Issues encountered with application of G74
  - Some software does not facilitate variable time constants for transient / sub-transient components
  - Limited guidance on the modelling of power electronics (DFIGs, PV, STATCOM)
  - A.C. decrement of fault level and modelling plant with very short A.C. time constants

- DG modelling assumptions
  - Inverter-connected generation modelled as equivalent synchronous model
  - 33kV: DG modelled
  - 11kV: DG modelled , DG modelled as an equivalent in EHV model
  - 0.4kV: DG modelled as an equivalent in EHV or mixture or not at all

Initial survey results on fault level modelling

- Load fault contribution modelling assumptions:
  - Different approaches taken by DNOs

- Is the load fault contribution of sufficient accuracy?
  - Yes
  - Unsure
  - No - it's unclear whether the values are still representative of today's loads
  - At what point should we move from HV to LV load modelling

- Safety margins between calculated fault levels and switchgear ratings vary from 0% - 5%

Initial survey results on fault level modelling

- Short-term paralleling allowed to exceed ratings by some DNOs
- Some DNOs have issues with data for generation connection studies
  - Difficult to obtain detailed technical data from customers
  - Due to the need for an equivalent synchronous in-feed
- Fault level is currently or expected to be a constraint on the connection of generation in some urban areas
- Number of uneconomic connections (due to fault level) unknown – DNO does not find out why customers do not proceed with developing projects

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Appendix D3 – Workshop feedback form

FlexDGrid

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FEEDBACK FORM

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

Date: 02.05.2013
Title of Workshop: Processes to enhance DNOs' knowledge of fault level
Venue: IET, Birmingham

Overall how satisfied were you with the event:

	1	2	3	4	5	
Very Dissatisfied	☐	☐	☐	☐	☐	Very Satisfied

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

	1	2	3	4	5	
Very Dissatisfied	☐	☐	☐	☐	☐	Very Satisfied

Overall how satisfied were you with the venue:

	1	2	3	4	5	
Very Dissatisfied	☐	☐	☐	☐	☐	Very Satisfied

Overall how satisfied were you with the catering:

	1	2	3	4	5	
Very Dissatisfied	☐	☐	☐	☐	☐	Very Satisfied

Overall how satisfied were you with the presentation:

	1	2	3	4	5	
Very Dissatisfied	☐	☐	☐	☐	☐	Very Satisfied

Additional comments:

Overall how satisfied were you with the workshop sessions:

	1	2	3	4	5	
Very Dissatisfied	☐	☐	☐	☐	☐	Very Satisfied

Additional comments:

PARSONS BRINCKERHOFF

THE UNIVERSITY OF WARWICK

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FEEDBACK FORM

What did you enjoy the most?
What could be improved?
Any other comments?
Alongside a number of other events, we are planning to hold a number of workshops relating to the FlexDGrid Project, specifically in the interests of knowledge sharing and capturing best practice and learning across DNOs. Would you be interested in attending our future events? Yes ☐ No ☐
Your details (please leave blank if you wish to remain anonymous): Name: Job Title: Company: Email address: Phone number:

Appendix E – Modelling methodology for integrating EHV and HV network models

Methodology for modelling the HV network and integrating the EHV and HV networks

This appendix details the methodology for modelling the 11 kV network as part of the SDRC-1 work package. The WPD data sources and the assumptions considered in this methodology are explained. In addition, the load flow and fault level calculation results for one of the substations modelled in FlexDGrid are presented.

WPD software tools and data sources

WPD utilises different software and data sources to analyse and maintain the information of the network assets and the customers. These data sources are briefly described below:

EMU is a geographical information system (GIS) platform for displaying the geographical locations and some electrical parameters of the system assets. For example, cables, overhead lines, circuit breakers and transformers.

Data Logger contains voltage and current activity recorded at half hourly intervals from metering points on the busbars and feeders of the 132, 66, 33 and 11kV networks.

CROWN is an asset management software database.

Long Term Development Statement (LTDS) provides network information and data for customers / connection applications and defines the jurisdiction of the WPD network.

GROND is a distribution system analysis software package to assist distribution engineers with carrying out network design and policy studies on the HV distribution networks.

IPSA+ was the primary power system analysis (PSA) tool used by Central Networks prior to the WPD acquisition. The PSA package was used for network planning, customer connection studies, and other analysis activities. The WPD 132, 66 and 33 kV networks are modelled in IPSA+.

PSS/E is the primary power system analysis software of WPD for modelling the 132,66 and 33 kV networks and the 11 kV network as part of FlexDGrid.

PowerOn Fusion is network management system used by WPD network operators for controlling the distribution networks. PowerOn Fusion provides the real time information about the status of the network configuration and the voltage and current at different points of system.

Modelling methodology

The above-mentioned data sources were assessed and datasets were selected for modelling the 11 kV network based on the most regularly updated and reliable datasets. Based on the available information, a methodology was developed, and trialled in the initial phase of FlexDGrid for modelling the 11 kV network associated with three primary substations.

The proposed modelling methodology has three elements:

- Modelling network topology
- Demand estimation
- Generation modelling

Figure E-1 shows the data sources used in the proposed modelling methodology.

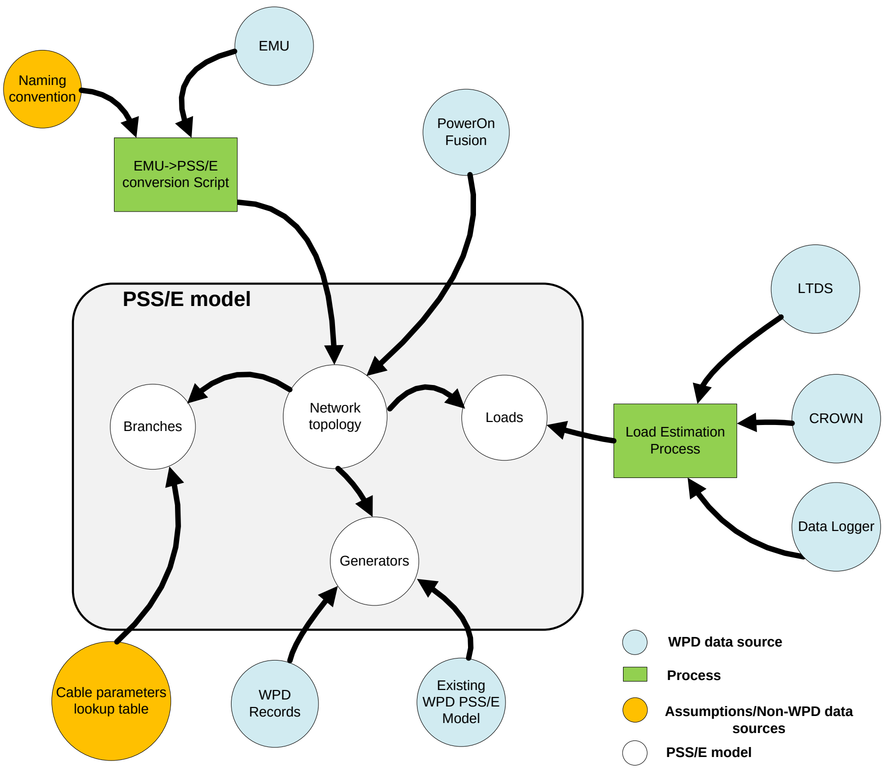

Figure E-1: 11 kV network modelling methodology

Network topology

EMU was used to identify the network connectivity and the type of conductors installed in different parts of the 11 kV network. This is because EMU is the most up-to-date data source representing the geographical connection of the network assets.

An Excel script has been developed to convert the EMU data to the PSS/E format. This script creates a model of network topology by analysing the geographical co-ordinates of the network assets.

Load estimation

The maximum current of 11 kV feeders recorded between 01/ 02/2012 and 01/02/2013 is divided among the distribution substations supplied by that feeder.
The historic maximum loading of 11 kV feeder can be retrieved using Data Logger. The maximum loading of feeder is then divided among the distribution substations supplied by that feeder, assuming a maximum demand index (MDI) as a dividing factor for each distribution substation. The MDI is:

- 70% of the transformer rating – This data comes from either Crown or EMU. If the transformer rating does not exist, then:

- Agreed Supplied Capacity (ASC) – These data are obtained Crown
  If ASC does not exist, then:

- Maximum demand recorded in Crown – These data is available for some of the substations.
  If there is no record in the Crown, then:

- Zero

After splitting the loads between the distribution substations, the total demand on the primary substation is scaled to agree with LTDS demand estimations. The power factor for load is similar to the power factor advised in LTDS for each primary substation.

Distributed generation modelling

In the exiting WPD PSS/E model, the 11 kV generators are connected to the 11 kV busbar at the primary substations with a circuit impedance representing the 11 kV feeder. The output of this project is a full model of 11 kV network, hence, these generators have been moved to the actual connection point on the 11 kV network.

Substation models

The proposed modelling methodology has been used to develop the PSS/E model of the 11 kV networks associated with three primary substations. Additional substations will be modelled in line with fault current limiter and fault level monitoring trials. Figures E-2, E-3 and E-4 illustrate the implementation of the modelling methodology for primary substations M, J and Q within the trial network area.

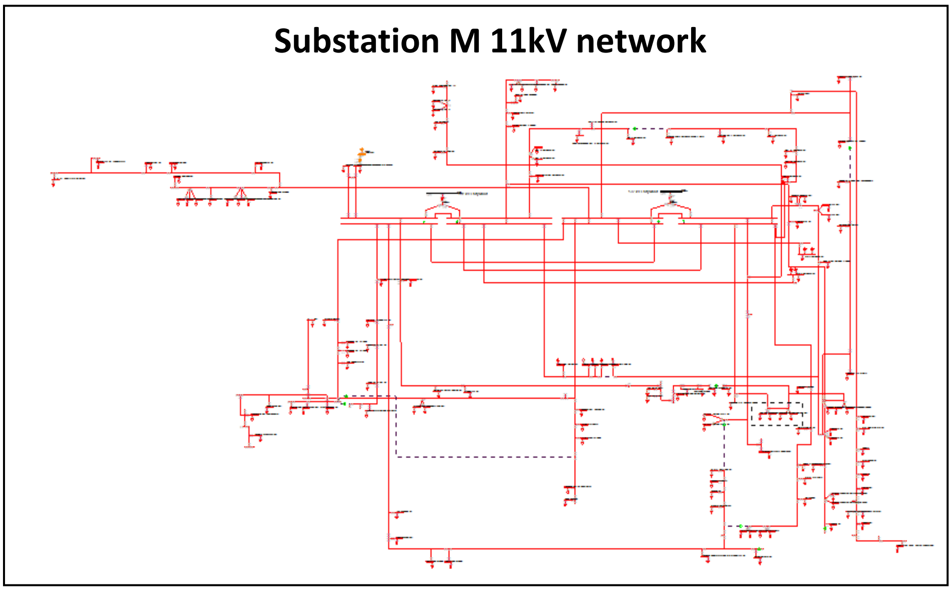

Figure E-2: Substation M 11 kV PSS/E model

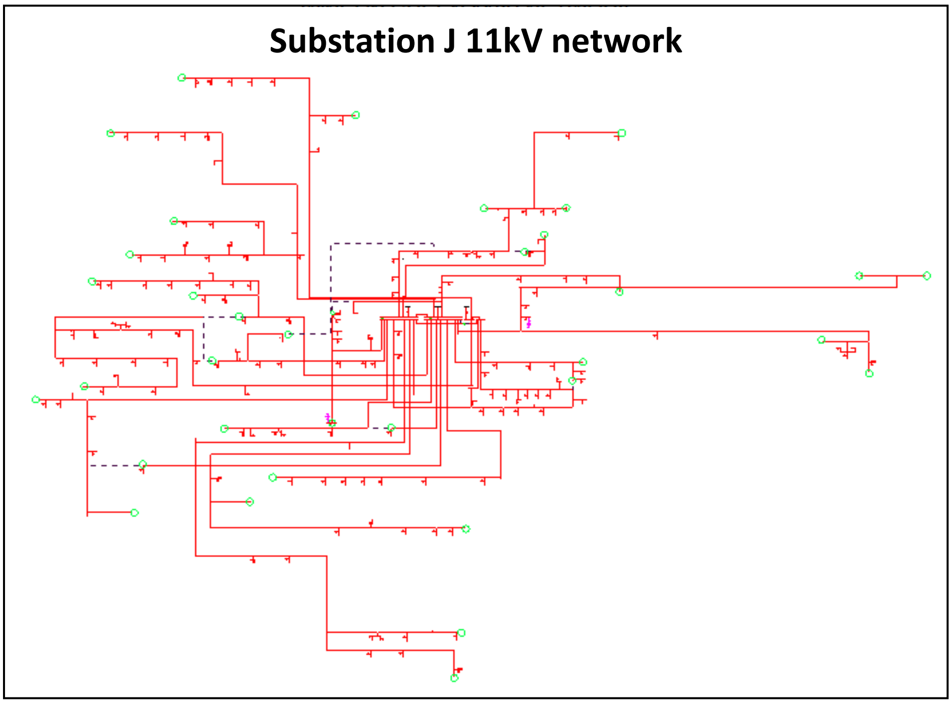

Figure E-3: Substation J 11 kV PSS/E model

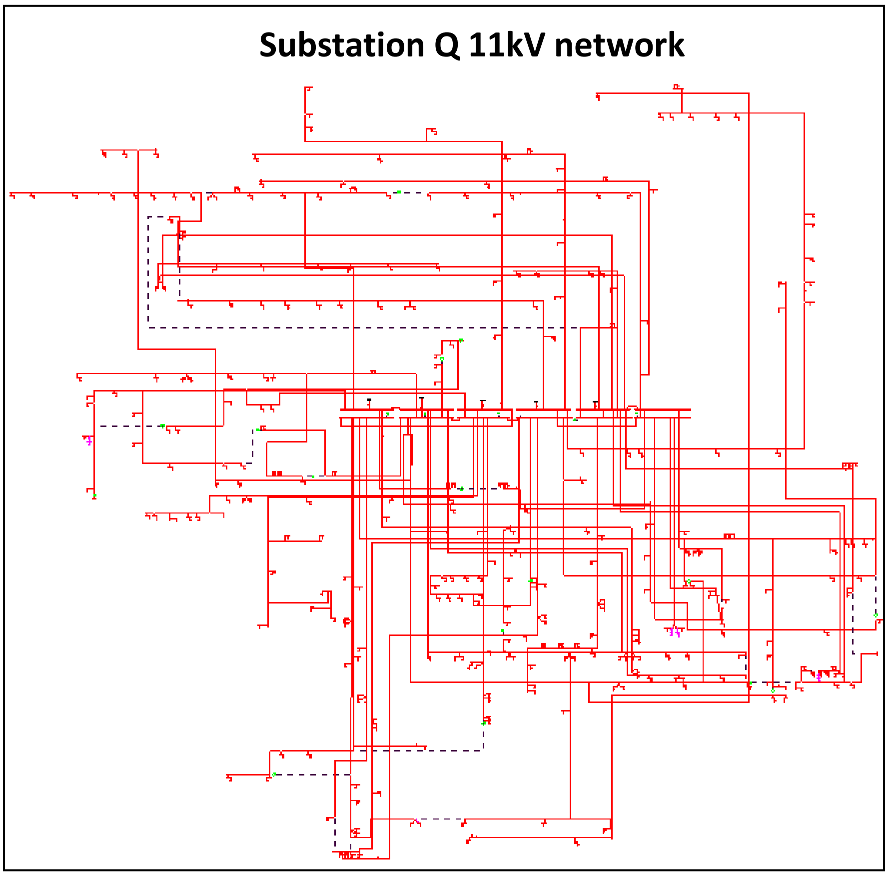

Figure E-4: Substation Q 11 network PSS/E model

The metrics of the model for each of the developed 11 kV networks associated with primary substations, as shown in Figure E-2 to Figure E-4, are given in Table E-1.

Table E-1: The dimension of the 11 kV network PSS/E modelled in FlexDGrid project

Substation name	Number of PSS/E nodes	Number of substations	Total cable length (km)	Number of generators
Substation M	365	138	41.04	5
Substation J	443	148	95.62	2
Substation Q	807	312	107.73	4

Integrating the HV and EHV networks

The developed models are integrated into the WPD EHV PSS/E model. Figure E-5 represents the business as usual (BaU) network model prior to the FlexDGrid project. Figure E-6 represents the schematic diagram of the 11kV network which, in BaU, is not integrated with the EHV network in the same power system analysis package.

Figure E-7 represents tangible output of FlexDGrid in terms of delivering to WPD an integrated network model that can be used by the project to test the enhanced fault level assessment processes throughout the project trials.

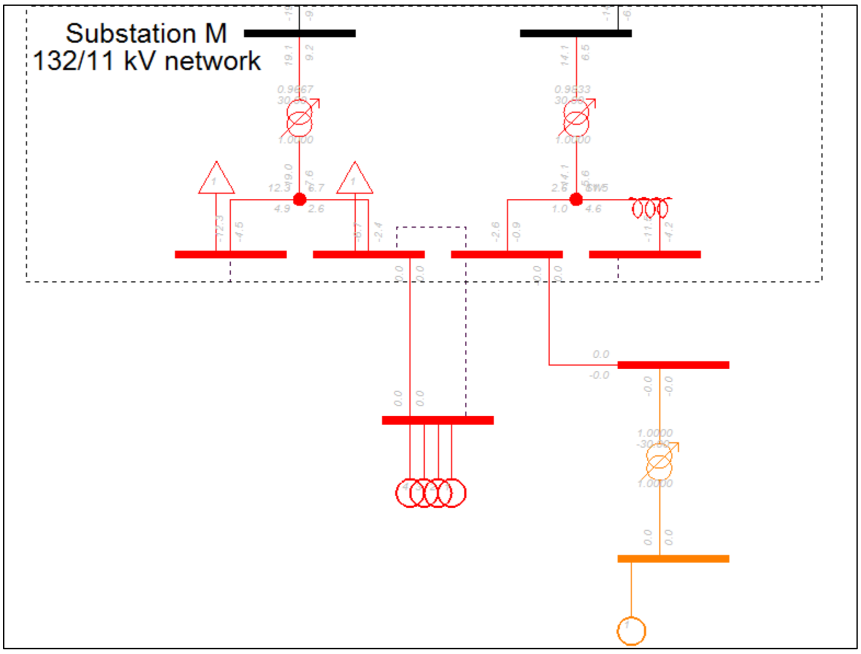

Figure E-5: Representation of the HV network (BaU pre-FlexDGrid) within the power system analysis package PSS/E

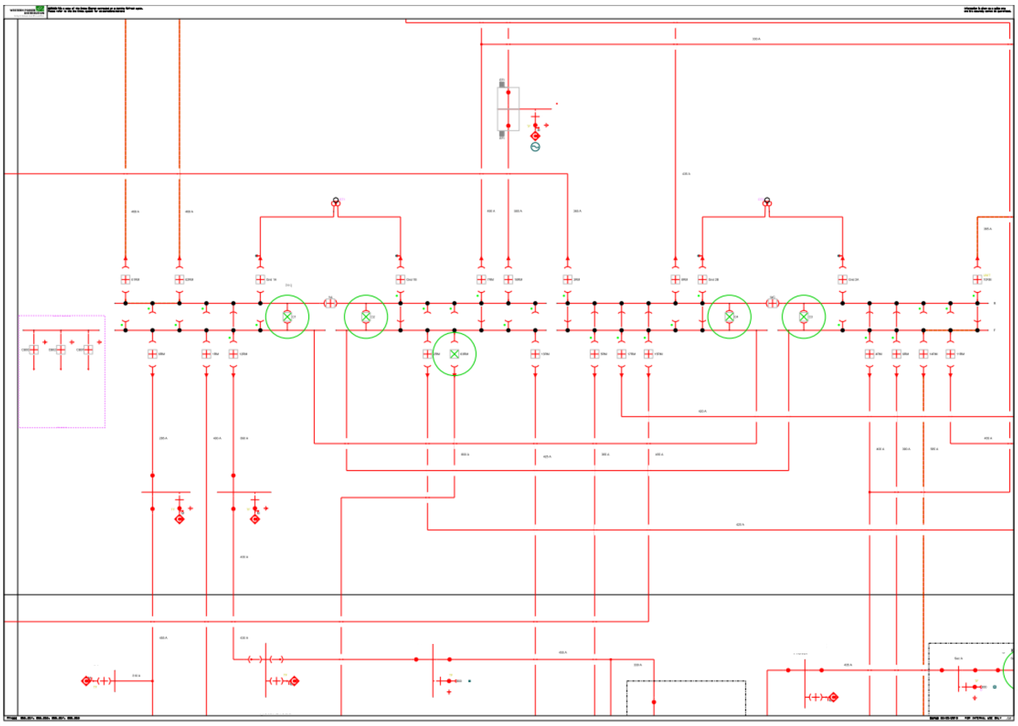

Figure E-6: Schematic representation of the HV network (BaU pre-FlexDGrid) within EMU

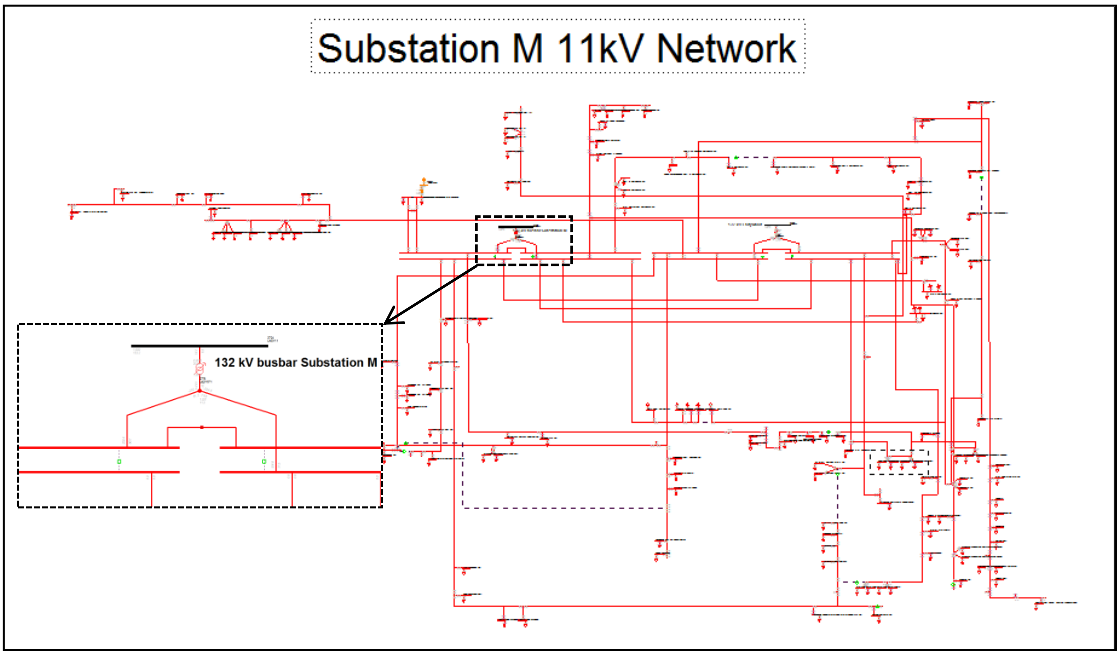

Figure E-7: Representation of the integrated HV network model within the power system analysis package PSS/E as a result of the FlexDGrid project

Model validation

The developed 11 kV model was validated against three validation criteria:

- Network topology consistency
- Load flow accuracy
- Short circuit accuracy

Network topology consistency: The connectivity of the 11 kV network for the PSS/E model was extracted from the EMU which is a geographical information system (GIS). This network connectivity was validated against the single line diagrams of 11 kV networks represented within PowerOn Fusion. This provided a cross reference check between two different WPD BaU databases. On this basis, there is good alignment between the developed PSS/E model and the 11 kV network single line diagram within PowerOn Fusion.

Load flow accuracy: The loading of the feeders obtained from a load flow study in PSS/E were compared with the original (scaled) values provided by WPD. The discrepancies between the values were within acceptable degree of accuracy (less than 5%). The discrepancy is due to losses on 11 kV networks and the slight voltage deviation from 1 p.u (11 kV) at the HV busbars at the primary substations. In addition, the voltage drop along the 11 feeders were also assessed and validated with manual calculation results. Figure E-8 shows the heat map representing the voltage profile on the substation M 11 kV network.

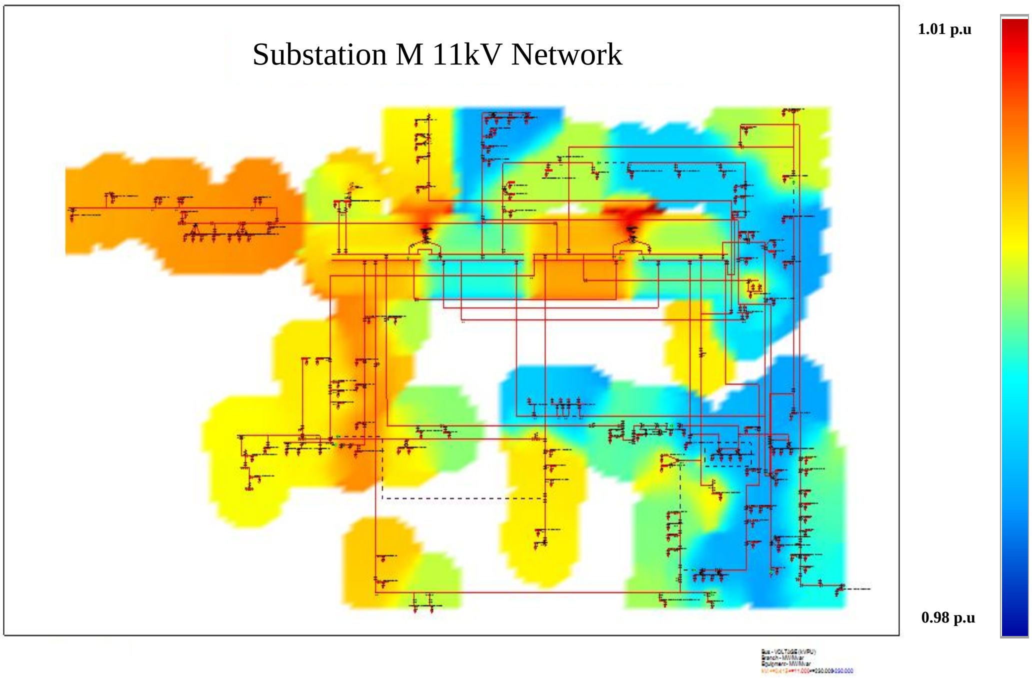

Figure E-8 Voltage profile heat map on the 11 kV network of substation M

Fault level accuracy: Three phase fault level studies were carried out on the developed PSS/E models assuming winter maximum demand operating conditions. The resultant fault levels at the 11 kV busbars of the primary substations were compared with those reported in the LTDS and an acceptable degree of accuracy (less than 1%) was observed. Figure E-9 shows the 3 phase fault level heat map substation M 11 kV network.

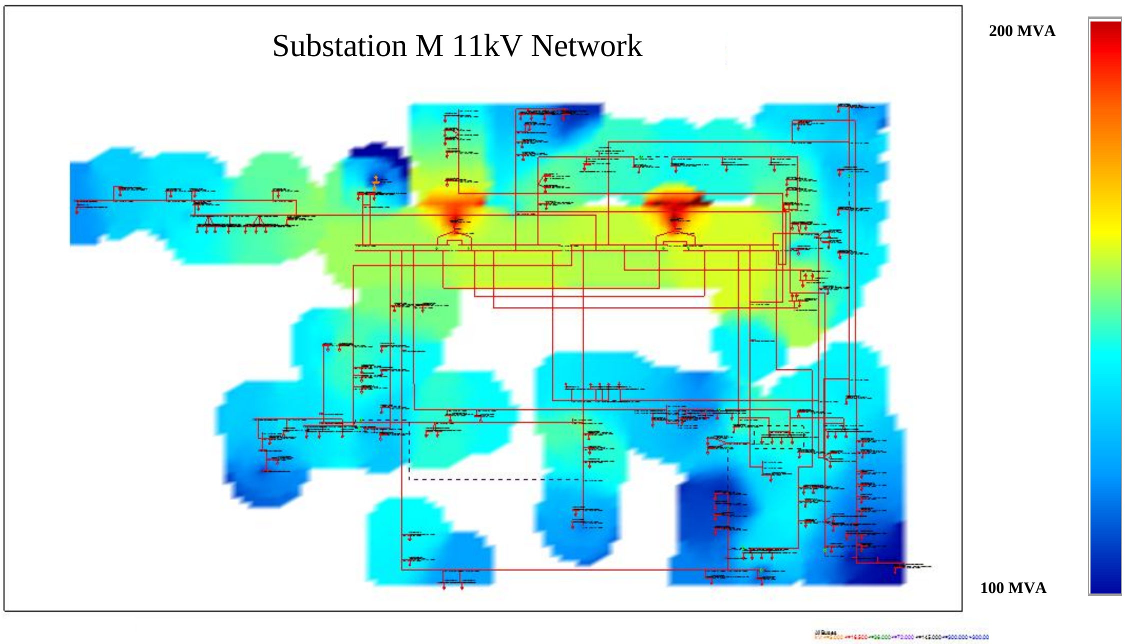

Figure E-9 shows the heat map fault level on the 11 kV network of substation M