Project Code/Version No: WPD T2 04 02

Low Carbon Networks Fund
Full Submission Pro-forma

Section 1: Project Summary

1.1 Project title

FLEXGRID - Advanced Fault Level Management in Birmingham

1.2 Funding DNO

Western Power Distribution (West Midlands)

1.3 Project Summary

FLEXGRID offers an improved Solution to the Problem of the timely and cost-effective integration of customers' generation and demand within urban HV electricity networks.

This project seeks to explore the potential benefits arising from Trials of three complimentary 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 will 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 FLEXGRID Solution can 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.

1.4 Funding

Second Tier Funding request (£k)	13513.76
DNO extra contribution (k)	0
External Funding (£k)	1669.87

1.5 List of Project Partners, External Funders and Project Supporters

Project Partners: Parsons Brinckerhoff; University of Warwick.

Project Suppliers: Subject to commercial negotiation S&C Electric and Outram Research Limited; Other project suppliers will be identified through an equipment tendering process to provide best value for money to customers.

Project Supporters: Birmingham City Council; Cofely; University of Southampton; University of Manchester.

1.6 Timescale

Project Start Date	1st December 2012
Project End Date	31st March 2017

1.7 Project Manager contact details

Contact name & Job title
Jonathan Berry - Low Carbon Networks Engineer

Telephone Number
0121 6 239 459

Email Address
jberry@westernpower.co.uk

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

Section 2: Project Description

Section Summary

This project addresses the need for timely and cost effective connection of customers who are constrained from connecting generation by electricity network Fault Level issues. Fault Level is a measure of the electrical stress when faults occur in the network. Distributed Generation can adversely affect Fault Level.

Three Methods will be Trialled and the benefits are to:

(i) Defer/avoid capital investment for customers and DNOs;

(ii) Avoid long connection lead times for low carbon generation;

(iii) Increase network efficiency and reduce customer interruptions (CIs) and customer minutes lost (CMLs); and

(iv) Secure long term sustainable and affordable electricity prices with assisted living benefits from combined heat and power (CHP).

Each of the Methods contribute to these benefits individually. When applied together the benefits are further enhanced.

2.1 Aims and objectives

Aims:

This project aims to develop and Trial an Advanced Fault Level Management Solution to improve the utilisation of DNO 11kV (HV) electricity networks while facilitating the cost-effective and early integration of customers' generation and demand connections.

The FLEXGRID Solution will provide DNOs with the capability to defer or avoid costly and prolonged network reinforcement, while improving security of supply.

The Problem to be resolved:

Fault Level is a measure of electrical stress when faults occur within networks. It is a growing issue in the connection of Distributed Generation (DG). Conventional solutions to manage Fault Level often entail significant capital costs and long lead times.

DECC's Carbon Plan[1] sets out a strategy for carbon reduction and as a result many local and national policies include Combined Heat and Power (CHP) plants.

The electricity infrastructure in dense urban environments was designed and developed for its former heavy industrial requirements. Whilst we can accommodate the power produced by DG within the existing network in some locations there are constraints because generation contributes to Fault Level, which may already be at, or close to, its allowable limit. Fault Levels must be maintained within equipment ratings: if exceeded, catastrophic failure could occur during a fault. DNO Fault Level calculations are currently based on fixed network conditions, involving essential safety margins and resulting in conservative Fault Level assessments.

[1] Department of Energy and Climate Change (DECC), 'The Carbon Plan: Delivering our low carbon future', Dec 2011.

2: Project Description cont.

Conventional Fault Level management solutions involve uprating or replacing transformers and, where large increases are required, replacing switchgear as well. For example, a 78 MVA Primary Substation in Birmingham requires two replacement higher loss transformers, costing about £4M and taking three years to complete in order to accommodate less than 3 MW of distributed generation. The upgrade involves the early retirement of fit-for-use assets and network losses will increase by 745,000 kWh per annum (319 tCO_2).

In order to meet carbon reduction targets in Birmingham's Central Business District (CBD)[2], the conventional Fault Level solution would involve switchgear and cable replacement at an estimated cost of £48.4M. This would involve significant public infrastructure disruption during necessary road excavations with elevated risks of power outages. There would also be an impact on customers' HV equipment. Neither of these costs are included in the estimate.

The Methods being trialled to solve the Problem:

In order to address the Fault Level management Problem, three Methods will be trialled and evaluated within the CBD of Birmingham. The findings from will be extrapolated in order to understand the wider applicability to GB urban networks. These Methods are:

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

Method Alpha: Enhanced Fault Level Assessment will explore the existing Fault Level calculation and connection assessment methodologies, defined in IEC 60909[3] and DNO internal policies. An open source Fault Level quantification methodology will be developed using probabilistic approaches to enhance analysis. This Method aims to facilitate the connection of more customers without compromising the safety of our employees and the public. Findings will be shared with DNOs and appropriate standards bodies for review and appropriate policy/standards updates. The methodology developed is likely to involve novel commercial frameworks with DG customers. Up to 10% capacity could be released through this Method. This is because current processes rely on the user to create 'realistic' voltage profiles through power flow simulation; furthermore, IEC 60909 recommends the use of a 'C factor' to create artificially high voltages. This can lead to unduly pessimistic Fault Level assessments.

Method Beta: Real-time Management will install real-time Fault Level measurement devices, for example those developed under the WPD LCNF Tier-1 project “Implementation of an Active Fault Level Management Scheme”, at ten Primary Substation sites. This will enable accurate Fault Level data to be gathered for various network running arrangements, and to verify the Fault Level assessed in Method Alpha. This will allow 11kV network configurations and the status of DG plant to be monitored on a more granular level. Up to 10% capacity could be released through this Method. Uncertainties in data, and the lack of real-time Fault Level monitoring capability, have led to conservative safety margins (up to 15%) in the current assessment of electricity Fault Levels.

Method Gamma: Fault Level Mitigation Technologies builds on technology developed and learning from existing IFI[4], ETI[5] and LCNF projects to create a system-level approach. Five Fault Level Mitigation Technologies will be selected for installation at five separate substations. Substation site feasibility studies have already been conducted between Initial Submission and Full Submission stages. During the Project design phase the most appropriate technologies will be selected for installation at each site to mitigate Fault Level issues.

....

[2] Central Business District - The commercial, office, retail and cultural centre of the city.
[3] International Electrotechnical Commission (IEC), 'IEC 60909: Short-circuit currents in three-phase a.c. systems', Jul 2001.
[4] Innovation Funding Incentive (IFI) - Ofgem incentive mechanism to encourage DNO innovation.
[5] Energy Technologies Institute (ETI) - Partnership between global industries and UK Government to accelerate the development of technologies that will help the UK to meet their climate change targets.

2: Project Description cont.

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

The Trials being undertaken to test that the Methods work:

Method Alpha: Enhanced Fault Level Assessment will be Trialled in the following way:

(i) Review connection applications and offers in Birmingham between 2009 and 2012, along with substation and network data for all of the Primary Substations within Birmingham CBD. This data will be used in order to understand how this Method could have been applied to those connections.

(ii) Develop Enhanced Fault Level Assessment processes that will characterise each Primary Substation within Birmingham's CBD (see Appendix B1), using novel Fault Level Indices[6], for different network running arrangements, and quantifying the capacity to accept additional generation connections.

(iii) Track new connection applications within the CBD of Birmingham for an initial period of six months from when Method Alpha is available, where Method Alpha will be applied to determine the difference and benefit over traditional approaches.

(iv) Assess longer term development of the Method through the projection of future demand and generation connections. This will include a projection beyond the LCNF Project duration, in line with selected scenarios of DECC's Pathways 2050 [7].

(v) Consult other DNOs, Industry and the appropriate stakeholders at various and suitable stages to provide an independent review of the Method.

Method Beta: Real-time Fault Level Management will be Trialled in the following way:

(i) Select ten Primary Substation sites for the installation of real-time Fault Level measurement devices, such as those developed under a WPD LCNF Tier-1 project "Implementation of an Active Fault Level Management Scheme". Details of the Primary Substation selection process are given in Section 2.3.

(ii) Model the ten Primary Substation sites, using power systems analysis software selected to have the capability to program inputs to be varied in real-time. This will include the modelling of Fault Level Mitigation Technologies.

(iii) Assess during the course of the project, the Fault Level contribution of new generation connections that take place at the ten Primary Substations sites. These will be assessed through modelling, and monitored once connected, and the results will be compared.

(iv) Design the network management logic to safely operate in all network configurations, making use of interlocking[8] to ensure that generation will not connect to an unsuitable network environment. This will be optimised through the introduction of automated switching sequences[9].

....

[6] Fault Level Indices - Ranking based on the fault current as a percentage of the equipment rating or network limit.
[7] Department of Energy and Climate Change (DECC), '2050 Pathways Analysis', Jul 2010.
[8] Interlocking - Method of protection against incorrect power system operation. This can be `electrical interlocking' or `mechanical interlocking' in the form of locks and keys.
[9] Automated switching sequence - Automatic network re-configuration to optimise running conditions.

2: Project Description cont.

Method Gamma: Fault Level Mitigation Technologies will be Trialled in the following way:

(i) Select five demonstration-ready Fault Level Mitigation Technologies for network installation at five separate Primary Substation sites in Birmingham. Details of the Primary Substation selection process are given in Section 2.3 and Appendix M.

(ii) Assess, through technology installation and Trials, the merits of this novel operating regime in terms of Fault Level reduction. Where Fault Level has driven transformers to be operated in split configuration (as defined in Figure 2.1a and Appendices C1 and C2), the Fault Level Mitigation Technologies could enable the Primary Substations to be operated in solid configuration (as defined in Figure 2.1b and Appendices C1 and C2). This would have the added benefit of reducing customer interruptions and customer minutes lost and increased network efficiency through loss reduction. Losses for split and solid network configurations are given in Appendix C3.

(iii) Quantify, during the course of the project, demand and generation connections that may take place at the five Primary Substations selected for trials and the merits of Fault Level Mitigation Technologies in light of these connections.

As a minimum Health and Safety requirement all Fault Level Mitigation Technologies to be Trialled will 'fail safe'.

The Solution that will be enabled by solving the Problem:

Each Method, if proved successful in Trials, will provide a component of the FLEXGRID Solution. Benefits from this Project include:

1. Deferring/avoiding capital investment associated with major network reinforcement caused by Fault Level issues;

2. Avoiding long lead times associated with network reinforcement or upgrades;

3. Connecting low carbon generation to the electricity network more quickly and cost effectively;

4. Reducing customer interruptions (CIs) and customer minutes lost (CMLs) through solid network configuration. Increased network efficiency and reduced losses by installing generation closer to demand centres, balancing load on transformers; and

5. Facilitating sustainable and affordable electricity prices[10].

All three Methods would add benefits individually, but when the Methods are applied together the benefits are further enhanced.

....

[10] CHP has been shown to reduce energy bills by 20-30%: Carbon Trust, 'Introducing Combined Heat and Power - A new generation of energy and carbon savings', Sept 2010.

2: Project Description cont.

2.2 Technical description of Project

Background

An important part of the design of electricity networks is the calculation of the currents which will flow when faults occur. Planning and design engineers carry out fault studies to determine the operating settings for the protection equipment and also the ratings for the circuit breakers and other electricity network assets. It is essential to calculate the fault current that would flow, if a fault occured, such that the ratings of circuit breakers are not exceeded and to ensure the fault current is not too low to be detected.

High Fault Levels, which exceed ratings, cause overstressing of equipment or disruptive failure of electricity network assets. Overstressed switchgear and network can lead to significant damage resulting in high repair costs, unplanned network outages and safety implications for DNO employees and the public.

DNOs have traditionally designed urban networks with high Fault Levels, in order for protection relays to distinguish between high load current and fault current on the system. If the Fault Level is low then the protection relays will not distinguish between high load current and fault current, causing nuisance tripping on the network[11]. This design with high Fault Levels is now acting as a barrier to the rapid introduction of distributed generation because generators cause an increase in Fault Level on the network to which they are connected. In addition, rotating electrical loads, such as motors, also contribute to, and increase, Fault Levels.

Once constructed, a network's Fault Level capacity cannot be easily increased. The capacity is dictated by the transformers, cables and switchgear. Conventional methods to reduce Fault Level can either impact system security or involve replacing expensive components.

If the network Fault Level capacity is exceeded for a new connection enquiry, the DNO is obliged to modify that network before a new connection can be accommodated. This can often entail substantial investment. Not all of the costs are charged to the new customer under current regulations, and the remainder is socialised across all DNO customers. Thus the benefits of this project will be seen by all DNO customers, not just new connections customers.

Fault Level is very difficult to measure and is assessed using assumptions to ensure that the calculated Fault Level is less than the actual Fault Level. This leads to large safety margins, which, at present are not consistently quantified by DNOs.

....

[11] Nuisance tripping - Unwarranted tripping of circuit breakers.

2: Project Description cont.

Technical Overview of Method Alpha: Enhanced Fault Level Assessment Processes

What is a Connection Assessment Process?

A connection assessment process is a series of technical and commercial steps by which the impact of a demand or generation connection to the electricity network is quantified. The connection assessment process considers the impact of new connections on voltage, power flows and Fault Level under worse-case network operating conditions. Connection assessments take into account how the network running arrangements vary with time including planned/unplanned outages.

Due to existing Fault Level issues, DNOs may split the network (as defined in Figure 2.1a and Appendices C1 and C2). The drawback of operating with this running arrangement is that security of supply to customers is reduced. Furthermore, in some urban areas, the Fault Level can be near acceptable limits even with split network operating configurations.

How is customer connection capacity unlocked through Method Alpha?

The Enhanced Fault Level Assessment Method will provide refined Fault Level analysis techniques to understand the areas of the network that are likely to exhibit Fault Level issues. This will be used to provide customers with more accurate and refined network connection offers.

Through Enhanced Fault Level Assessment there will be an increase in the accuracy of Fault Level calculations and reduced modelling uncertainty. The Method will develop a Fault Level Index, in a similar manner to equipment load indices and health indices. The Fault Level Index will be used to characterise substations and determine where to deploy Fault Level monitoring and mitigation equipment. The Fault Level headroom gain, and additional capacity for customers' connections, is denoted by `α' in Figure 2.2b.

Technical Overview of Method Beta: Real-time Management

What is the difference between monitoring, measuring and modelling in real-time?

Through the use of new real-time Fault Level monitoring techniques (see Appendix K), the prospective Fault Level can be measured on a periodic basis. Monitoring devices will use both natural and artificial disturbances seen on the network, taking in to account the network characteristics and using these to determine the Fault Level. On inception of a fault, the fault currents can also be measured at a particular instant in time and used to calibrate the monitored Fault Level. Real-time modelling uses computer simulations with inputs that vary in real-time in order to assess Fault Level.

How is customer connection capacity unlocked through Method Beta?

The Real-time Management Method will enable accurate Fault Level data to be gathered for various network arrangements. This will be used to verify the Fault Level assessed through the Trial of Enhanced Fault Level Assessment processes. The maximum acceptable measurement error of the Fault Level monitoring device is considered to be ±5% of the actual in-feed values.

Through Real-time Management, the increased visibility and confidence in network operating conditions could allow the safety margin to be reduced without compromising the safety of DNO employees and the public. This will be facilitated by integrating the monitored and measured values with WPD's existing operational management systems. The Fault Level headroom gain, and allowable additional capacity for customers' connections, is denoted by `β' in Figure 2.2c.

Technical feasibility of Fault Level monitoring

A comprehensive and critical review of Fault Level monitoring developments over the past twenty years is given in Appendix K1. The Fault Level monitoring technique, described in Appendix K, focuses on 11kV networks and synchronous generator fault contribution, which is representative of CHP integration within urban HV electricity networks. In this context accurate Fault Level monitoring is achievable with an acceptable level of accuracy. This could lay the foundation for further work, which could deal with a range of voltage levels, network topologies and generator types.

The proposed technique involves a novel equipment network integration process. This has been independently reviewed and the case for the proposed Trials has been verified by leading academics in the field of Fault Level monitoring (see Appendix I).

2: Project Description cont.

Technical Overview of Method Gamma: Fault Level Mitigation Technologies

The Fault Level Mitigation Technologies Method will limit the fault current in HV electricity networks. The installation of a Fault Level Mitigation Technology (described in Appendix L) may necessitate automatic changes of network arrangements at certain times, which can affect voltages and other network parameters. Therefore, in order to deliver a system-level Solution, new technologies such as voltage conditioning units will be installed and evaluated if required as part of the Solution.

What is a Fault Level Mitigation Technology?

A Fault Level Mitigation Technology comprises a device that ensures the fault current remains within switchgear and network equipment ratings. Fault Level Mitigation Technologies will allow protection equipment to operate to isolate the fault and maintain the integrity of the electricity network.

The Fault Level Mitigation Technologies described in Appendix L use different methods to provide the mitigation. Technologies to reduce the fault current at the instant of a fault do this through the addition of significant impedance to the network. Some technologies detect the presence of fault current on the network and at this point provide additional impedance to the network, other technologies provide a permanent impedance increase. The latter technologies may be installed in a manner to reduce their time connected time to the network, where they are to be connected only when Fault Level is considered to be an issue, therefore reducing the impact of the additional impedance on the network.

What is a voltage conditioning unit?

A voltage conditioning unit is a device that controls electricity network voltages (e.g. a FACTS device[12]) when system disturbances occur. Examples of system disturbances include the switching on of a large demand or generator, the switching off of a large demand or generator and the step-change in voltage that could occur when planned or unplanned electricity network equipment outages occur.

How is customer connection capacity unlocked through Method Gamma?

Technologies will be installed in substations which currently exhibit Fault Level issues and where new connections are expected to cause an increase in fault currents. This Method adds Fault Level capacity by reducing fault currents. The Fault Level headroom gain, and allowable additional capacity for customers' connections will be quantified, as denoted by `γ' in Figure 2.2d.

Can the Methods support each other?

Each of the Methods can unlock Fault Level capacity (Figures 2.2b, c and d). Combining all three Methods further enhances the benefits (Figure 2.2e).

Why are the Methods innovative?

Enhanced Fault Level Assessment will deliver novel design tools and will have a direct impact on distribution network planning by identifying the most appropriate locations for Fault Level monitoring equipment. Novel Fault Level monitoring equipment will be installed within Primary Substations and will have a direct impact on distribution network planning and operation by identifying appropriate Fault Level Mitigation Technologies to deploy in different network environments. The introduction of Mitigation Technologies to manage Fault Level on a system-wide level is a novel operational method. All three Methods will facilitate the development of novel commercial contracts with generation customers. For the first time, benefits will be quantified for the management of Fault Level on a system-wide basis.

....

[12] Flexible alternating current transmission systems (FACTS) - Power electronics based systems that allow the flow of active (useful) power to be optimised. These devices are now manufactured for distribution systems.

2: Project Description cont.

2.3 Description of design of trials

The Trials have been designed in the following way, to ensure they are statistically sound and sufficiently robust to capture the learning.

Statistical design of the Trials

The City of Birmingham is expected to see typical to high levels of DG integration, due to the City Council's CHP policy and commitment to reducing the city's carbon emissions by 60% by 2026 [13]. Birmingham already exhibits Fault Level issues, which DG will further contribute to, as seen in Appendix Q. These Fault Level issues are likely to be found in other UK regions, which have targeted DG as part of their strategic carbon reduction plans (see Appendix B).

The novel connection assessment process, which will be developed through Method Alpha (Enhanced Fault Level Assessment), will be Trialled in the following ways, to ensure the results are statistically sound:

1. Through analysis of historic generation applications, to establish what the benefits of the Solution would have been if the Method had been applied;

2. Every connection application for an initial period of six months in the Trial area will be assessed using the Enhanced Fault Level Assessment processes, representing a suitable proportion of the total number of connections received in the West Midlands region; and

3. Simulation of future connection scenarios using probabilistic approaches, based on DECC Pathways 2050.

The categorisation of substations according to the drivers for network reinforcement is given in Table 2.1. These drivers include safety issues and the potential integration of CHP into a variety of customer sites.

In order to understand the variation in Fault Level and cover a variety of drivers for network reinforcement, ten substations have been selected to trial the Fault Level Management Method (Beta). Ten substations deliver a significant proportion of the city's electricity demand and represent the power delivery requirements of other GB cities. This allows trending data to be generated, accounting for anomalies. These Trials will run for at least a year to capture the variation in Fault Level from different network running arrangements.

In Method Gamma, five Substations will be selected to increase the probability of new connection applications occurring inside the Trial area and to accommodate the range of Mitigation Technologies already identified (see Appendix M). These Trials will run for at least a year to capture the variation in Fault Level due to different network running arrangements. The five substations will provide design templates for the installation of Fault Level Mitigation Technologies in other parts of GB.

Robust to capture the learning

`Learning Reviews' will be an agenda item at our monthly project steering review meetings. The learning will be captured using the same robust methodology, already employed on existing Future Networks projects in WPD's Programme of Work. Where appropriate this will be fully integrated with other active projects and will be disseminated to project suppliers.

In addition, 'expert challengers' have been identified to ensure that the Trials proceed in a robust way and to provide independent verification of the Methods at key project gateway reviews.

2.4 Changes since Initial Screening Process (ISP)

No substantial changes to the scope or financing of the project.

Through technology and specific site investigation, the project has been considerably de-risked.

....

[13] Birmingham City Council, 'Birmingham: Climate change action plan 2010+', Mar 2010.

2: Project Description Images, Charts and tables.

Figure 2.1a
Fault Current Flow in Split Configuration

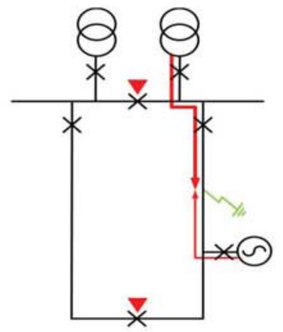


Figure 2.1b
Fault Current Flow in Solid Configuration

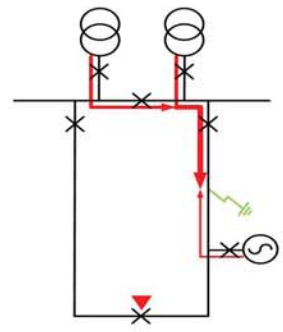


Figure 2.2a
Base case connection capacity

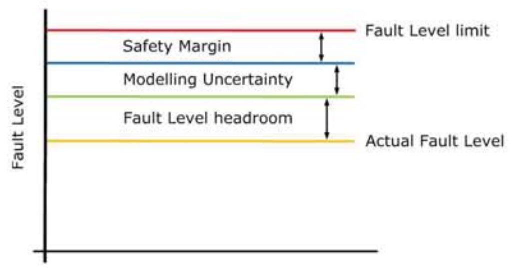


Figure 2.2b
Potential connection capacity unlocked through Method α

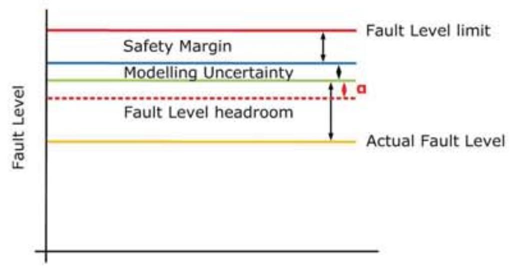


Figure 2.2c
Potential connection capacity unlocked through Method β

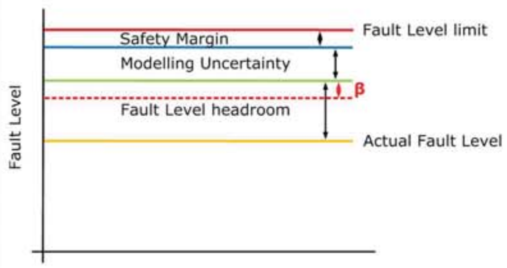


Figure 2.2d
Potential connection capacity unlocked through Method γ

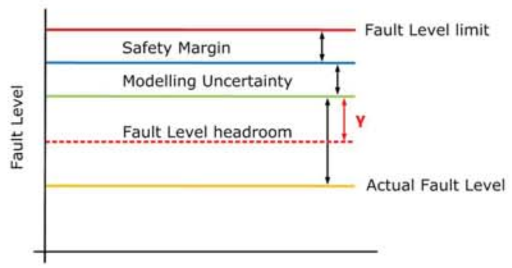


Figure 2.2e
Potential connection capacity unlocked through Methods α, β and γ

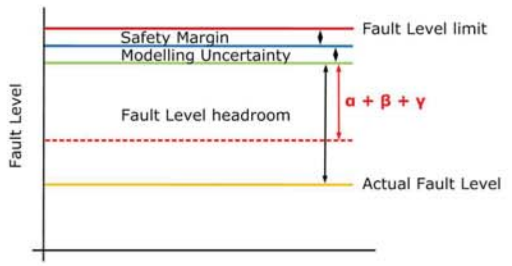


Table 2.1- Summary substation selection table

Driver for substation selection and associated CHP integration	Proposed substation for Fault Level mitigation	Proposed substation for Fault Level monitoring
Health and safety	A	A, G , J
I&C (Airport and Exhibition Centre)	B	B
Public services development (Library and Hospital)	C , E	C , E
Residential development	D	D, I
Future projected demand growth		F, H

Section 3: Project Business Case

Section Summary

Fault Level-related capital expenditure for UK DNOs has increased from DPCR4 to DPCR5 and is expected to continue increasing because of an escalating demand for DG connections and a consequential reduction in Fault Level `headroom' available in existing networks.

Traditional reinforcement schemes involve significant investment in higher-rated network assets; as a consequence, DG connections requiring reinforcement cost more and take longer to provide. The proposed Solution will avoid these issues using retrofit technologies.

Birmingham is typical of regions throughout GB requiring Fault Level reinforcement and has been selected to host Trials because the cost of deploying Fault Level solutions delivers greater value to customers than alternative Trial locations.

DNO business benefits, above and beyond capex and project time savings, include improvements in customer service, and enhanced public/employee safety.

The implementation of the Solution will provide a number of environmental and sustainability benefits which are also identified in DECC's Carbon Plan, including greater efficiency in generating heat and electricity leading to CO_2 emission reductions.

Background

From DPCR 4 to DPCR 5, the total Fault Level-related capital expenditure for UK DNOs has more than tripled from £41.3M to £131.6M[14]. This capital investment is driven by increased connections, such as CHP generation plant, which increase Fault Level and fault current flows during fault conditions.

If the capital expenditure continues to increase at the same rate, as DG connections to the network become more prevalent, the total investment across the GB during RIIO-ED1, based on conventional solutions, would be £670.9M. This demonstrates the case for innovative solutions that facilitate similar, or increased, levels of DG integration without costly reinforcement. Innovative solutions will deliver direct savings to generation customers through cheaper connections. All customers would see lower growth of socialised tariffs as a result of reduced network reinforcement costs. Conventional solutions are not only more expensive but also lead to delays in generation connections. Furthermore, Fault Level driven asset replacement means that healthy assets are being upgraded prematurely, in some cases many years before the end of their design lifetime.

Birmingham has been selected to host Trials for a number of reasons. If assessed on a £/capita basis, the cost of deploying Fault Level solutions delivers greater value to customers, due to the customer density of the urban environment, than alternative Trial locations. Also, Birmingham represents a typical urban regeneration environment and the CHP integration issue is a Problem faced by many other UK cities, as seen in Appendix B3.

....

[14] Ofgem, `Further update to the cost assessment', Oct 2009.

3: Project Business Case contd.

DG offers many benefits, such as reducing losses through reduced electricity miles[15], increased security of supply by dispersing generation over a greater physical area and enabling islanding[16] as an appropriate network provision. Furthermore, the reduced carbon emissions associated with combined heat and power plants lead to additional energy efficiencies. Hence DECC is incentivising the development of CHP and offering attractive `green' investment opportunities[17].

Trialling the Methods will develop low-risk Solutions to the Problem that will not impede or in any way delay the connection of new generation or demand customers. The equipment to support the Fault Level Management and Fault Level Mitigation Methods can be readily installed as retrofit technologies within existing Substations.

If innovative Solutions, such as the Methods proposed for the Trials in this project, are not deployed, investment in less efficient transformers, upgraded cables and higher-rated circuit breakers will still occur through future regulatory price control review periods. However, customer connections will be more costly and take longer to complete. Costs to individual customers will be higher due to network reinforcement, as will the socialised cost. The proposed Solution will avoid these issues, provide learning above and beyond conventional solutions and accelerate the transition towards a low carbon economy.

Project deliverables

This project will deliver the following:

1. An Enhanced Fault Level Assessment process to improve the accuracy and precision of Fault Level calculations.
2. Real-time Measurement to further refine the accuracy and precision of Fault Level calculations, indicating available headroom to DNO operation and network planning teams.
3. Trialling the installation and operation of Fault Level Mitigation Technologies on a system-wide level, which will demonstrate the extent to which conventional solutions can be delayed or deferred completely.

Additional learning (Potential for new learning)

As seen in Figure 3.1, this project addresses a gap in the current Trials that are being financed through the Low Carbon Networks Fund mechanism. No other Tier-2 projects investigate Fault Level constraints. The differentiators and learning from other previous IFI, ETI and LCNF projects are given in Appendices O and N respectively.

....

[15] Electricity miles - Representation of the physical electrical distance between generation and demand. The greater the distance, the greater the electrical losses associated with the electricity network.
[16] Islanding - Use of distributed generation to provide network supply during loss of mains generation provision.
[17] Department of Energy and Climate Change (DECC), 'CHP incentives', 2012.

3: Project Business Case contd.

Changes to the WPD business in the next 5 - 10 years

WPD's key goals include customer service, reliability of the network and efficiency of operation. In this Project we will contribute with:

- Further improved customer service and flexibility, responding to connection applications more quickly and giving customers more informed cost estimates of connections, without compromising on the standard and quality of service provided;
- Further improved customer service in terms of security of supply and reliability, reducing customer interruptions and customer minutes lost, whilst providing cheaper and quicker network connections;
- Further improved operational safety of personnel;
- Further informed strategy investment decisions, moving into RIIO-ED1 and avoidance of stranded assets or the need for premature replacement of assets; and
- Increased understanding of Fault Level issues.

Financial benefits delivered by this project

Quantification of installation costs

The traditional solution to Fault Level problems, changing transformers, in a dense urban environment costs in the region of £4M. This Solution has been seen to unlock headroom of 3MW, based on a 4.5MVA/MW fault in-feed[18], meaning the installation cost is £1.33M / connected MW of generation.

The installation of a Fault Level Mitigation Technology may cost £2M with an unlocked generation capacity connection headroom of 22MW, based on a 4.5MVA/MW fault in-feed, if the project proves successful. The installation cost for this Solution is £91k / connected MW of generation.

This represents a substantial decrease in the installation cost and unlocks over seven times the capacity for DG accommodation, compared to the conventional reinforcement solution. The variables in the installation costs are: The type of generation and therefore the fault in-feed contribution, ranging from between 1 - 6 MVA / MW; The cost of Fault Level Mitigation Technologies, £1M - £2M; Transformer replacement costs £2M - £4M; and the location of installation.

If the most expensive Fault Level Mitigation Technology and the cheapest conventional reinforcement options are compared, the capacity for DG connections could still be increased seven-fold if the Fault Level Mitigation Technology option is chosen.

....

[18] Department of Trade and Industry (DTI),'The contribution to distribution Fault Levels from the connection of distributed generation', May 2005.

3: Project Business Case contd.

Method costs and extrapolation

Detailed Base Case Costs, Methods Costs and extrapolation assumptions are given in Appendix J.

Method Alpha: The cost of assessing customers' connection applications is £216k / year for the base case Method, compared to £144k / year for Method Alpha. Once fully implemented as Business as Usual, the financial saving of Method Alpha (Enhanced Fault Level Assessment) could be £1M / year. This represents a UK saving of £10M over a ten year period.

Method Beta: The cost of implementing Method Beta in to a single Primary Substation is £300k. There is currently no efficient method for comparison; therefore this represents a GB expenditure of £84M over a ten year period. To ensure that benefits of the Project are not duplicated, all benefits for Method Beta and Method Gamma are represented in Method Gamma.

Method Gamma: The cost of reinforcing a single Primary Substation by up-rating switchgear would be £9.7M. This represents the most efficient method currently in use on GB distribution systems in order to unlock the required capacity for customers' connections to meet carbon reduction targets. Once fully implemented as Business as Usual, the financial saving of Method Gamma (Fault Level Mitigation Technologies) could be £38.4M throughout the trials area. This represents a GB saving of £1075M over a ten year period.

Upgrading transformers unlocks limited capacity for customers' connections. Therefore, extensive switchgear and cable upgrades would be needed to make the conventional solution comparable to the innovative Solution.

Generation customer benefits delivered by this project

If proved successful, implementation of the Trialled Methods would position DNOs to respond to generation and demand connection applications more quickly, increasing the efficiency of a DNOs customer service and facilitating quicker customer connections to the electricity network. Furthermore, generation and demand connection customers can be provided with more accurate cost estimates, allowing the customers to connect to the network more cost-effectively.

Benefits to all customers:

The reduced cost of network investment could lead to lower overall socialised costs. The location and integration of distributed generation close to large centres of demand will reduce losses and lead to a reduction in the increase of Distribution Use of System (DUoS) charges. The security of supply benefits, resulting from the operation of transformers in solid configuration will lead to reduced CIs and CMLs.

3: Project Business Case contd.

Applicability of learning to other DNOs

Birmingham is a large city, with an electricity network designed to cope with a dense urban environment's needs. This typifies the urban electricity networks found within other parts of WPD West Midlands' DNO area and that of DNOs throughout GB.

In Table 3.1, the percentage of substations with Fault Levels greater than 80% of the switchgear rating are summarised for each DNO. This demonstrates the applicability of the learning to other DNOs.

In Table 3.2, Fault Level-related capital expenditure is summarised. WPD West Midlands has increased its Fault Level-related capital investment significantly from DPCR4 to DPCR5. This is also the case for other DNOs: Northern Power Grid (for both Yorkshire and the North East), UK Power Networks (across the Eastern parts of the network) and Scottish Power (both North and South licence areas). With the GB wide increase in generation connection applications, the Fault Level-related capital investment is likely to increase further in future Distribution Price Control Review periods.

Most DNOs will have the same 132 / 11kV transformer units which will have been sourced from the same base of manufacturers and suppliers. Also, 11kV network infrastructure assets are found commonly across the UK, with standardised design practices for the 11kV network across GB.

The learning, and potential loss reductions (as seen in Appendix C3), derived from operating transformers in parallel will be applicable to all DNOs.

This project also compliments the learning outcomes from other LCNF projects (as seen in Appendix N), for example ENW's `Capacity to Customers' project uses a circuit selection methodology that is required to *"avoid circuits fed from primaries which are run split owing to extant fault level constraints preventing solid operation"* [19]. They also note that *"closing radial feeders to create a closed loop is likely to increase fault levels slightly, which may be problematic in the rare locations where fault levels are already close to equipment ratings, and particularly undesirable for the connection of new generation customers in urban networks when fault level margin is limited."* This indicates that the Fault Level issue already exists in their networks, or that Fault Level issues are anticipated in the near future.

The learning from this project will be highly applicable to other DNOs and will extend the knowledge and understanding gained from trialling Fault Level Mitigation Technologies on an individual basis, to demonstrate the application and integration of Fault Level Mitigation Technologies on a system-wide level. Fault Level is a key topic of discussion between DNOs at dissemination events and it has been selected by the DNOs to have a dedicated workshop at the 2012 LCNF conference.

....

[19] Electricity North West, 'Low Carbon Networks Fund full submission pro-forma: Capacity to Customers (C_2C), Appendix 10 - Description of the methodology for the selection of HV and 33kV circuits to be included within the trial', 2011.

3: Project Business Case contd.

Environmental and sustainability benefits delivered by this project

The implementation of the Solution will provide a number of environmental and sustainability benefits:

1. CHP integration will lead to greater efficiency in generating heat and electricity leading to CO_2 emission reductions.
2. Installing CHP close to large demand centres delivers CO_2 emission reductions due to minimised electricity miles.
3. The installation of Fault Level Mitigation Technologies could allow network energy efficiencies. This would reduce electricity losses by 120,000 kWh (corresponding to a saving of 51 tCO_2) on an annual basis.

Other project benefits:

Wider industry benefits include informing equipment manufacturers of DNOs' technology needs in making the transition towards a future network.

Industrial and Commercial customer benefits include the strengthening of the business case for CHP integration and the potential for reduced electricity costs, which in turn reduces the operational expenditure for industrial and commercial businesses.

Health and safety benefits delivered by this project include improved safety of WPD operational staff through real-time Fault Level monitoring of Primary Substations. Also, automated switching sequences will be used to manage the risk of exceeding Fault Level switchgear ratings.

3: Project Business Case images, charts and tables.

Table 3.1 Substations with Fault Levels greater that 80% of the switchgear rating

DNO's Name	Area	% of substations with Fault Levels > 80% of the switchgear rating	
		33kV	11 / 6.6kV
Electricity North West	North West	14	9
Northern Power Grid	NEDL	13	42
	YEDL	16	34
Scottish Power	SP Manweb	32	Not available
	SPN	34	8
Scottish and Southern Energy Distribution	SEPD	12	14
	SHEPD	1	2
UK Power Networks	London Network	39	21
	East Network	50	7
	South East Network	25	14
Western Power Distribution	East Midlands	15	20
	West Midlands	10	6
	South Wales	15	14
	South West	6	7

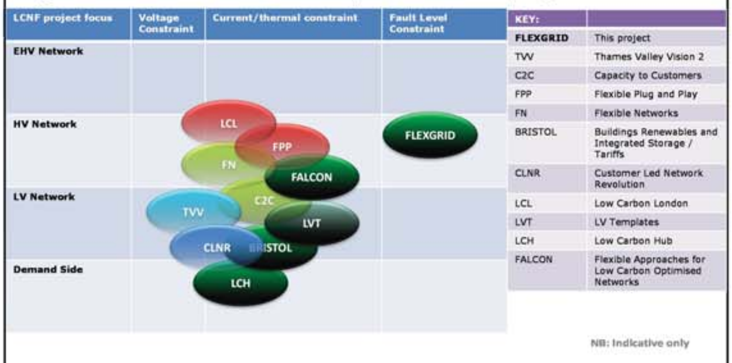
Source: DNO Long Term Development Statements

Table 3.2 Fault Level related capital investment

DNO's Name	Area	DPCR4 actual (£m)	DPCR5 forecast (£m)	OFGEM baseline updated (£m)
Electricity North West	North West	4.8	2.5	2.5
Northern Power Grid	NEDL	1.0	8.9	8.9
	YEDL	2.7	14.1	14.1
Scottish Power	SP Manweb	5.9	14.7	14.7
	SPN	1.1	17.3	17.3
Scottish and Southern Energy Distribution	SEPD	1.2	4.3	4.3
	SHEPD	0.1	2.0	2.0
UK Power Networks	London Network	4.1	1.3	1.3
	East Network	2.8	28.3	25.1
	South East Network	0.6	3.0	3.0
Western Power Distribution	East Midlands	17.0	9.4	9.4
	West Midlands	0	25.8	25.4
	South Wales	0	0.7	0.7
	South West	0	2.9	2.9
Total		**41.3**	**135.2**	**131.6**

Source: Ofgem, 'Electricity Distribution Price Control Review, Further update to the cost assessment', Oct 2009

Figure 3.1 Differentiators from previous LCNF projects



Section 4: Evaluation Criteria

Section Summary

Facilitating the Carbon Plan: ***The UK Government has identified distributed generation (DG) as a major low carbon energy enabler and an important part of the future electricity generation mix: In cities DG will enable the supply of low carbon heat and power to both public and private sector customers. Birmingham City Council has a policy to integrate CHP into new developments in order to support their target to provide a 60% carbon reduction by 2026.***

Low Carbon Electricity: ***This project will help unlock capacity to support district heating networks, particularly in urban areas with more densely packed demand for heat. The learning from the Project will be transferable to rural environments that exhibit Fault Level issues.***

Value for money to distribution customers: ***If the cost of network reinforcement to facilitate Fault Level reduction was to be socialised across the distribution customers in Birmingham, as is currently the case due to Fault Level reinforcement not being fully chargeable to new connecting customers (as described in section 2.2), this would result in approximately £150 per distribution customer. If the cost of Method Gamma in the Advanced Fault Level Management Solution was to be socialised across distribution customers in Birmingham, this would result in approximately £31 per distribution customer. This represents an 80% reduction in the socialised cost of delivering low carbon electricity infrastructure for Birmingham.***

Knowledge that can be shared amongst all DNOs: ***If successful, FLEXGRID can be used as a long-term planning and operational solution, when offering new connections' customers alternatives to conventional reinforcement, when integrating load or generation into the distribution network.***

Project Partners: ***The University of Warwick and Parsons Brinckerhoff, as project partners, will bring complimentary skills in delivering the academic analysis and practical development of the project objectives.***

Facilitating the Carbon Plan

The Carbon Plan aims to deliver carbon emission cuts of 34% on 1990 levels by 2020. This national target is devolved, in part, through local government carbon emission reduction targets as set out in their strategy planning documents. The Carbon Plan sets out ways to generate 30% of the UK's electricity from renewable sources by 2020 in order to meet the legally binding European Union (EU) target to source 15% of the UK's energy renewable sources by 2020.

The UK Government has identified distributed generation (DG) as a major low carbon energy enabler and an important part of the future electricity generation mix[20]. By facilitating the integration of DG within the built environment, this project will accelerate the development of a low carbon energy sector. Specifically for cities it will enable the supply of low carbon heat and power to both public and private sector customers.

Birmingham City Council has a policy to integrate CHP into every new development (domestic developments over 50 homes and Industrial and Commercial (I&C) developments over 1000 m^2) in order to support their target to provide a 60% carbon reduction by 2026 [21]. This project will position WPD to respond to Birmingham's low carbon initiative whilst informing DNOs of solutions to accommodate DG within Fault Level-constrained electricity networks. Additional benefits may be created through electricity network efficiency improvements. Installing DG closer to large electrical demand centres reduces the losses associated with transmitting and distributing electrical power.

....

[20] Department of Energy and Climate Change (DECC), '2050 Pathways Analysis', Jul 2010.
[21] Birmingham City Council, 'Birmingham: Climate change action plan 2010+', Mar 2010.

4: Evaluation Criteria contd.

This project also supports the Carbon Plan in paving the way towards a `smarter' electricity grid in the UK, and will accelerate the development of a low carbon energy sector by creating more choice for customers, allowing generation to connect more quickly and cost-effectively to the electricity network.

Aspects of the Carbon Plan which the Solution facilitates

Low Carbon Electricity: The three Methods being tested in this project will unlock capacity to facilitate the integration of low carbon generation. The distribution electricity sector will need to deliver an increase of 30 - 60% of electricity demand flow in order to facilitate the electrification of heating, transport and industrial processes. Through this project the integration of low carbon generation could support significant demand increases in urban environments.

Low Carbon Buildings: This project supports the strategic initiative to work with local authorities, where appropriate, to lay the foundations for district heating networks, particularly in urban areas with more densely packed demand for heat. This should enable the long term delivery of heat from low carbon sources.

Low Carbon Industry: This Solution would lay the foundation for industry to play an active role in the future energy markets through demand side management[22] and DG.

Low Carbon Transport: As the demand for electricity will significantly increase with the advent of electric vehicle integration, this project will support this demand increase by facilitating the integration of DG close to large demand centres.

Agriculture, Land Use, Forestry and Waste: This Project prioritises urban environments, where there is the greatest Fault Level problem. The Project facilitates the connection of Energy from Waste[23] (EfW). Birmingham City Council already has a significant EfW plant[24] connected, which has been in operation since 1996.

Contribution made by the roll out of the Methods to facilitate the Carbon Plan

At present, the initial capital outlay incurred by the developers of low carbon generation as a result of network reinforcement requirements may be prohibitive to the timely and cost effective integration of the customers' connections.

The roll out of the proposed Methods across GB has significant potential to facilitate the early and cost-effective integration of customers' generation connections. The Methods could provide key tools to DNOs in overcoming the barrier that network reinforcement is to facilitating the above mentioned aspects of the Carbon Plan.

....

[22] Demand side management - Actions undertaken by distribution network operators to influence customers to change their electricity use, in terms of quantity and/or time of use.
[23] Energy from Waste (EfW) - Burning of waste which would otherwise go to landfill to produce heat and/or electricity.
[24] Tyseley Energy from Waste plant converts 350,000 tonnes of Birmingham's waste into electricity each year. Birmingham City Council, `What happens to our waste'.

4: Evaluation Criteria contd.

Outline of the potential carbon benefits across the total energy sector

Once fully deployed, the roll out of the Methods across GB could be reasonably expected to deliver 5.05 $MtCO_2$ / year emissions reduction across the total energy sector, if widespread CHP adoption takes place as indicated by DECC. The breakdown of this figure is provided in Table 4.1.

Financial benefit: Trialling new Methods that deliver a lower cost Solution than most efficient current methods used in GB

The following financial analysis has been completed at the project scale showing the benefit at the scale of the project.

Method Alpha - Enhanced Fault Level Assessment

Base Case Cost: The most efficient method currently in use on the GB Distribution System would be for a planning engineer to conduct a system study to assess the impact of customers' connections. The typical HV connection study time is 3 days per connection, costing approximately £900 per connection.

Method Cost: The Enhanced Fault Level Assessment processes are expected to reduce the connection study time from 3 days to 2 days, through refinements and constructed network models, costing approximately £600 per connection.

Financial Benefit: On the basis of the volume of connection studies received per year, the financial benefit of the project to WPD West Midlands would be £72k per year.

The customer benefit of this Method is impossible to quantify exactly, however if this Method is successful it could save conventional reinforcement. An example of which in WPD was a cost in the region of £4M to connect 0.75MW of generation.

Method Beta - Real Time Fault Level Management

Base Case Cost: There is currently no base case (conventional) method for the Real-time Management Method. The financial cost of implementation would be significant for each DNO licence area.

Method Cost: The Real-time Fault level Management Method is expected to cost £300k per substation.

Financial Benefit: The Base Case Cost has not been quantified, and therefore assumed to be zero. On the basis of monitoring installations in the ten substations proposed in this project, the financial benefit of Method Beta would be -£3M.

The customer benefit of this Method is impossible to quantify exactly, however if this Method is successful it could save conventional reinforcement. An example of which in WPD was a cost in the region of £4M to connect 0.75MW of generation.

4: Evaluation Criteria contd.

Method Gamma - Fault Level Mitigation Technologies

Base Case Cost: The most efficient method currently in use on the GB Distribution System would be to upgrade the network equipment (switchgear and cables) to accommodate the required level of low carbon generation integration. The approximate cost of this method would be £9.7M per Primary Substation (Project cost £48.4M) across the five selected substations.

Method Cost: The Fault Level Mitigation Technologies Method would be expected to deliver the same level of low carbon generation integration but cost in the region of £2M / substation (Project cost £10M - across 5 substations).

Financial Benefit: Considering the five substations proposed for Trials in this project, the financial benefit is estimated to be £38.4M.

4: Evaluation Criteria contd.

Quickly releasing capacity

Method Alpha could release up to 10% Fault Level capacity per HV substation being considered in this project. 10% Fault Level capacity corresponds to 25 MVA Fault Level capacity headroom and 5.6 MW connection capacity headroom[25] per substation. On the basis of the ten substations being considered in this project, 56 MW connection capacity headroom could be released. Using traditional reinforcement methods would take in the region of three years to complete. Method Alpha could release this capacity within 12 months.

The capacity Method Alpha could release across GB is 1568 MW within 12 months of the full deployment of the Method, based on deployment at two locations per DNO licence area.

Method Beta could release up to 10% Fault Level capacity per HV substation being considered in this project. 10% Fault Level capacity corresponds to 25 MVA of Fault Level capacity headroom and 5.6 MW connection capacity headroom per substation. On the basis of the ten substations being considered in this project, 56 MW of connection capacity headroom could be released. The alternative reinforcement method would take three years to complete. Method Beta could release this capacity within two years.

The capacity Method Beta could release across GB is 1568 MW within two years of the full deployment of the Method.

Method Gamma could release 50%[26] Fault Level capacity per HV substation being considered in this project. 50% Fault Level capacity corresponds to 125 MVA of Fault Level capacity headroom and 27.7 MW connection capacity headroom per substation. On the basis of the five substations being considered in this project, 138.5 MW of connection capacity headroom could be released. The alternative method reinforcement method would take three years to complete. Method Gamma could release this capacity within three years also.

The capacity Method Gamma could release across GB is 3878 MW within three years of the full deployment of the Method.

Method Alpha, Beta and Gamma combined is expected to release the summation of the individual Methods' capacity plus 10%, a conservative assessment to be validated by the project, from the benefit of applying the Methods together.

Method Alpha: 5.6MW
Method Beta: 5.6MW
Method Gamma: 27.7MW

Methods combined: 42.79MW / substation

……………………………………

[25] Based on a Fault Level limit of 250MVA and a Fault Level in-feed of 4.5 MVA / MW.
[26] Average from received Request for Information (RfI) responses.

4: Evaluation Criteria contd.

(b) Provides value for money to distribution customers

The size of benefits delivered to customers

This project aims to create greater choice for customers and developers, allowing them to connect more quickly and cost-effectively to the electricity network. This could be of particular benefit in cases where network reinforcement can be deferred or avoided.

If the cost of network reinforcement to facilitate Fault Level reduction was to be socialised across the distribution customers in Birmingham, as is currently the case due to Fault Level reinforcement not being fully chargeable to new connecting customers (as described in section 2.2), this would result in approximately £150 per distribution customer. If the cost of Method Gamma in the Advanced Fault Level Management Solution was to be socialised across distribution customers in Birmingham, this would result in approximately £31 per distribution customer. This represents an 80% reduction in the socialised cost of delivering low carbon electricity infrastructure for Birmingham[27].

Open competitive procurement processes for services and equipment

During the bid development phase, an open and competitive procurement process was initiated for academic services and product supply. An Expression of Interest was distributed to 14 academic institutions across the UK with a proven track record in electrical distribution research. Using the Achilles database, Requests for Information were distributed to suppliers of Fault Level mitigation equipment, Fault Level monitoring equipment and voltage conditioning unit equipment.

In order to deliver the best value to customers and ensure fair market prices, this project will select technology vendors through a competitive process, which will be a full tender process on award of the project in line with the current EU procurement legislation.

Where it is most appropriate WPD will utilise existing framework agreements, using systems already in place to provide best value for money to customers.

………………………………………

[27] Based on £48.5M network reinforcement, £10M to deliver Method γ and 323,000 distribution customers in Birmingham.

4: Evaluation Criteria contd.

(c) Generates knowledge that can be shared amongst all DNOs

Outline of Incremental Learning

The following incremental learning is expected to be provided by the project:

- Developing novel connection processes which, by being shared with other DNOs, can be applied to all UK networks with Fault Level constraints for new connections;
- Building on the learning outcomes from previous IFI, ETI and LCNF trials, this project will accelerate the Technology Readiness Level (TRL) of Fault Level Management Technologies; and
- Helping to develop the business case that will attract and engage generators to adopt a more flexible solution (in line with the Carbon Plan) as opposed to a traditional fixed network reinforcement solution.

Due to the integrated nature of the project, Methods Alpha and Beta inform Gamma. The installation of Method Gamma will provide significant learning that will inform Methods Alpha and Beta. This means that the greatest benefit is gained through the implementation of all three Methods. The integrated Method approach is given in Figure 4.1.

Applicability of the new learning to other DNOs

Through investigation of all DNOs Long Term Development Statements (LTDS)[28], all DNOs have Fault Level issues to a greater or lesser extent, which are likely to become more severe.

At present all DNOs plan for worse-case Fault Level contribution and equipment ratings when planning demand and generation connections. By gaining a more in-depth understanding of the assumptions that underpin Fault Level calculations, this will enhance network knowledge and allow these assumptions to be verified and refined.

Through the advanced modelling and measurement carried out an open-source Fault Level quantification methodology will be developed. This methodology will use probabilistic approaches that can be shared with all DNOs.

New Fault Level monitoring equipment will allow the monitored Fault Level to be compared with the calculated Fault Level. This will generate new learning by analysing the differences between monitored and calculated values. This knowledge can be used to inform network planning and operational decisions, to increase network utilisation.

……………………………………

[28] Long Term Development Statement (LTDS) - Statement published annually by DNOs to make network information available to the public domain. This enables anyone interested in connecting generation or load to the network to identify opportunities or constraints on the network.

4: Evaluation Criteria contd.

(d) Involvement of other partners and external funding

Outline of Project Partners and why they are appropriate

The resources to deliver the Project are of a sufficient size and quality to ensure delivery. A summary of the project partners (Parsons Brinckerhoff and the University of Warwick) is given below. Detailed partner descriptions are given in Appendix H.

Parsons Brinckerhoff

Parsons Brinckerhoff will provide technical engineering consultancy services, including electricity network modelling, independent advice on equipment installations, document control, quality assurance, technical knowledge transfer and support broader learning dissemination.

Parsons Brinckerhoff is contributing to the support and delivery of other Tier-1 and Tier-2 Low Carbon Networks Fund projects, hence are familiar with LCNF governance arrangements and the overall objectives.

Parsons Brinckerhoff has worked with WPD in the area of Fault Level management and has provided support on this project since initial conception. WPD is working with Parsons Brinckerhoff on the Tier-1 project "Implementation of an Active Fault Level Management Scheme". The Tier-1 project will feed in to and inform this Tier-2 project. Parsons Brinckerhoff are a partner on this Tier-1 project.

The University of Warwick

The University of Warwick (UoW) will be providing academic engineering support with the real-time monitoring of Fault Levels, the development of Fault Level management and Fault Level mitigation strategies. They will also support the broader learning dissemination.

Through the involvement in this project the UoW will also support research in to the social and economic impact of enabling DG to connect to the electricity network through Fault Level management and mitigation.

The UoW will also be required to integrate with the University of Bath who are responsible for knowledge management on WPD's existing Tier-2 projects.

How secure is the funding?

There is a Memorandum of Understanding (MoU) in place with both Parsons Brinckerhoff and the University of Warwick and framework contracts have been drafted ready to be confirmed on notification of project award.

WPD and all project partners are committed to providing at least 10% contribution of the total Project cost.

4: Evaluation Criteria contd.

Third Party participation in the Project

WPD makes use of the ENA's LCNF section on their website and the Achilles database. WPD is currently working with Achilles to discuss the merits of providing an LCNF search criteria to further support industry in taking an active role in LCNF projects.

WPD now has mature processes for actively seeking ideas for projects and making interested parties aware of LCNF collaboration opportunities. WPD's group mailbox has received over a hundred queries in 12 months, as well as having an up to date website requesting ideas. The Future Networks Team review every query/proposal received and a reply is provided to all.

The WPD evaluation process includes a concept form which helps determine whether the best projects and ideas would be progressed under the 1st or 2nd Tier LCNF mechanisms.

The Health and Safety Executive (HSE) would be involved, as they would when new equipment or practices are introduced to the distribution network. During the detailed design phase of the project WPD engineers will determine the elements of the project that require HSE input and the relevant timings.

4: Evaluation Criteria contd.

(e) Relevance and timing

Addressing those developments associated with a move to a low carbon economy which are more likely to happen

This project focuses on facilitating the integration of low carbon generation and demand connections, such as CHP. CHP has been identified in the Carbon Plan as a key low carbon future enabler[29]. CHP is also a key low carbon enabler for DECC Pathways[30]. Birmingham City Council's Strategic Planning Document plans to deliver 60% carbon emission savings by 2026. Since the increased production of low carbon electricity has been identified as a likely means by which heat and transportation sectors are decarbonised, the Methods in this project address those developments associated with a move to a low carbon economy which are more likely to happen.

Use of the Methods in future business planning and impact on business plan submission in future price controls

If successful, FLEXGRID can be used as a long-term planning and operational solution, when offering new connections customers alternatives to conventional reinforcement, when integrating load or generation into the distribution network.

Solving technical constraints associated with DG integration

This project focuses on 11kV urban electricity networks which, as a result of CHP integration, experience Fault Level issues. Fault Level represents the first technical barrier to DG integration in these networks.

Other LCNF projects focus on voltage and thermal issues. As DG integration increases these networks too will start to experience Fault Level issues. By carrying out the proposed Trials in FLEXGRID the learning and processes will be generated ready to inform these projects. Through considered design processes Fault Level Mitigation Technologies will be deployed such that the impact on other technical issues (thermal and/or voltage) is minimised.

....

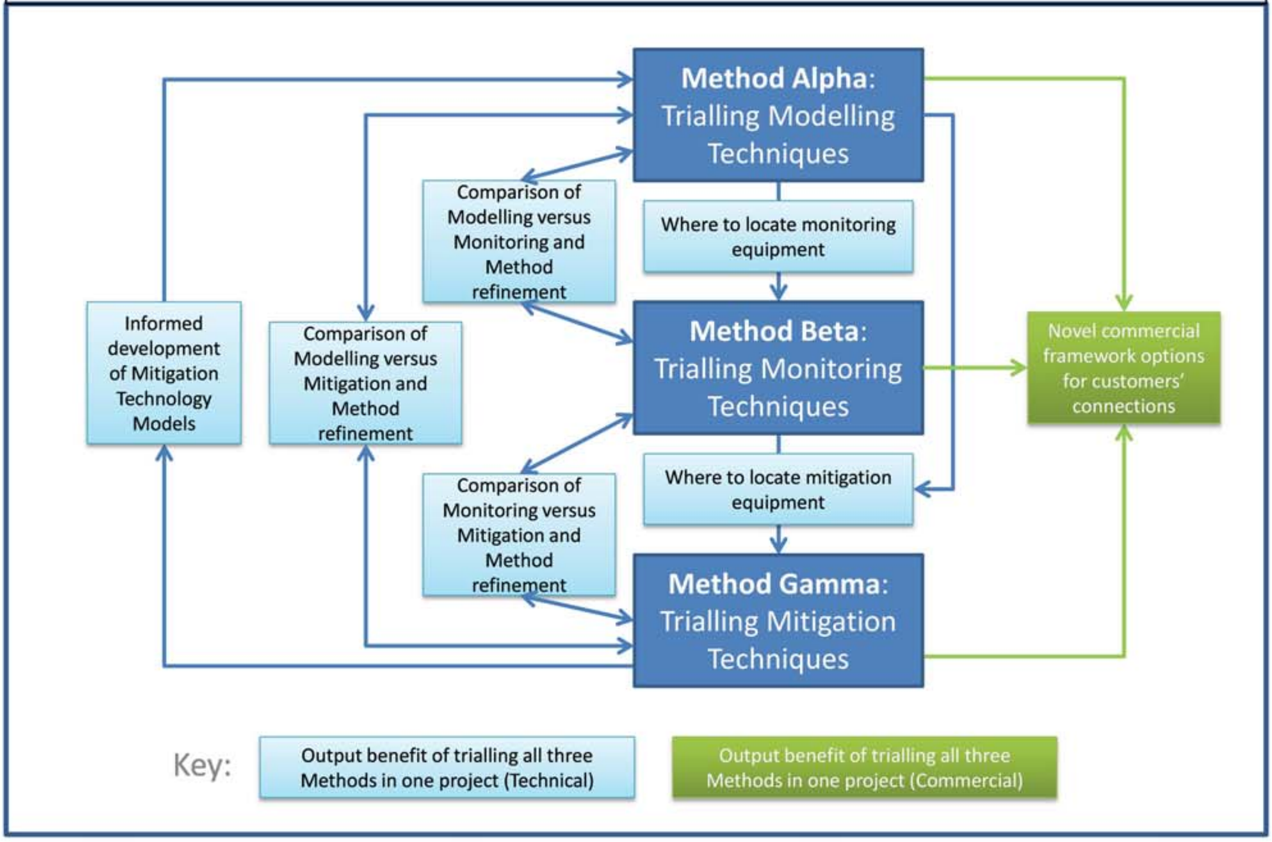
[29] Department of Energy and Climate Change (DECC), 'The Carbon Plan: Delivering our low carbon future', Dec 2011.
[30] Department of Energy and Climate Change (DECC), '2050 Pathways Analysis', Jul 2010.

4: Evaluation Criteria images, charts and tables.

Table 4.1 Summary of carbon emissions savings

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 (mT)
Scenario 1: 10% of homes in Birmingham	0.6	0.4	71.2	41,000	0.06
Scenario 2: Trial Fault Level Mitigation Technology substations	1.95	1.22	214.5	123,379	0.18
Scenario 3: 50% of homes in Birmingham	3.3	2.0	356.4	205,000	0.30
Scenario 4: 50% of homes in the UK	210	131	23,051	13,258,500	19.37
Scenario 5: 140 substations in the UK with Fault Level Mitigation Technologies	54.7	34.2	6,006	3,454,601	5.05

Figure 4.1 Integrated Method Approach



Project Code/Version No

Section 5: Knowledge dissemination

☐ Put a cross in the box if the DNO does not intend to conform to the default IPR requirements

Section Summary

Knowledge capture will include the development of Enhanced Fault Level Assessment processes together with the design, specification and installation of appropriate Fault Level Monitoring and Fault Level Mitigation Technologies; development of novel commercial frameworks; quantification of Fault Level headroom and potential customer connection capacity gains.

Key audiences include DNOs, Distributed Generation/CHP customers and developers and Academia. Six-monthly DNO workshops, open-source policy documents, and `Webex' sessions will provide knowledge exchange amongst DNOs. WPD also has a specific website to provide collaborative areas for project partners and interested parties, ensuring all key learning is captured and disseminated appropriately.

This project conforms with the default IPR requirements.

5.1 Learning dissemination

Knowledge capture

Since knowledge capture and dissemination is key to the success of this project, the importance of having a comprehensive plan for capturing new learning is recognised. In keeping with the driver to accelerate the development of low carbon technologies, it is important to ensure that early discoveries are disseminated straight away.

Key knowledge capture outputs

1. Knowledge capture from Method Alpha:
    - 1.1. Application of Enhanced Fault Level Assessment processes.
    - 1.2. DNO wide acceptability for new design and modelling methodologies.

2. Knowledge capture from Method Beta:
    - 2.1. Design and installation of Fault Level Monitoring equipment.
    - 2.2. Verification of the accuracy of current Fault Level modelling processes.
    - 2.3. Verification of the accuracy of the Enhanced Fault Level Assessment processes.

3. Knowledge capture from Method Gamma:
    - 3.1. Design and installation of Fault Level Mitigation Technology.

4. Knowledge capture from all Methods:
    - 4.1. Development of novel commercial frameworks.
    - 4.2. Quantification of Fault Level headroom and potential customer connection capacity gains associated with each separate Method and combinations of the three Methods.
    - 4.3. Cost-benefit analysis of the three Methods, separately and combined.

5: Knowledge dissemination contd.

Key audiences

Through the WPD websites[31], regular reports, publications and project updates will be made available to the key audiences identified below:

1. Other DNOs - will provide peer review of Method Alpha and be provided key learning and outputs as soon as available.
2. Generation customers / CHP developers - stakeholder engagement and workshops will be used to provide key information and take learning in to the project to best meet customers' needs.
3. Academia - Technical learning will be disseminated through reports and papers as well as at specific dissemination and knowledge sharing events.
4. Industry - Knowledge dissemination events will be organised to ensure that learning is appropriately shared with industry.

Other interested stakeholders, such as demand customers, Government, commercial and residential developers and standards bodies will be invited to web-based and public events.

Recognising the importance of collaboration and knowledge transfer within DNOs across GB, six-monthly DNO workshops will be organised. In addition, open-source policy documents will be made available and `Webex' sessions will be set up to allow low carbon knowledge exchange amongst DNOs. WPD also has a specific website[32] to provide collaborative areas for project partners and interested parties, ensuring all key learning is captured and disseminated.

5.2 IPR

Only required if a DNO does not intend to conform to the default IPR arrangements.

This project conforms with the default IPR requirements.

……………………………………

[31] www.westernpowerinnovation.co.uk; www.LowCarbonUK.com
[32] www.LowCarbonUK.com

5: Knowledge dissemination contd.

5: Knowledge dissemination images, charts and tables.

Knowledge dissemination images

Section 6: Project readiness

Requested level of protection require against cost over-runs (%). 0

Requested level of protection against Direct Benefits that they wish to apply for (%). 0

Section Summary

WPD's Board of Directors is fully engaged with FLEXGRID, from project inception and throughout the entirety of the bid process. The governance model includes a Project Steering Group comprising key stakeholders and decision makers within WPD and the partner organisations.

Project Plan: A high-level milestone plan has been constructed with input from our partners.

Project readiness considerations include consideration of project transition from bid to delivery; governance model; delivery team skills; partner and customer engagement; project logistics; and learning/experience from earlier projects.

Measures employed to minimise cost overruns and shortfalls include the use of WPD commodity items where possible, a phased project approach, strong project governance by WPD Senior Management, an initial detailed design phase, and rigorous risk management processes.

The project proposal has been prepared by Western Power Distribution in conjunction with Parsons Brinckerhoff, with information provided from other project partners and equipment suppliers.

In the event that the take up of low carbon technologies and renewable energy in the Trial area is lower than anticipated, the project plan will still deliver learning through demonstrating how the Fault Level technologies can be deployed in typical DNO substations.

Why the Project can start in a timely manner

Senior management commitment: WPD's Board of Directors are fully engaged with FLEXGRID, from project inception and throughout the entirety of the bid process. WPD's Board of Directors have obtained commitment from the directors of Pennsylvania Power and Light, WPD's parent company.

The governance model includes a Project Steering Group comprising key stakeholders, involving WPD senior management and the partner organisations. The internal Steering Group will be responsible for ensuring that FLEXGRID achieves its stated Successful Delivery Reward Criteria (Section 9). Our chosen partners have all committed to attending the Project Advisory Group, as evidenced by the letters of support contained in Appendix I.

6: Project readiness contd.

WPD internal stakeholder engagement: WPD has a low carbon and sustainability vision, focused through a single Future Networks Programme.

During the bid preparation stage, key internal stakeholders have been identified and actively engaged to ensure successful project delivery. These key project roles are defined in the project's organisational structure (see Appendix G). They are focussed on the key aspects of WPD's main business, such as Policy, Primary Network Design and Health, Safety and Environment.

WPD is currently delivering four of the ten existing LCNF Tier-2 projects. The valuable experience gained through these projects will help to ensure that FLEXGRID achieves a timely start and is delivered successfully.

Project Plan: A high-level milestone plan has been constructed with input from our partners. This plan is contained in Appendix D and provides a firm footing for detailed design activities to take place in a timely manner.

Project readiness considerations: In order to achieve a timely start, the planning of this project is critical and this has been represented by considering the key focus areas:

1. Seamless transition from bid to delivery;
2. Governance model;
3. Experienced delivery team;
4. Partner engagement;
5. Customer engagement;
6. Project logistics; and
7. Learning from 2010 and 2011 projects.

6: Project readiness contd.

Account of how the costs and benefits have been estimated

Estimation of costs

1. Costs (as given in Appendix A) have been calculated using a bottom up and top down methodology.

2. Project partners have quoted fixed prices for the majority of their services.

3. Conventional costs, feeding into the Base Case, have been estimated based on previous experience of implementing traditional solutions.

4. Method Costs have been estimated based on credible information from suppliers and citable sources.

Estimation of benefits

The benefits of the project have been estimated using projected HV investment as provided in Appendix J. In quantifying the benefits, a number of scenarios have been considered with varying levels of low carbon generation integration (see Appendix P).

Measures employed to minimise cost overruns and shortfalls in Direct Benefits

1. The costs have been calculated using a bottom-up and top-down methodology.

2. Costs for WPD commodity items have been used where possible to provide a greater level of certainty.

3. In line with the development and Trial of the three Methods, the project has been broken down into separate and distinct phases to provide a detailed overview of each area.

4. Strong governance will be implemented where project tolerances will be set by WPD Senior Management.

5. Through a detailed design phase, uncertainty in the project will be reduced at an early stage.

6. Risk management processes will be implemented throughout the project: In keeping with rigorous risk management processes, every risk will be assigned an owner, based on the risk rating and the ability of the individual to manage the risk (see Appendix E). An example contingency plan is given in Appendix F.

6: Project readiness contd.

Accuracy verification of information

1. The project proposal has been prepared by Western Power Distribution in conjunction with Parsons Brinckerhoff, with information provided from other project partners and equipment suppliers.

2. The bid has been prepared by a dedicated team of engineers, led by a single WPD project manager.

3. The proposal has been through independent checking processes, peer review processes and sent to project partners to ensure the accuracy of information.

4. Information provided from partners has been reviewed by WPD to ensure accuracy.

Planning for uncertain DG uptake

In the event that the take up of low carbon technologies and renewable energy in the Trial area is lower than anticipated, the project plan will still deliver learning in the following ways:

1. Method Alpha (Enhanced Fault Level Assessment) will still deliver benefits by informing WPD and other DNOs of the potential increase in precision of network modelling tools.

2. Method Beta (Real-time Management) will still deliver benefits by informing WPD and other DNOs of real-time changes in network Fault Level.

3. Method Gamma (Fault Level Mitigation Technologies) will still deliver learning since the Fault Level mitigation measures will allow Primary Substations to be operated with a solid network running arrangement, delivering potential loss reductions by equalling the load on parallel transformers and reducing CIs and CMLs. The Method would also still provide learning on the effectiveness and suitability of the Mitigation Technologies.

6: Project readiness contd.

The processes in place to identify project suspension

In order to ensure that the project proceeds smoothly, the project contains gateway reviews at critical stages in its lifecycle, which are clearly indicated in the Project Plan.

The aim of gateway reviews are to assess whether or not the project can progress successfully to the next stage. They provide assurance that the project is on track and being run in an efficient and cost-effective manner and give further assurance to stakeholders and project team members alike that the project can proceed.

The gateway review is a snap-shot at the point at which the review takes place. As such, recommendations are based on the documents provided and the review process is intended to be supportive and forward looking.

WPD senior management, with the Project Manager will:

1. Review the project plan, cost model and RAID log[33];
2. Review the output of the phase;
3. Assess outputs against the Successful Delivery Reward Criteria; and
4. Ensure that the best available skills and experience are deployed on the project.

WPD senior management will review and agree the risk level associated with the project and assign a status in the form of a Delivery Confidence Assessment. This assessment will then provide the Project team recommended actions. Actions fall in the following categories:

1. Critical (Do Now): to increase the likelihood of a successful outcome, it is of the greatest importance that the project should take action immediately;
2. Essential (Do By): to increase the likelihood of a successful outcome, the project should take action in the near future. Whenever possible, essential recommendations should be linked to project milestones and/or a specified timeframe;
3. Recommended: the project would benefit from the uptake of this recommendation. If possible recommended actions should be linked to project and/or a specified timeframe;
4. Halt the project: the project has exceeded the tolerances set and agreed at project initiation and the situation is deemed to be irrecoverable. The Project is to be halted and WPD senior management will contact Ofgem to discuss and agree the way forward.

This approach will give all the parties involved clarity and consistency from the outset.

....

[33] Risk, Assumption, Issues and Dependencies Log

6: Project readiness contd.

6: Project readiness contd.

6: Project readiness images

Project readiness Images

Section 7: Regulatory issues

☐ Put a cross in the box if the Project may require any derogations, consents or changes to the regulatory arrangements.

Section Summary

No derogation requirements have been envisaged for the application of Methods Alpha, Beta and Gamma.

Derogation requirements

No derogation requirements are envisaged for the application of Methods Alpha, Beta and Gamma. If any need arises WPD would apply through the normal channels.

Licence consents requirements

No licence consent requirements have been identified.

Licence exemptions requirements

No licence exemption requirements have been identified.

Regulatory arrangement change requirements

No changes to regulatory arrangements have been identified.

Are any of the above required for the Project or as contingency in the event the Project is not successful?

None of the above requirements have been identified as contingency in the event the Project is not successful.

7: Regulatory issues contd.

7: Regulatory issues images, charts and tables

Regulatory issues images

Regulatory issues images

Section 8: Customer impacts

Section Summary

This project will develop novel commercial frameworks, which will facilitate flexible connection options for generation and demand customers. Contracts and supplementary connection agreements will also be developed with appropriate customers, on an opt-in basis.

During the project, the University of Warwick will conduct research work on the socio-economic impact of CHP integration and Fault Level mitigation with specific focus on low income households in the Birmingham area. WPD will be involved in the facilitation of the CHP installation programme and in the management of associated local distribution networks. Following this analysis, further research work will be done to assess the social and economic benefits of FLEXGRID.

All customer involvement will be on a voluntary basis.

There are no planned customer interruptions. There is a minimal risk that this project could cause unplanned interruptions.

No protection from IIS penalties is sought.

Customer Engagement

Novel commercial frameworks

This project will develop novel commercial frameworks, which will facilitate flexible connection options for generation and demand customers to the distribution network. Contracts will be developed with customers, on an opt-in basis, that have the capability to be actively managed with short notice connections to, and disconnections from, the distribution network. For example, a generation customer may have flexibility to be disconnected from the distribution network when Fault Levels are assessed to be approaching allowable limits. The disconnection of the generation customer will reduce the potential fault current in-feed, ensuring the network Fault Level remains within allowable limits.

Supplementary connection agreements will be developed with Industrial and Commercial (I&C) customers participating in the Trials. For example, as given in Appendix I, Cofely is in support of this concept and, depending on the generation and demand applications received during the project timescale, the implementation of these contracts will be explored further.

8: Customer impacts contd.

Socio-economic impact of CHP integration and Advanced Fault Level Management

During the project, the University of Warwick will conduct research work on the socio-economic impact of CHP integration and Fault Level mitigation.

The research work aims to investigate the potential welfare effects of changes in overall expenditure and tariff structures for different social and income groups of customers. The specific focus will be on low income households in the Birmingham area, where WPD would be involved in the facilitation of the CHP installation programme and in the management of local distribution networks, which interact with the CHP plant.

Following this analysis, further research work will be done to assess the social and economic benefits of FLEXGRID.

All customer involvement will be on a voluntary basis.

Outline of interaction with customers' premises

Method Alpha: Enhanced Fault Level Assessment: The implementation of this Method in Phase 1 will have no adverse customer impact. However, there could be planned interaction with customers to gather the data to feed into the Enhanced Fault Level Assessment processes.

Method Beta: Real-time Management: The implementation of this Method in Phase 2 could involve planned interaction with customers and customers' premises to install additional Fault Level monitoring equipment.

Method Gamma: Fault Level Mitigation Technologies: There is no planned interaction with customers' premises as part of the implementation of this Method.

Number and duration of planned interruptions

Method Alpha: Enhanced Fault Level Assessment: There are no planned customer interruptions to Trial this Method.

Method Beta: Real-time Management: There are no planned customer interruptions to Trial this Method.

Method Gamma: Fault Level Mitigation Technologies: There are no planned customer interruptions to Trial this Method.

8: Customer impacts contd.

Risk of unplanned interruptions

Method Alpha: Enhanced Fault Level Assessment: There is no expectation of unplanned customer interruptions to Trial this Method.

Method Beta: Real-time Management: There is a minimal risk that the implementation of this Method could cause unplanned interruptions. The cause of the interruption would be mal-operation of the Fault Level monitoring device.

Steps have been undertaken to avoid unplanned customer interruptions. These include:

1. Rigorous factory acceptance testing and site acceptance testing of equipment prior to commissioning.
2. Development of Emergency Return to Service plans[34].
3. Appropriate protection of the conventional network with redundancy.

Method Gamma: Fault Level Mitigation Technologies: There is a minimal risk that the implementation of this Method could cause unplanned interruptions. The cause of the interruption would be mal-operation of the Fault Level mitigation device.

Steps have been undertaken to avoid unplanned customer interruptions. These include:

1. Rigorous factory acceptance testing and site acceptance testing of equipment prior to commissioning.
2. Development of Emergency Return to Service plans.
3. Appropriate protection of the conventional network with redundancy.

Protection from the Interruption Incentive Scheme (IIS) penalties

No protection from IIS penalties is sought.

....

[34] Emergency Return to Service (ERTS) plan - Strategy to restore supply to customers within a set time frame in the case of an emergency during a planned outage. For customers with more than one supply, the actions set out in the strategy would be used if the customer was to lose their alternative supply.

8: Customer impacts contd.

8: Customer impacts images, charts and tables

Customer Impacts images

Section 9: Succesful Delivery Reward Criteria

Criterion (9.1)

Specific: Develop an Enhanced Fault Level Assessment process.

Measurable: Workshop and report on 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.

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 1st June 2013, with the publication being available to other DNOs interested parties thereafter.

Evidence (9.1)

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.

Criterion (9.2)

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 1st December 2013, with potential adoption into BaU by the end of the project.

Evidence (9.2)

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.

9: Succesful delivery reward criteria contd.

Criterion (9.3)

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 1st June 2013.

Evidence (9.3)

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.

Criterion (9.4)

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 development, trialled and tested by the end of the project.

Evidence (9.4)

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.

9: Succesful delivery reward criteria contd.

Criterion (9.5)

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 December 2015.

Evidence (9.5)

1. Installation of equipment in ten Primary Substation sites.
2. Open-loop (non-network controlling) test results being disseminated.

Criterion (9.6)

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 December 2016.

Evidence (9.6)

1. Installation of equipment in five Primary Substation sites.
2. Dissemination of open-loop (non-network controlling) test results and system-level learning.

9: Succesful delivery reward criteria contd.

Criterion (9.7)

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 December 2016.

Evidence (9.7)

1. Dissemination of closed-loop (network controlling) test results and system-level learning.

Criterion (9.8)

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 December 2016.

Evidence (9.8)

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 at by December 2016.
    d. LCNF Annual Conference.
2. Publication of reports.

Section 10: List of Appendices

Appendix A - Costs

Appendix B - Maps

- B1 - Substations in Birmingham
- B2 - CHP development in Birmingham
- B3 - CHP development in the UK

Appendix C - Network Diagrams

- C1 - Network configurations
- C2 - Fault Level in-feed for split and solid configurations
- C3 - Losses for split and solid configurations

Appendix D - Project Plan

Appendix E - Risk Register

Appendix F - Contingency Plan

Appendix G - Organogram

Appendix H - Project Partners

- H1 - Parsons Brinckerhoff
- H2 - University of Warwick

Appendix I - Letters of Support

- I1 - Cofely District Energy
- I2 - Birmingham City Council
- I3 - Parsons Brinckerhoff
- I4 - University of Warwick
- I5 - University of Southampton
- I6 - University of Manchester

Appendix J - Base Case

Appendix K - Fault Level Monitoring: Business case and technical feasibility

- K1 - Business case and literature survey
- K2 - AFLMS Test Report
- K3 - Supplement to AFLMS Test Report (Waveform distortion and voltage considerations)

Appendix L - Overview of Fault Level Mitigation Technologies

Appendix M - Overview of Substations and suitability for Technology inclusion

Appendix N - Learning from IFI, ETI and LCNF projects

Appendix O - Differentiators from previous LCNF projects

Appendix P - Benefits

Appendix Q - Generation effect on Fault Level

Appendix R - Glossary of terms

Appendix A – Costs

A - Full Financial Spreadsheet submitted with the bid

Second Tier Funding Request

		2012/13	2013/14	2014/15	2015/16	2016/17	Total
Cost	*From Project Cost Summary sheet*						
	Labour	276.12	265.87	583.66	540.38	175.91	1,841.93
	Equipment	-	2,226.48	6,780.89	1,970.00	110.00	11,087.37
	Contractors	270.96	509.88	490.37	543.94	271.38	2,086.53
	IT	45.85	7.83	0.90	4.05	0.45	59.08
	IPR Costs	-	-	1.80	-	1.80	3.60
	Travel & Expenses	52.18	64.86	160.24	155.38	47.54	480.21
	Payments to users & Contigency	64.51	308.48	802.33	321.92	61.61	1,558.84
	Decommissioning	-	-	-	-	-	-
	Other	-	9.90	5.40	5.40	9.00	29.70
	Total	709.61	3,393.30	8,825.58	3,541.07	677.70	17,147.27
External funding	*Any funding that will be received from Project Partners and/or External Funders - from Project Cost Summary sheet*						
	Labour	10.00	8.84	4.45	5.00	3.53	31.82
	Equipment	-	264.28	835.17	208.71	0.10	1,308.27
	Contractors	13.65	36.46	39.32	43.66	26.10	159.19
	IT	0.22	0.62	0.08	0.34	0.05	1.30
	IPR Costs	-	-	0.15	-	0.20	0.35
	Travel & Expenses	2.25	3.37	3.11	3.72	2.01	14.46
	Payments to users & Contigency	2.61	31.44	88.27	26.19	3.30	151.81
	Decommissioning	-	-	-	-	-	-
	Other	-	0.78	0.45	0.45	0.99	2.67
	Total	28.72	345.79	971.01	288.07	36.28	1,669.87
DNO extra contribution	*Any funding from the DNO which is in excess of the DNO Compulsory Contribution - from Project Cost Summary sheet*						
	Labour	-	-	-	-	-	-
	Equipment	-	-	-	-	-	-
	Contractors	-	-	-	-	-	-
	IT	-	-	-	-	-	-
	IPR Costs	-	-	-	-	-	-
	Travel & Expenses	-	-	-	-	-	-
	Payments to users & Contigency	-	-	-	-	-	-
	Decommissioning	-	-	-	-	-	-
	Other	-	-	-	-	-	-
	Total	-	-	-	-	-	-
Initial Net Funding Required	*calculated from the tables above*						
	Labour	266.12	257.02	579.21	535.38	172.38	1,810.11
	Equipment	-	1,962.20	5,945.71	1,761.29	109.90	9,779.10
	Contractors	257.31	473.42	451.05	500.28	245.28	1,927.34
	IT	45.63	7.21	0.82	3.71	0.40	57.78
	IPR Costs	-	-	1.65	-	1.60	3.25
	Travel & Expenses	49.93	61.49	157.13	151.67	45.53	465.75
	Payments to users & Contigency	61.90	277.05	714.05	295.73	58.31	1,407.04
	Decommissioning	-	-	-	-	-	-
	Other	-	9.12	4.95	4.95	8.01	27.03
	Total	680.89	3,047.52	7,854.57	3,253.00	641.42	15,477.39
Direct Benefit:	*from Direct Benefits sheet*						
	Total	-	-	-	-		-
DNO Compulsory Contribution / Direct Benefits	*from Project Cost Summary sheet*						
	Labour	26.61	25.70	57.92	53.51	17.31	181.06
	Equipment	-	196.22	594.57	176.01	10.99	977.79
	Contractors	25.73	47.34	45.11	50.02	24.99	193.19
	IT	4.56	0.72	0.08	0.37	0.04	5.78
	IPR Costs	-	-	0.16	-	0.17	0.33
	Travel & Expenses	4.99	6.15	15.71	15.16	4.58	46.59
	Payments to users & Contigency	6.19	27.70	71.41	29.56	5.89	140.75
	Decommissioning	-	-	-	-	-	-
	Other	-	0.91	0.49	0.50	0.83	2.73
	Total	68.09	304.75	785.46	325.12	64.80	1,548.22
Outstanding Funding required	*calculated from the tables above*						
	Labour	239.51	231.32	521.29	481.87	155.07	1,629.06
	Equipment	-	1,765.98	5,351.14	1,585.28	98.91	8,801.31
	Contractors	231.58	426.07	405.95	450.26	220.29	1,734.15
	IT	41.07	6.49	0.74	3.34	0.36	52.00
	IPR Costs	-	-	1.48	-	1.44	2.92
	Travel & Expenses	44.94	55.34	141.41	136.51	40.95	419.15
	Payments to users & Contigency	55.71	249.34	642.65	266.17	52.42	1,266.29
	Decommissioning	-	-	-	-	-	-
	Other	-	8.21	4.45	4.46	7.18	24.29
	Total	612.80	2,742.76	7,069.11	2,927.88	576.62	13,929.18
balance	13,513.76	0.00	10,158.19	3,325.80	532.76	(5.27)	13,513.76
interest		0.00	236.72	134.84	38.59	5.27	415.42
							13,929.18

Bank of England interest rate 0.5%

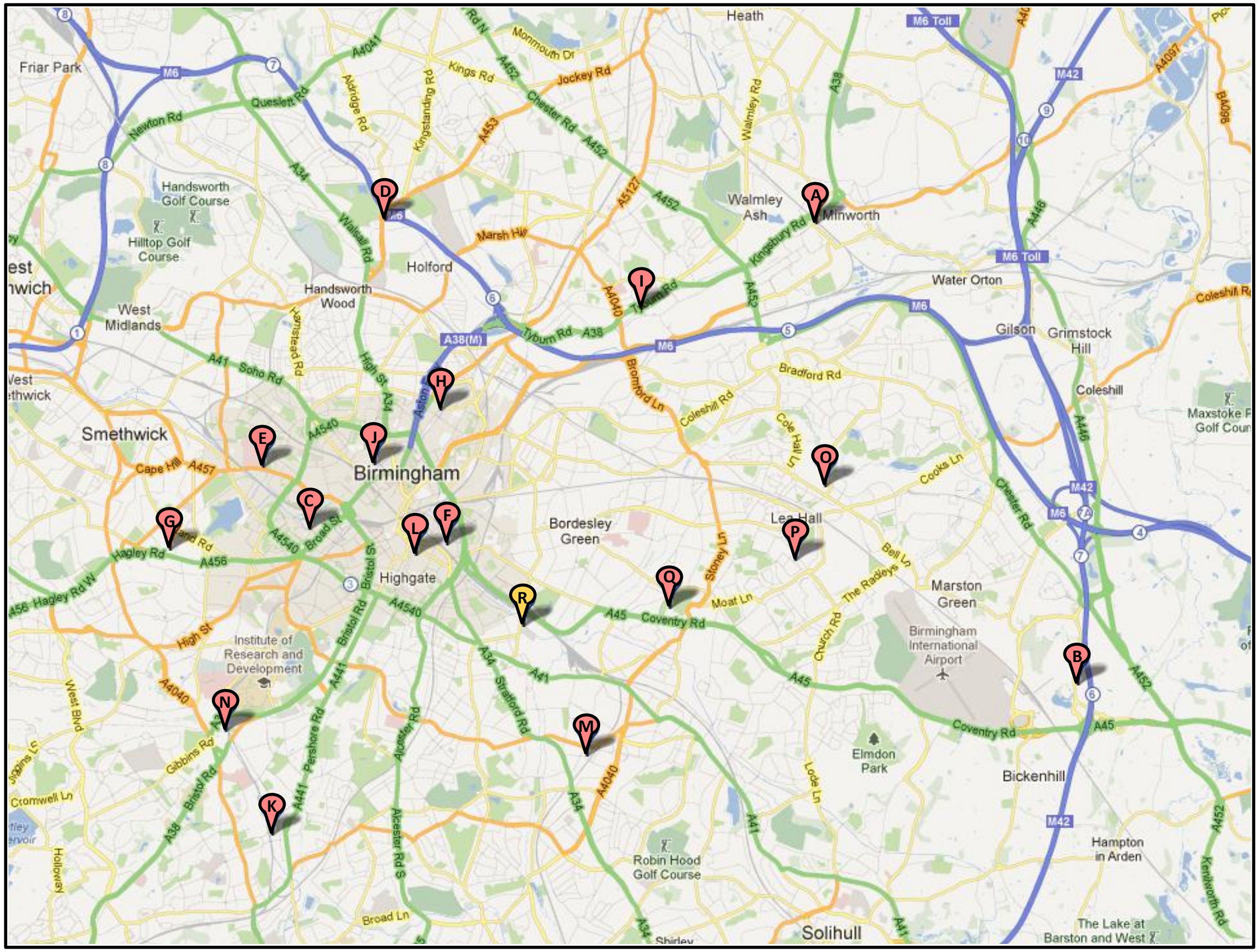
interest rate used in calculation 2.0%

SECOND TIER FUNDING REQUEST £ 13,513.76

RPI adjustment	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Index	244.6	251.4	260.2	269.9	280.8	287.8
Annual inflation	3.10%	2.80%	3.50%	3.80%	4.00%	2.50%

n.b the Second Tier Funding Request calculation should use the Bank of England Base rate plus 1.5% on 31 June of the year in which the Full Submission is made.

B1 - Primary Substations in Birmingham: Break Fault Level for busbar running solid with two transformers in parallel (worst scenario) compared to WPD Fault Level policy limit (250MVA)



map data © 2012 Google

Substations

FLI0 – FLI1

FLI2 – FLI3

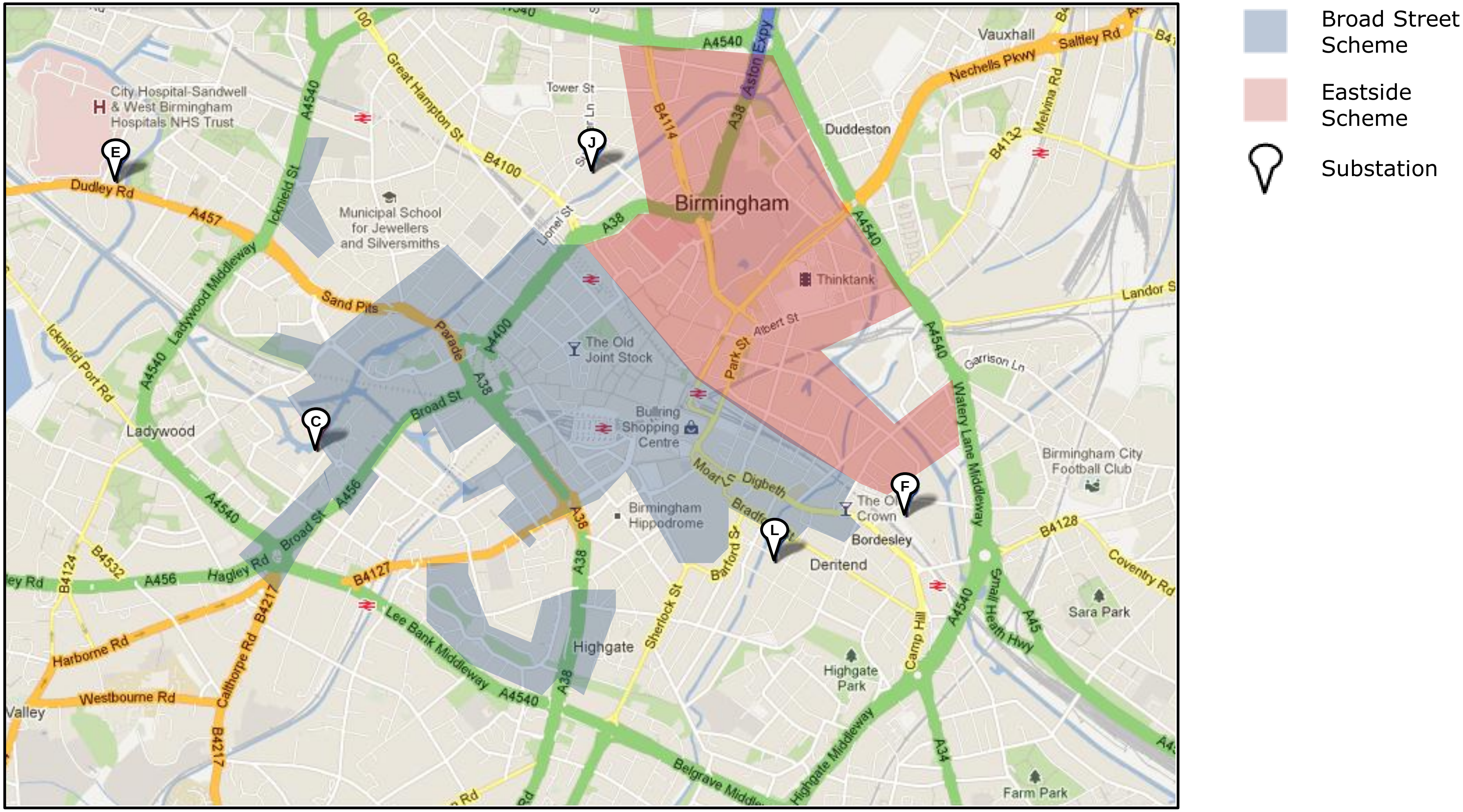
≥ FLI4

Break Fault Level is the symmetrical r.m.s. fault current at 90ms.

Fault Level index rankings calculated for the break Fault Level as a percentage of the WPD Fault Level policy limit (250MVA).

Fault Level index	Fault Level as a percentage of the network limit
FLI0	0 – 49%
FLI1	50 – 59%
FLI2	60 – 69%
FLI3	70 – 79%
FLI4	80 – 89%
FLI5	90 – 99%
FLI6	100 – 109%
FLI7	110 – 119%
FLI8	120 – 129%
FLI9	130 – 139%
FLI10	> 140%

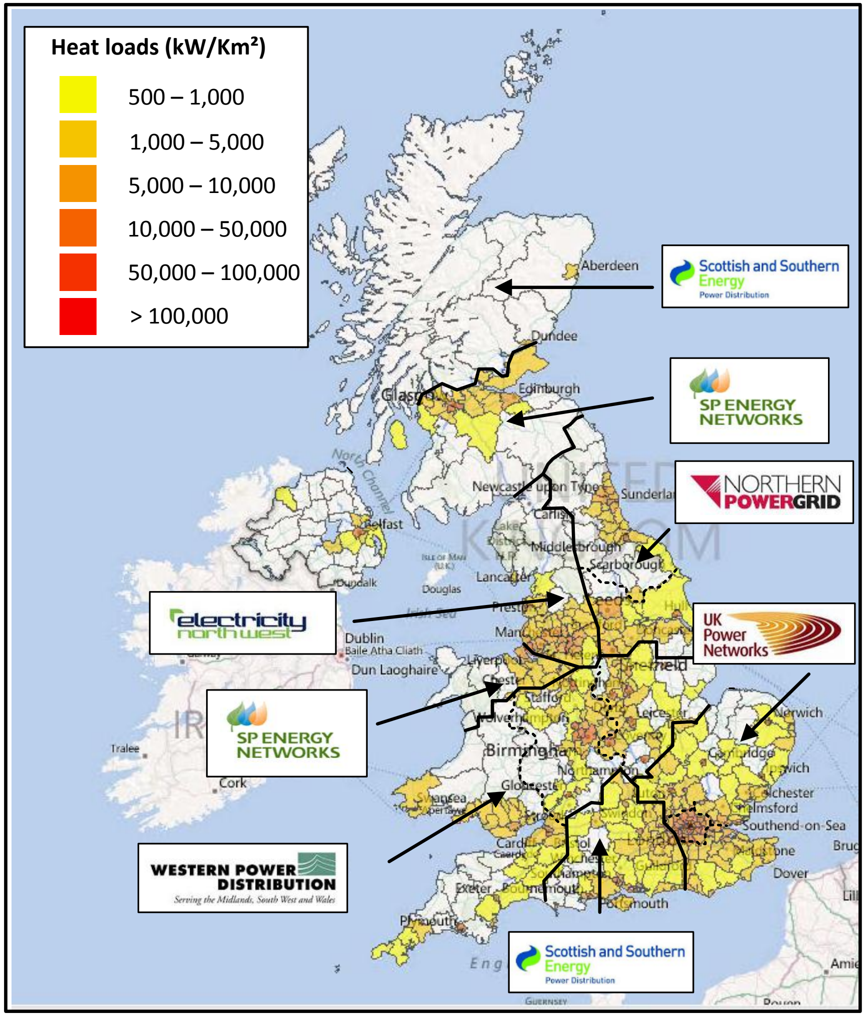
B2 – CHP Development in Birmingham – Areas of Interest

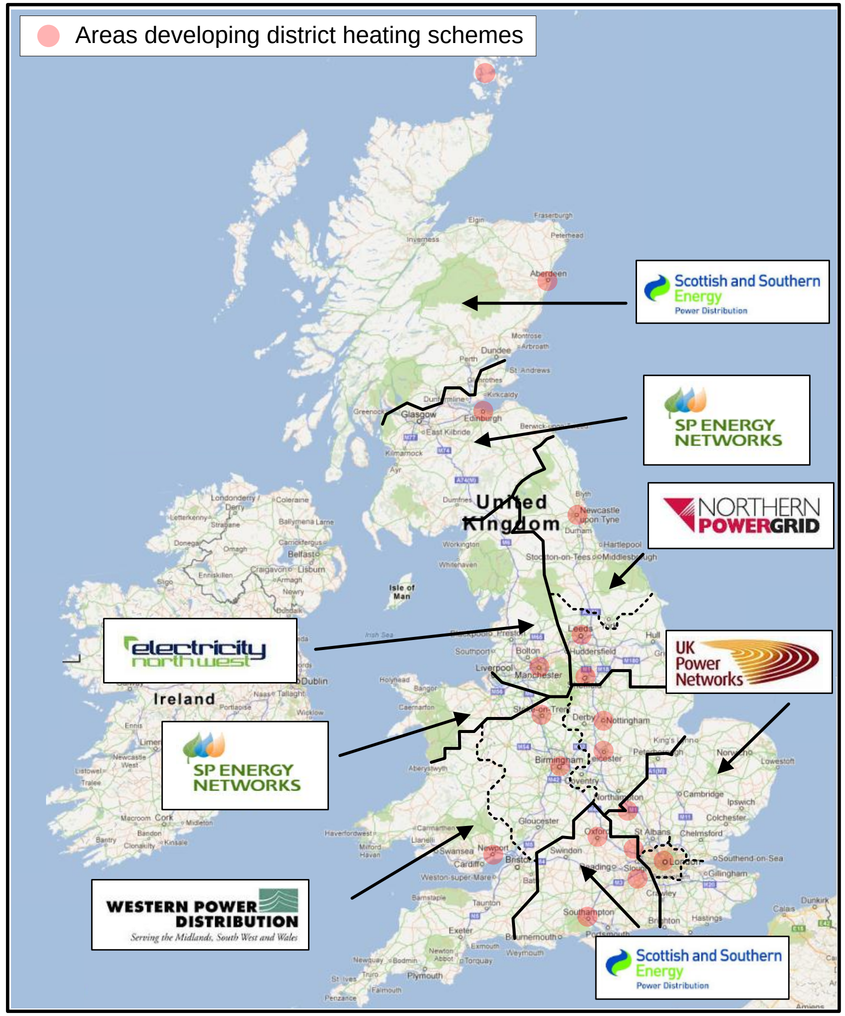


map data © 2012 Google

Source: Cofely GDF Suez, 'Full Plan of Broad Street & Eastside Schemes', Rev. 23

B3 – CHP Development in the UK





map data © 2012 Google

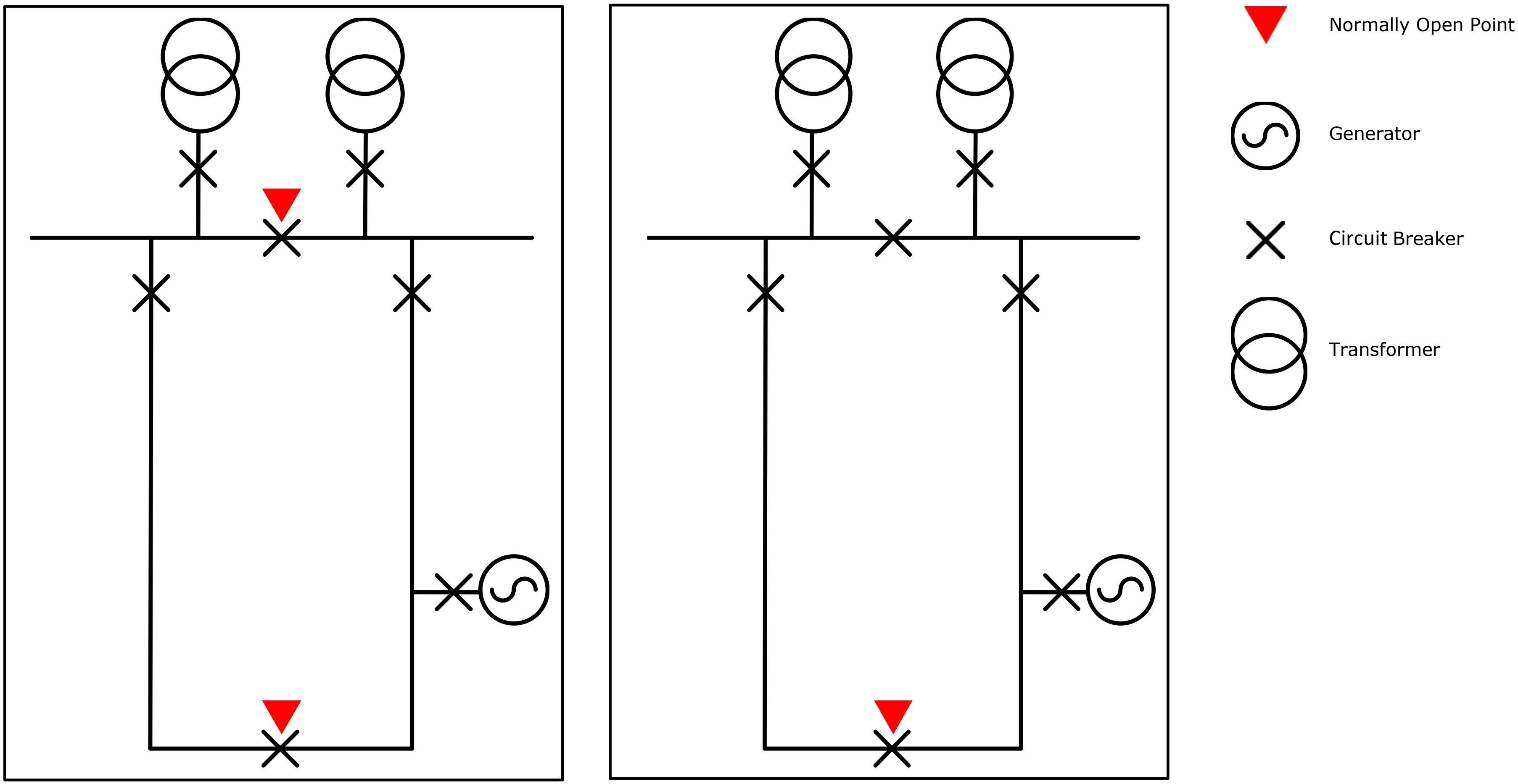
a) Heat load in the UK by DNO area (potential areas for CHP) [1]

b) Areas with existing or proposed district heating schemes [2]

[1] Source: DECC, 'UK CHP Development Map', http://chp.decc.gov.uk/developmentmap/

[2] Sources: AEA, 'District Heating and Heat Mapping', Nov 2010, http://chp.decc.gov.uk/cms/assets/pdf/BSRIA-AGM-Heat-Map-Presentation-final2.pdf. UKDEA, 'Introduction', 2012, www.ukdea.org.uk/en/home/introduction

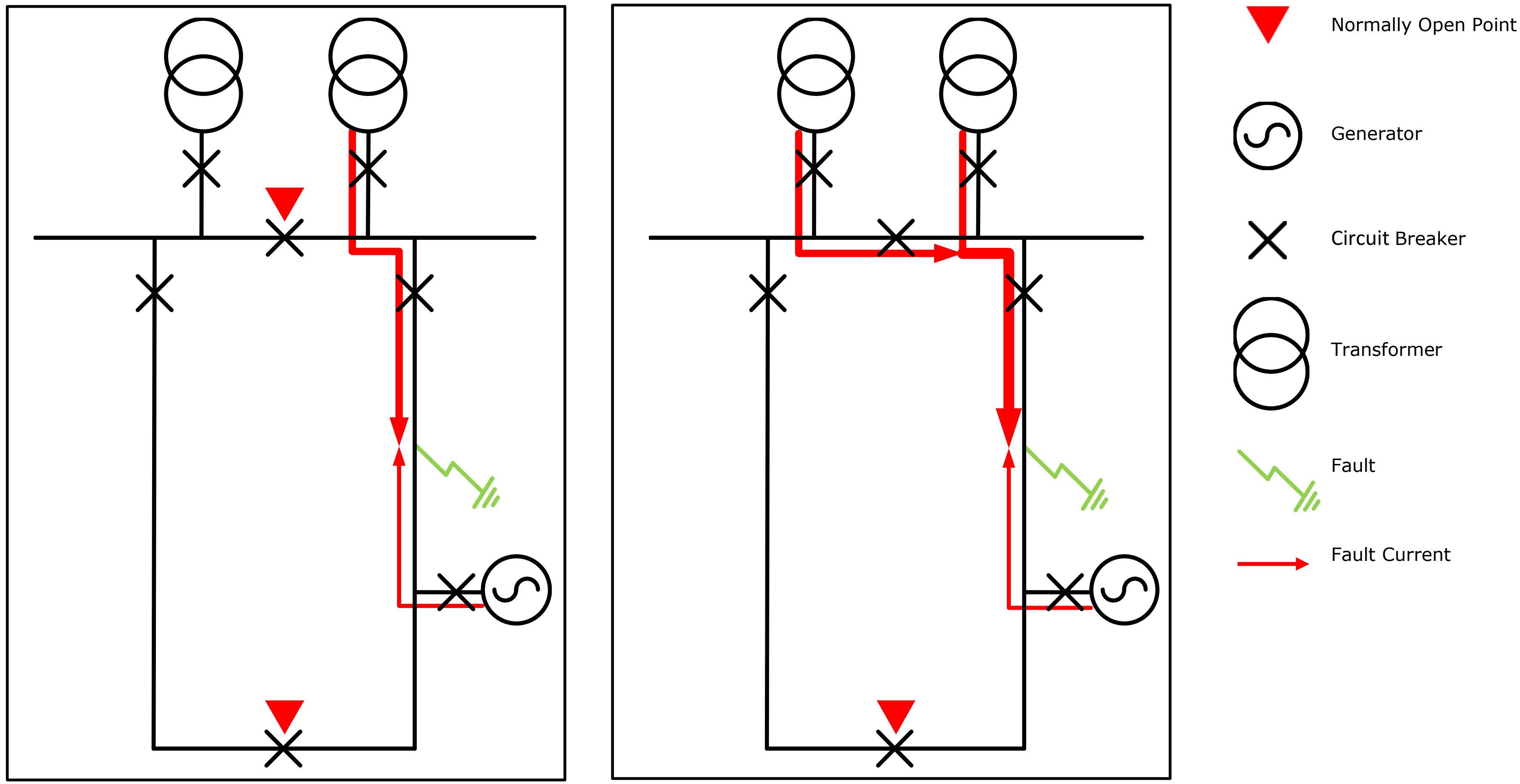
C1 –Network Configurations



a) Split configuration (open)

b) Solid configuration (parallel)

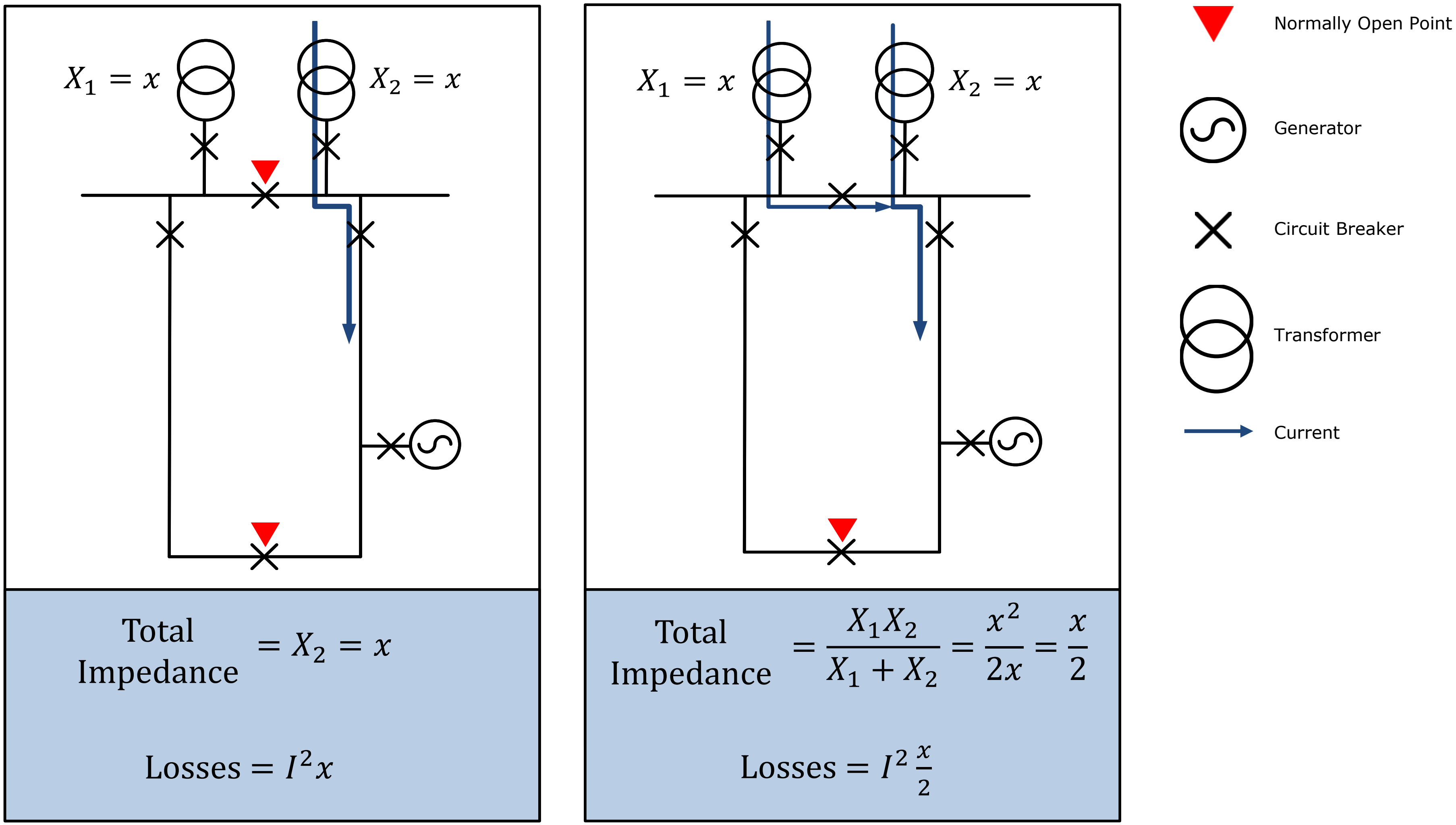
C2 – Fault In-feed for Split and Solid Network Configurations



a) Fault in-feed for split configuration

b) Fault in-feed for solid configuration

C3 – Losses for Split and Solid Network Configurations



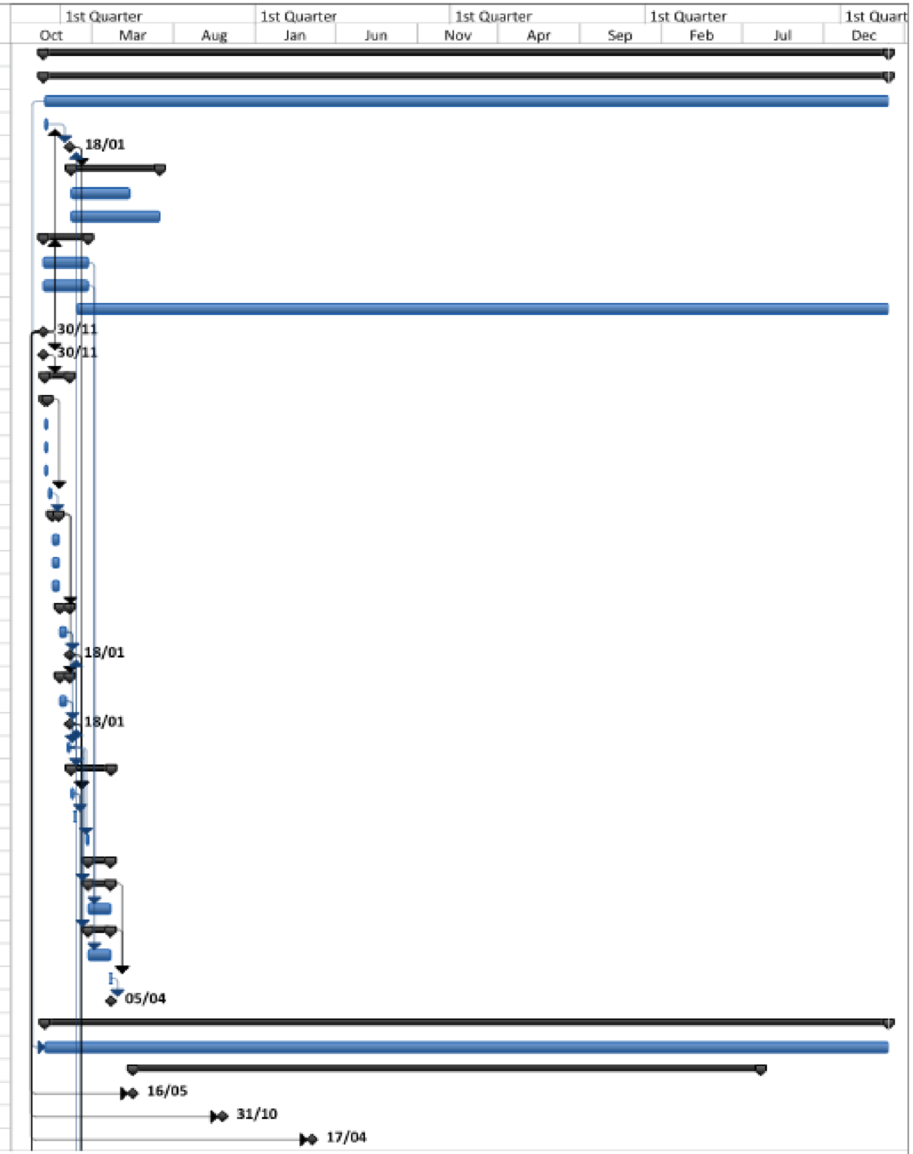
a) Losses for split configuration

b) Losses for solid configuration

Appendix D – Project Plan

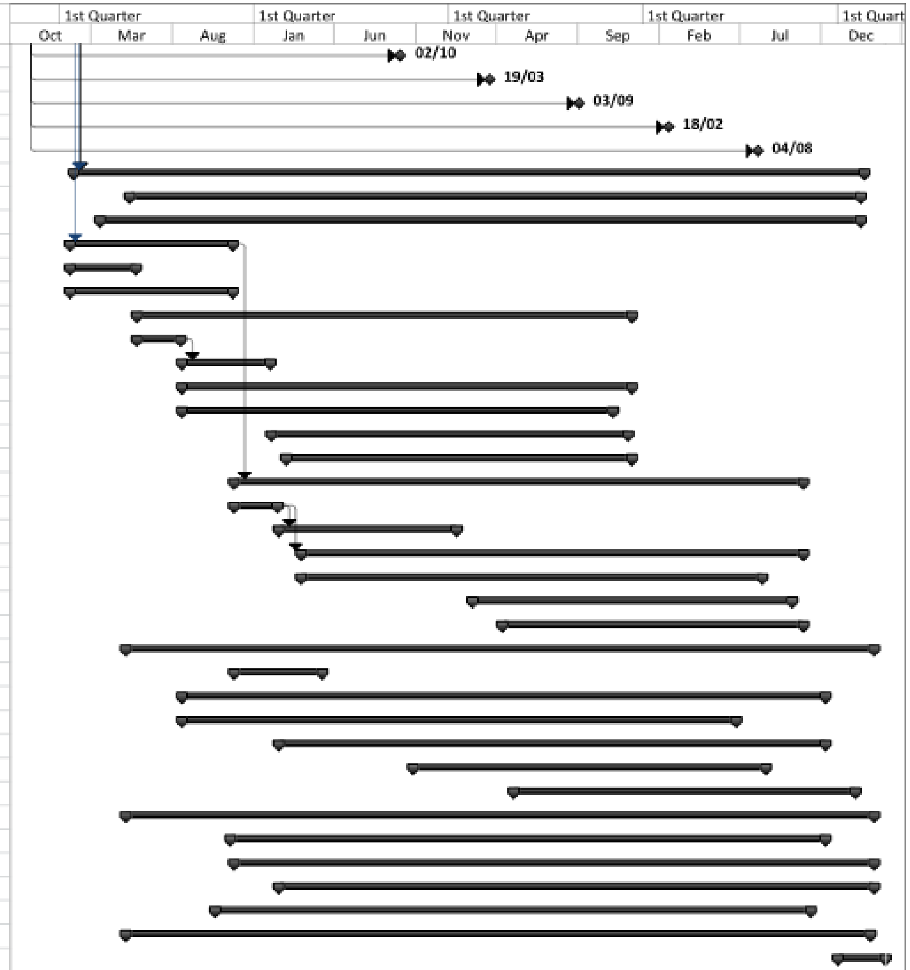
D – Project Plan

ID	Task Name	Start	Finish
1	**FLEXGRID**	**Fri 30/11/12**	**Fri 31/03/17**
2	**Project Management**	**Fri 30/11/12**	**Fri 31/03/17**
3	Manage Project	Mon 03/12/12	Fri 31/03/17
4	Produce PID	Mon 03/12/12	Fri 07/12/12
5	PID Signed off	Fri 18/01/13	Fri 18/01/13
6	**Tender Process - Equipment**	**Mon 21/01/13**	**Fri 05/07/13**
7	Monitoring	Mon 21/01/13	Fri 10/05/13
8	Mitigation	Mon 21/01/13	Fri 05/07/13
9	**Partner Collaboration Agreement process**	**Fri 30/11/12**	**Thu 21/02/13**
10	Form CA with PB	Fri 30/11/12	Thu 21/02/13
11	Form CA with UoW	Fri 30/11/12	Thu 21/02/13
12	Communication and Stakeholder Engagement	Fri 01/02/13	Fri 31/03/17
13	Funding Award	Fri 30/11/12	Fri 30/11/12
14	Project Direction received	Fri 30/11/12	Fri 30/11/12
15	**Project Initiation**	**Mon 03/12/12**	**Fri 18/01/13**
16	**Consolidation in to existing governance structure**	**Mon 03/12/12**	**Fri 07/12/12**
17	Establish Project's governance requirements	Mon 03/12/12	Fri 07/12/12
18	Establish project tolerances	Mon 03/12/12	Fri 07/12/12
19	Confirm escalation process	Mon 03/12/12	Fri 07/12/12
20	Initial meeting with WPD senior management	Mon 10/12/12	Fri 14/12/12
21	**Review Bid**	**Mon 17/12/12**	**Fri 28/12/12**
22	Review Aims	Mon 17/12/12	Fri 28/12/12
23	Review Objectives	Mon 17/12/12	Fri 28/12/12
24	Review Deliverables	Mon 17/12/12	Fri 28/12/12
25	**Project team members selection**	**Mon 31/12/12**	**Fri 18/01/13**
26	Identify team members	Mon 31/12/12	Fri 11/01/13
27	Confirm team members	Fri 18/01/13	Fri 18/01/13
28	**Project team location selection**	**Mon 31/12/12**	**Fri 18/01/13**
29	Identify team location	Mon 31/12/12	Fri 11/01/13
30	Confirm team location	Fri 18/01/13	Fri 18/01/13
31	Senior management meeting	Mon 14/01/13	Fri 18/01/13
32	**Mobilisation**	**Mon 21/01/13**	**Fri 05/04/13**
33	Project Team kick-off meeting	Mon 21/01/13	Fri 25/01/13
34	Update RAID Log	Mon 28/01/13	Mon 28/01/13
35	Set up bank account	Mon 18/02/13	Fri 22/02/13
36	**Partner Mobilistation**	**Fri 22/02/13**	**Thu 04/04/13**
37	**Formalise relationship with PB**	**Fri 22/02/13**	**Thu 04/04/13**
38	Sign Collaboration Agreement	Fri 22/02/13	Thu 04/04/13
39	**Formalise relationship with UoW**	**Fri 22/02/13**	**Thu 04/04/13**
40	Sign Collaboration Agreement	Fri 22/02/13	Thu 04/04/13
41	Confirm partner internal governance processes	Fri 05/04/13	Fri 05/04/13
42	Full mobilation to Solution Design gateway review	Fri 05/04/13	Fri 05/04/13
43	**Reporting**	**Mon 03/12/12**	**Fri 31/03/17**
44	Create Status Report for Senior Management - produce and update monthly	Mon 03/12/12	Fri 31/03/17
45	**Ofgem Reporting**	**Thu 16/05/13**	**Thu 04/08/16**
46	Create and submit Ofgem report	Thu 16/05/13	Thu 16/05/13
47	Create and submit Ofgem report	Thu 31/10/13	Thu 31/10/13
48	Create and submit Ofgem report	Thu 17/04/14	Thu 17/04/14



Appendix D – Project Plan

ID	Task Name	Start	Finish
49	Create and submit Ofgem report	Thu 02/10/14	Thu 02/10/14
50	Create and submit Ofgem report	Thu 19/03/15	Thu 19/03/15
51	Create and submit Ofgem report	Thu 03/09/15	Thu 03/09/15
52	Create and submit Ofgem report	Thu 18/02/16	Thu 18/02/16
53	Create and submit Ofgem report	Thu 04/08/16	Thu 04/08/16
54	**Project team meetings**	**Mon 28/01/13**	**Mon 20/02/17**
70	**Senior management meetings**	**Mon 13/05/13**	**Mon 13/02/17**
74	**Project Forum meetings**	**Mon 18/03/13**	**Mon 13/02/17**
78	**Phase 1 - Detailed Design**	**Mon 21/01/13**	**Fri 22/11/13**
79	**Project Design**	**Mon 21/01/13**	**Fri 24/05/13**
84	**Enhanced FL Assessment**	**Mon 21/01/13**	**Fri 22/11/13**
87	**Phase 2 - Real-time FL Management**	**Mon 27/05/13**	**Fri 11/12/15**
88	**Procurement**	**Mon 27/05/13**	**Fri 16/08/13**
92	**Delivery**	**Mon 19/08/13**	**Fri 31/01/14**
94	**Installation**	**Mon 19/08/13**	**Fri 11/12/15**
95	**Site Readiness**	**Mon 19/08/13**	**Fri 06/11/15**
106	**Monitoring installation**	**Mon 03/02/14**	**Fri 04/12/15**
117	**Monitoring Commissioning**	**Mon 03/03/14**	**Fri 11/12/15**
128	**Phase 3 - FL Mitigation Technologies**	**Mon 25/11/13**	**Fri 28/10/16**
129	**Procurement**	**Mon 25/11/13**	**Fri 14/02/14**
133	**Delivery**	**Mon 17/02/14**	**Fri 16/01/15**
135	**Installation**	**Mon 31/03/14**	**Fri 28/10/16**
136	**Site Readiness**	**Mon 31/03/14**	**Fri 12/08/16**
142	**Mitigation Installation**	**Mon 16/02/15**	**Fri 07/10/16**
148	**Mitigation Commissioning**	**Mon 13/04/15**	**Fri 28/10/16**
154	**Phase 4 - Trials**	**Mon 06/05/13**	**Fri 10/03/17**
155	**Enhanced Model Testing**	**Mon 25/11/13**	**Fri 09/05/14**
157	**Closed-loop Methodology**	**Mon 19/08/13**	**Fri 09/12/16**
158	**Monitoring**	**Mon 19/08/13**	**Fri 24/06/16**
164	**Mitigation**	**Mon 17/02/14**	**Fri 09/12/16**
170	**Real-time Modelling**	**Mon 27/10/14**	**Fri 19/08/16**
175	**Mitigation Technology performance analysis**	**Mon 04/05/15**	**Fri 03/02/17**
178	**Knowledge Transfer and Learning Dissemination**	**Mon 06/05/13**	**Fri 10/03/17**
179	**Training**	**Mon 18/11/13**	**Fri 09/12/16**
181	**Reports**	**Mon 25/11/13**	**Fri 10/03/17**
183	**Academic Dissemination**	**Mon 17/02/14**	**Fri 10/03/17**
185	**Conferences**	**Mon 21/10/13**	**Fri 11/11/16**
187	**Workshops**	**Mon 06/05/13**	**Fri 03/03/17**
189	**Project Closure**	**Mon 02/01/17**	**Fri 31/03/17**



Appendix E – Risk Register

E – Risk Register

Risk Register			
Project Name:	*FLEXGRID*	**Project Manager:**	*Jonathan Berry*

Risk Ref. No.	Risk Status	Owner	High Level Definition "There is a risk that..."	Impact	Probability	Proximity	Rating	Movement	Raised by	Raised on	Target Date	Last Updated	Cause "...because of..."	Effect "...leading to..."	Mitigation Action Plan	Signs that the risk is about to occur or become an Issue	Issue ID
Next No.	Dropdown list	Responsible for mgmnt	Details of the Risk	See Table below Score 1-5	See Table below Score 1-5	See Table below Score 1-5	Auto Calculated	If risk has changed to a higher / lower priority	Who raised the Risk?	when was it raised?	Target Date for Resolution	Late date the risk was updated	What will Trigger the Risk?	What will happen if it occurs?	How will this Risk be avoided?	How do you know if Risk has Occurred?	ID of Issue Risk has transferred to
R001	Raised	Jonathan Berry	Insufficient WPD resource for project delivery	3	2	4	24	⇩	RH	pre bid submission	06.07.13	12.07.12	Insufficient WPD resource for project construction phase	Methods Beta and Gamma not deliverable	The business is aware of the resourcing requirements to deliver the project	Delivery schedule slip	
R002	Raised	Jonathan Berry	Partners and supporters perception of the project changes	4	2	4	32	⇔	JB	pre bid submission	06.10.12	06.08.12	Unclear communications and objectives	Project partners unhappy with the project delivery, potentially no longer wishing to support the project	Work with all project partners and supporters through the design and development of the project. Ensure communications are clear and the objectives are known.	Feedback from partners and supporters	
R003	Raised	Jonathan Berry	Cost of high cost items are significantly higher than expected	3	2	4	24	⇩	JB	pre bid submission	01.01.13	06.08.12	Procurement stage of the project results in higher costs than in the submission spreadsheet	The project contingency built in to the submission spreadsheet being used or if exceeding the contingency refer to the project board	RfIs have been issued and received to understand the industry cost of high value items	Indications from Tender process after funding award	
R004	Raised	Jonathan Berry	No suitable FL Mitigation Technologies will be available	4	1	4	16	⇔	JB	pre bid submission	01.01.13	06.08.12	No technologies available due to space or technology constraints	The unavailability to deploy Method Gamma	Initial RfI of FL Mitigation Technologies has already taken place, identifying a number of suitable solutions with a review of substations to include these in to	No suitable Technology proposals received at the tender stage	
R005	Raised	Jonathan Berry	No suitable FL Monitors will be available	4	1	4	16	⇩	JB	pre bid submission	01.01.13	06.08.12	No technologies available due to space or technology constraints	The unavailability to deploy Method Beta	Initial RfI of FL Monitors has already taken place, identifying a number of suitable solutions with a review of substations to include these in to	No suitable Technology proposals received at the tender stage	
R006	Raised	Jonathan Berry	The overall project scope and cost could creep	4	2	3	24	⇔	JB	pre bid submission	01.05.13	08.08.12	Poor control, underestimation of costs at bid stage, changes in technical scope, partner uncertain of scope	Increased cost, delays in project schedule, dissemination outputs are poor quality	Early planning, RfI process and project accountant role identified to manage project costs	Project costs slip	

Appendix E – Risk Register

Risk Register			
Project Name:	*FLEXGRID*	**Project Manager:**	*Jonathan Berry*

Risk Ref. No.	Risk Status	Owner	High Level Definition "There is a risk that..."	Impact	Probability	Proximity	Rating	Movement	Raised by	Raised on	Target Date	Last Updated	Cause "...because of..."	Effect "...leading to..."	Mitigation Action Plan	Signs that the risk is about to occur or become an Issue	Issue ID
Next No.	Dropdown list	Responsible for mgmnt	Details of the Risk	See Table below Score 1-5	See Table below Score 1-5	See Table below Score 1-5	Auto Calculated	If risk has changed to a higher / lower priority	Who raised the Risk?	when was it raised?	Target Date for Resolution	Late date the risk was updated	What will Trigger the Risk?	What will happen if it occurs?	How will this Risk be avoided?	How do you know if Risk has Occurred?	ID of Issue Risk has transferred to
R007	Raised	Jonathan Berry	A partner may withdraw from project or have oversold their solution	5	2	4	40	⇩	JB	pre bid submission	01.01.13	08.08.12	Misunderstood technical requirements, misrepresentation of solution	Delay in schedule, inability to achieve successful delivery reward criteria	Consider if activity is critical, understand if activity can be picked up by an existing partner/supplier or seek new partner	Partner underdelivers	
R008	Raised	Jonathan Berry	The Project delivery team does not have the knowledge required to deliver the project	5	3	5	75	⇔	JB	pre bid submission	01.01.13	08.08.12	Lack of continuity from bid to delivery	A gap in project delivery knowledge	Detailed documentation of technical solution, key members of bid team proceed to project team	Project underdelivers	

IMPACT	PROBABILITY	PROXIMITY	MOVEMENT
5 – Inability to deliver, business case/objective not viable **4 –** Substantial Delay, key deliverables not met, significant increase in time/cost **3 –** Delay, increased cost in excess of tolerance **2 –** Small Delay, small increased cost but absorbable **1 –** Insignificant changes, re-planning may be required	**5** – Certain **4** – More likely to occur than not **3** – 50/50 chance of occuring **2** – Less likely to occur **1** – Very unlikely to occur	**5 –** Imminent **4 –** Likely to be near future **3 –** Mid to short term **2 –** Mid to long term **1 –** Far in the future	⇧ ⇩ ⇔

F – Contingency Plan

A contingency plan has been written for the significant risks on the Risk Register. All risks will be continually monitored and appropriate risk will be referred to the project board. Below are details of how we will mitigate against significant risks becoming an issue and the contingency plans.

R003: Costs of high cost items are significantly higher than expected

Mitigation
- Requests for Information (RfI) have been issued and received to ensure WPD understand the industry cost of the Project's high value items

Contingency
- Re-evaluate the technology specification and requirements
- Look to reduce the number of technology installations

R004: No suitable FL Mitigation Technologies will be available

Mitigation
- Through the RfI process the availability and lead time for delivery has been discussed and recorded for each Technology
- Mitigation Technologies are to be chosen at a high Technology Readiness Level (TRL)
- Substation site investigation has taken place to determine site suitability for Mitigation Technology inclusion

Contingency
- Change the Trial location sites to provide locations suitable for the Technology installation
- Utilise different FL Mitigation solutions to deliver the Project's objectives

R005: No suitable FL Monitors will be available

Mitigation
- Through the RfI process the availability and lead time for delivery has been discussed and recorded for each Monitoring solution
- A FL Monitor has been developed and tested successfully as part of WPD's future networks' programme
- Substation site investigation has taken place to determine site suitability for FL Monitor inclusion

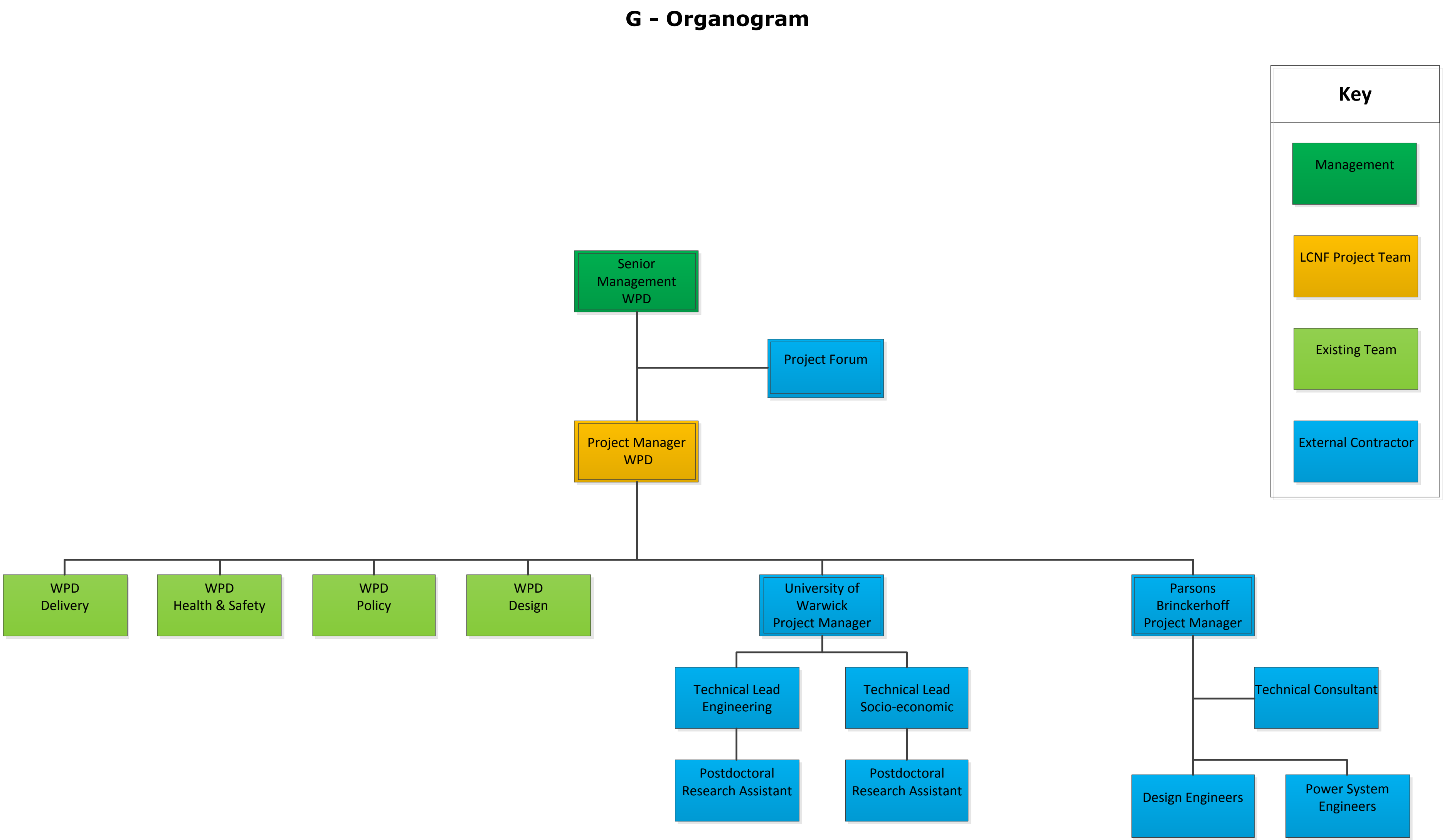
Contingency
- Change the Trial location sites to provide locations suitable for Monitoring installation
- Utilise different FL Monitor solutions to deliver the Project's objectives

R007: A partner/supplier may withdraw from the project or have oversold their solution

Mitigation
- All partners have been provided full visibility of the Project's aims, objectives and deliverables
- Suitable suppliers have been identified to deliver technologies with a track record of successful delivery
- Memorandum of Understanding is in place with all partners and framework collaboration agreements are in place to be signed on Project award
- Through the Project's bid phase, partners competence and resource has been assessed to ensure they're available to positively input to the Project

Contingency
- Look at utilising an existing partner/supplier to pick up the other partner/supplier's activities
- Consider if the activity is critical to successful delivery of the Project

Appendix G – Organogram



H - Project Partners

Organisation:	Parsons Brinckerhoff
Role Summary:	Parsons Brinckerhoff will be providing technical engineering consultancy services, including electricity network modelling, independent advice on equipment installations, consortium management, document control and quality assurance.

Parsons Brinckerhoff role in bid preparation: Parsons Brinckerhoff (PB) has helped WPD to develop the Advanced Fault Level Management project, from project conception through the Initial Screening Pro-Forma to the preparation of the Full Submission Pro-Forma. Through integration of PB Engineers within WPD's offices we have made ourselves familiar with the systems of work and align with WPD's delivery-focused approach to engineering. PB is highly committed to the technical support of WPD in delivering this project.

What does Parsons Brinckerhoff bring to the Advanced Fault Level Management Project: Innovation is at the heart of PB's heritage and, by working closely with DNOs, we gain an intimate understanding of the problems and issues that need resolution, particularly when focusing on the transition towards a low carbon economy. From this knowledge base we are able to help design and develop creative solutions that will facilitate innovation within the UK's electricity networks.

Track record: PB is actively involved in the delivery of Low Carbon Networks Fund projects both at Tier-1 and Tier-2 levels. In 2010, PB led a consortium that received the IET's Innovation Award in the Power and Energy category for the 'Active Management of Distributed Generators based on Component Thermal Properties'.

Project Understanding: In helping WPD to shape and develop the Advanced Fault Level Management bid, PB has gained invaluable insight and an intimate understanding of the project. This, together with the links developed during the delivery of the Tier 1 project 'Implementation of an Active Fault Level Management Scheme' will aid in the seamless transition from bid stage to project delivery.

Partner Engagement: During the bid development stage, PB embedded engineers within WPD's offices, thereby becoming engaged with WPD staff and forming important points of contact, ready for project delivery. PB has also supported WPD with partner selection and the evaluation of Requests for Information from equipment suppliers.

Parsons Brinckerhoff contribution to project benefits: PB has helped WPD to formulate the business case and design the trials for the Advanced Fault Level Management project. Our strong client relationships will aid WPD in assessing the applicability of the Solution to other DNOs.

Industry Knowledge: PB is a leader in the development and operation of infrastructure to meet the needs of communities around the world. PB provides consultancy services for a range of clients within the electricity industry and together with our parent company, Balfour Beatty, we look to provide innovative outputs in the work we deliver.

Organisation:	The University of Warwick (School of Engineering and Warwick Business School)
Role Summary:	Provide support in component and network modelling; development of algorithms; case studies for commissioning; evaluation of project limitations and benefits including socio-economic impacts; assistance with dissemination of project outcomes.

The University of Warwick's role in bid preparation:
The University of Warwick was selected as the academic partner on this project through a competitive process. The University suggested the inclusion of the socio-economic studies which have now been incorporated into this bid, along with a number of other suggestions for dynamically reconfiguring the network with no or minimal requirement for hardware upgrades. The University has also provided a suggested model for dissemination of outcomes throughout the course of the project.

What does the University of Warwick bring to the Advanced Fault Level Management Project:
The University has thoroughly assessed all aspects of the proposed project to define the areas in which it can make the greatest contribution. These include but are not necessarily limited to:

- Cutting edge research and expertise in power systems engineering
- Cutting edge research and expertise on the economic analysis of energy consumption and energy markets, from production through to end use
- On-site CHP and high voltage electricity network with over ten years of experience in CHP infrastructure management and integration of measures to improve energy efficiency
- Access to Science City Research Alliance equipment for real-time, hardware-in-the-loop simulations to support the commissioning, demonstration and training stages of the project.
- Use of the University's award winning conference facilities (centrally located within the UK) for interim workshops and final dissemination event

Track record:
Energy and cities research are of key strategic importance to the University of Warwick and as a result two new Global Priority Programmes (GPPs) have recently been established: Energy Efficiency and Sustainable Cities. The GPPs have been established to draw together excellent academic research from across the University. Collaborations with selected corporate partners underpin the multidisciplinary research carried out in the GPPs.

Professor Li Ran has provided academic support to many engineering projects in collaboration with industrial partners. In a recent project, Li Ran organized a university team to provide simulation support to a project involving Mott MacDonald, Snamprogetti (Italy), Entropose (France), Shell Global Solutions, ABB and FKI in developing a Power Management System for the 132 kV voltage and reactive power control strategy, for Nigerian Liquefied Natural Gas's (NLNG) Bonny Island Plant. Dr Monica Giulietti has previously collaborated with the Department of Energy and Climate Change, the Energy Retail Association and Platts; her research focuses on the regulation of energy markets and welfare effects of market outcomes including fuel poverty.

Project Understanding:
As Great Britain moves towards a low carbon economy the Fault Level is a growing issue for DNOs as more distributed generation (DG) is connected to the network. This is a significant issue in dense urban environments like Birmingham where a tight Fault Level tolerance in 11KV substations is compounded by a requirement to include CHP in all new developments over a certain size. The University has significant capabilities in this area of power systems engineering and will combine this with our socio-economic expertise to assess the efficacy of Fault Level Management Technologies and in the impact on the end user.

Partner Engagement:
During the bid writing process the University has worked closely with representatives from Western Power Distribution and Parsons Brinckerhoff to ensure that our contribution adds significant value at every stage of the project. Discussions have been held either face to face or by teleconference to develop the bid and incorporate improvements to the methodology (e.g. State Estimation) and entirely new aspects like the socio-economic impact of Fault Level Mitigation and CHP integration into the network.

The University of Warwick's contribution to project benefits:
The University brings significant applied expertise in power systems engineering and the economics of the energy industry to the partnership. In addition, the University Campus has a self-contained high voltage network and one of the largest and most advanced CHP systems in the UK, enabling the whole campus to be used as a demonstrator for validation of the algorithms developed in this project. Being centrally located and easily accessible from the rest of the UK the University's award winning conference facilities are ideally placed to host dissemination activities throughout the course of the project.

The University will also derive significant benefit from this project by enabling us to keep our research and teaching activities current and relevant. In addition, as an operator of a small high voltage network with an increasing amount of associated distributed generation, the University will derive significant benefit from the project outcomes, and the opportunity to carry out some initial validation studies on our own HV network.

Industry Knowledge:
The University of Warwick's Corporate Relations Unit has an experienced business development team dedicated to Energy and Smart & Sustainable Cities. Through this team the University has a number of active collaborations with both large and small organisations from within the energy industry.

The University of Warwick is partnered with Birmingham University to form the Science City Research Alliance. SCRA proactively seeks to forge strategic collaborations and partnerships with organisations from both the public and private sectors, and through the Energy Efficiency Project (led by Warwick) has assisted or collaborated with 19 businesses to-date.

I – Letters of Support

COFELY
District Energy Limited

Cofely District Energy
is the new name for
Utilicom

utilicom™

Jonathan Berry
Innovation and Low Carbon Networks Engineer
Future Networks
Western Power Distribution
Tipton
West Midlands
DY4 0HH

Dear Mr. Berry

RE: WPD Low Carbon Networks Fund Tier-2 Project – Advanced Fault Level Management

Cofely is very pleased that Western Power Distribution is proposing to support Birmingham City Council's target of reducing carbon emissions by 60% towards 2026.

As a major provider of Low Carbon Energy Generation in the Birmingham district we are fully supportive of this exciting and innovative project. We believe it could unlock Birmingham's capacity to integrate significant generation to support Birmingham City Council's along with the Government's carbon objectives.

We would like to wish Western Power Distribution every success with their bid to Ofgem and look forward to exploring opportunities to be involved in the project.

Yours sincerely

Simon Woodward

COFELY DISTRICT ENERGY LIMITED
Garrett House, Manor Royal, Crawley, West Sussex, RH10 9UT

Telephone: 01293 549944 – Fax: 01293 535785
www.cofely.co.uk

REGISTERED OFFICE: STUART HOUSE, CORONATION ROAD, HIGH WYCOMBE, BUCKINGHAMSHIRE HP12 3TA
A COMPANY REGISTERED IN ENGLAND No. 1508399

Awarded to Utilicom Group Limited

Birmingham City Council

Jonathan Berry
Innovation and Low Carbon Networks Engineer
Future Networks
Western Power Distribution
Tipton
West Midlands
DY4 0HH

1st August 2012

Dear Mr Berry

RE: WPD Low Carbon Networks Fund Tier-2 Project – Advanced Fault Level Management

Birmingham City Council is very pleased that Western Power Distribution has recognised the importance of supporting our aim in making Birmingham a leading green city with the highest standards for energy efficiency and a goal of substantially reducing the city's overall carbon emissions.

The City Council has a proven track record of taking action to reduce the Council and the City's energy use and associated carbon emissions. The creation of city centre distributed energy networks through the Birmingham District Energy Company and the installation of solar PV panels on social housing combined with the creation of the Birmingham Energy Savers programme for Green Deal delivery, demonstrate our commitment. We are therefore fully supportive of this project looking to facilitate the connection of additional and widespread distributed generation in the Birmingham area and specifically Combined Heat and Power units.

On behalf of Birmingham City Council, I would like to wish you every success with your proposal and we look forward to working with you in the future.

Yours sincerely

Sandy Taylor

Sandy Taylor
Head of Climate Change and Environment

Phone 00 44 (0)7970 815054
Email sandy.taylor@birmingham.gov.uk
Twitter @greenbirmingham
Address Development Directorate, 4th Floor, 1 Lancaster Circus, Birmingham B4 7DQ

PARSONS BRINCKERHOFF

Manchester Technology Centre, Oxford Road
Manchester M1 7ED, United Kingdom
Tel: 44-(0)161-200-5000
Fax: 44-(0)161-200-5001

www.pbworld.com

6 August 2012

WPD FLEXGRID LCNF Tier 2 project

Parsons Brinckerhoff (PB) fully supports WPD's bid for LCNF Tier 2 funding for its FLEXGRID project.

PB is a leader in electrical power distribution consultancy, providing independent technical advice and project management to stakeholders throughout the energy sector and around the world. Clients include regulators, utilities, asset owners and managers, government departments, project-financing banks and academic institutions. PB offers the ability to deliver excellence and innovation to our clients within the growing field of low carbon and sustainable electricity networks.

PB believes that the FLEXGRID project will demonstrate a means to support the widespread deployment of Distributed Generation (DG), encouraged by DECC's Low Carbon Plan, in a way to deliver best value to DG owners, WPD's customers and other stakeholders.

Once demonstrated, the methods identified in FLEXGRID can be quickly deployed throughout similar regions within GB to help defer network capex and reduce delays in DG installations.

Yours faithfully
Parsons Brinckerhoff

K Jackson

KATHERINE JACKSON
Director, Power Systems

Parsons Brinckerhoff Ltd
Registered in England and Wales No. 2554514
Registered Office:
Amber Court, William Armstrong Drive
Newcastle upon Tyne NE4 7YQ

Appendix I – Letters of Support

THE UNIVERSITY OF
WARWICK

14th August 2012

To Whom It May Concern:

FLEXGRID LCNF project application - Western Power Distribution (WPD)

The University of Warwick (UoW) has been selected, through an independent consultation process, as an academic partner for WPD's bid to the Low Carbon Networks Fund (FLEXGRID project) and fully supports this application.

Warwick is the leading research intensive university in the Midlands and at a national level was ranked seventh overall in the 2008 Research Assessment Exercise. In recognition of the importance of the Energy research agenda, Warwick has invested heavily over recent years in academic expertise and strategic support in this area. The University was also successful in securing a £10 million investment from AWM/eRDF for state-of-the-art Energy research facilities as part of the Warwick-Birmingham Science City Research Alliance which will be drawn on during Warwick's involvement in this project. Further expertise of relevance to this project include power system modelling, power electronics, energy management, combined heat and power (CHP) and other distributed generation (DG) management and global energy economics. UoW already collaborates with a number of corporate partners to deliver excellent, applied research which addresses key issues being faced by the energy industry.

UoW believes that for widespread uptake of DG in dense urban environments to be successful the issue of fault level management needs to be addressed first since DG tends to increase the fault level and adds significantly to the variation of short circuit current distribution in the network. The adverse effects of the fault level issue, without appropriate management, include the requirements of large scale upgrading to switchgears in the system and total overhaul of the protection schemes, which will seriously hinder the deployment of DG including CHP units. The project aims to develop active fault management techniques, based on real-time estimation of the fault levels in the network, to exploit the existing network to the maximum without sacrificing the reliability of power supply to customers. This will enable fast deployment of DG including CHP units, while also indicating the most effective ways to upgrade the network in the future. The end target is to reduce the carbon footprint and increase customer benefits. This will be achieved through the FLEXGRID project and once demonstrated in Birmingham the project outcomes will be applicable to other UK networks.

UoW will work closely with the other project partners and the urban community to develop the needed techniques and maximise benefit. In addition to the agreed project plan of work UoW agrees to contribute to the project in the following ways: (i) fund 50% of one PhD studentship, (ii) provision of a University Representative for project meetings at no cost to the project and, (iii) allow access to the University's HV and CHP networks for algorithm development and validation.

Thank you for your consideration of this application.

Yours faithfully,

UNIVERSITY OF WARWICK RESEARCH SUPPORT SERVICES

Dr Peter Hedges
Director, Research Support Services

Research Support Services
The University of Warwick
Coventry CV4 7AL United Kingdom
Tel 024 7652 3716
Email p.a.hodges@warwick.ac.uk

UNIVERSITY OF Southampton

Mr Jonathan Berry
Low Carbon Networks Engineer
Western Power Distribution
6th Floor
Toll End Road
Tipton, West Midlands DY4 0HH

Dear Mr Berry,

Support for Western Power Distribution bid "Advanced Fault Level Management in Birmingham" to Low Carbon Networks Fund

I am writing to provide my considered, professional opinion regarding the technical feasibility and DNO learning opportunities presented by the Low Carbon Networks Fund proposal from Western Power Distribution regarding real-time fault level monitoring.

I have been working in the area of fault level analysis and monitoring for 6 years and therefore have a good understanding of the issues surrounding the integration of distributed generation into electrical networks, and in particular the fault level issues this presents.

I have studied the literature, including conference papers, journal papers and industrial reports, which are pertinent to the aims and work proposed by WPD.

The subject matter is important because the proposed fault level monitoring technique provides much greater temporal resolution of fault level, which facilitates the project's aim to explore novel commercial contracts with customers.

The timing is right because passive methods can no longer be relied upon to provide regular fault level estimates or measurements. The lab tests show the network impact of an active fault level monitoring method within limits (recognising the limitation regarding repetition rates) and I believe it is appropriate to seek to trial this approach on actual networks within the context of the Tier 2 bid. The proposal is well conceived and relevant as it focuses on 11kV networks and CHP integration, which is valuable but also a good place to start as accurate fault level monitoring is achievable with an acceptable level of accuracy in these cases. This work could lay the foundation for further work which could deal with a range of voltage levels, network topologies and generator types in the future.

It has the right level of innovation in that it will help to answer key questions but is building on solid groundwork carried out with industrial partners (Outram Research Limited, S&C Electric, Parsons Brinckerhoff) and by other DNOs, for example, Scottish Power.

Overall, I would state that the potential benefits of the Advanced Fault Level Management techniques defined are clearly explained and that further trials and demonstrations on real-time fault level monitoring techniques and devices are wholly appropriate and justified.

Yours sincerely

Prof. Andrew Cruden
Professor of Energy Technology

Electro-Mechanical Research Group, Engineering Sciences, University of Southampton,
Highfield Campus, Southampton, SO17 1BJ, Hampshire, U.K.

Tel: +44 (0)23 8059 7660
Fax: +44 (0)23 8059 7322
Email: A.J.Cruden@soton.ac.uk

MANCHESTER
1824

The University of Manchester

School of Electrical and Electronic Engineering
The University of Manchester
Po Box 88
Sackville Street
Manchester M60 1QD
+44(0)161 306 9200
www.manchester.ac.uk

14 October 2012

Dear Jonathan,

Ref:- LCNF FLEXGRID Advanced Fault Level Management in Birmingham.

As Head of Electrical Energy and Power Systems at the University of Manchester, I am pleased to write this reference to support your application for LCNF funding. In the 1980's, I led an R&D team at GEC which developed a new type of protection that used superimposed components to measure the source impedance of a transmission line. The concepts developed in the 1980's were later used by my research students at UMIST to measure the fault level on transmission networks. More recently, the emphasis has moved from transmission to urban distribution networks and the fault level problems of dispersed generation and CHP. In the future many urban networks will have severe fault level problems, which will either be solved by expensive network reinforcement or by smart solutions involving fault level assessment, management and mitigation, i.e. the main deliverables of this proposal.

The first priority of this proposal is to measure the fault levels within urban networks, especially when local CHP facilities or other types of generators are connected. Conventional rotating machines deliver high fault currents, especially during the transient periods, which may risk the integrity of 11kV circuit-breakers. The DNO needs to know for every second of the year if the breaker is capable of breaking the fault current. If it is not, the DNO needs to delay the breaker, perhaps until the transient as decayed, or temporarily split a busbar, before opening the breaker. The former has been used in the past, but it extends the fault clearance time and risks thermal damage to transformers. Whilst the latter involves a more complex protection and control architecture which must continuously adapt to the fault level conditions. The classical solution is to split a busbar and continuously operate the network with only one transformer supplying a radial feeder. This is illogical since the use of one transformer reduces reliability and increases customer minutes lost. A smarter solution is to normally operate the 11kV network with the sectionalizing breakers closed, ensuring at least two transformers or lines supply urban loads. However, if the instantaneous fault level is above the breaker capacity, the busbar could be temporarily split and the fault level hopefully reduced to an acceptable level. Finally, the normal running arrangements of the network should be restored when the fault level reduced, which might be due to the planned disconnection of dispersed generators by their owners. What is not acceptable, unless it has been agreed in advance, is a DNO disconnecting a generator because the fault level is too high.

The main priority of this project is to understand if small variations in network operating conditions, caused by the switching of generation or load, will cause voltage and current changes sufficient to allow the fault level to be calculated. Outram Research are experts in the extraction of useful signals from noisy data and based on published data, I am confident their technique for fault level estimation will help DNOs manage their network and allow a higher penetration of urban dispersed generation. I assume PV, vehicles to grid (V2G), wind and micro-hydro will have power electronic interfaces that will limit the fault current, but this will not be true of CHP and small scale bio-mass or gas fueled synchronous generators. Note:- I am a member of the Greater Manchester Energy advisory group and the greatest electricity network challenges in Manchester are the latter and air-sourced heat pumps.

A proposed solution has already been tested by S&C Electric in their test facilities in Chicago and the results look promising, although further tests with network connected dispersed generation are required. S&C Electric are a globally leading manufacturer of distribution network automation equipment and in conjunction with WPD, Parsons Brinckerhoff, Outram and the University of Warwick have the capability to help future cities become more sustainable and to ensure our future distribution networks are flexible and reliable.

Yours faithfully

P.A.C

Prof. Peter Crossley. Head of Electrical Energy & Power Systems

Appendix J – Base Case

J1 - Financial Benefit of Method Alpha

Base Case Definition	Method Definition
Quantification of the typical Engineering Study cost required to respond to connection applications, using most efficient method currently in use on the GB Distribution System.	Quantification of the typical Engineering Study cost required to respond to connection applications, using the new connection assessment methodology.

Base Case Costs			Method Costs		
Description	**Quantity**	**Unit**	**Description**	**Quantity**	**Unit**
Typical study time	3	days	Typical study time	2	days
Engineer's rate	40	£ / h	Engineer's rate	40	£ / h
Working hours	7.5	h / day	Working hours	7.5	h / day
Cost of study	0.9	£k / study	Cost of study	0.6	£k / study
Studies per engineer per year	76	studies	Studies per engineer per year	114	studies
Cost per engineer per year	68.4	£k / year	Cost per engineer per year	68.4	£k / year
Connection applications / year	240	applications	Connection applications / year	240	applications
Cost to business	**216**	**£k / year**	**Cost to business**	**144**	**£k / year**

Projected Savings		
Description	**Quantity**	**Unit**
Savings in WPD West Midlands	72	£k / year
Savings across WPD (4 licence areas)	288	£k / year
Savings across UK DNOs (14 licence areas)	1,008	£k / year
Savings across UK DNOs (5 years)	**5,040**	**£k**
Savings across UK DNOs (10 years)	**10,080**	**£k**

J2 - Financial Benefit of Method Beta

Base Case Definition	Method Definition
There is currently no efficient method for comparison, as Fault Level is not currently monitored.	Quantification of the typical cost of monitoring Fault Levels in Birmingham using new technologies.

Base Case Costs			Method Costs		
Description	**Quantity**	**Unit**	**Description**	**Quantity**	**Unit**
			Cost of Fault Level Monitoring technology	300	£k / substation
			Number of substations	10	substations
Cost to business	**0**	**£k / year**	**Cost to business**	**3,000**	**£k / project**

Projected Savings		
Description	**Quantity**	**Unit**
Savings in WPD West Midlands	-3,000	£k
Savings across WPD (4 licence areas - 1 city per licence area)	-12,000	£k
Savings across UK DNOs (14 licence areas - 1 city per licence area)	-42,000	£k
Savings across UK DNOs (5 years - 1 city per licence area)	**-42,000**	**£k**
Savings across UK DNOs (10 years - 2 cities per licence area)	**-84,000**	**£k**

J3 - Financial Benefit of Method Gamma

Base Case Definition	Method Definition
Quantification of the typical cost of mitigating Fault Level issues in Birmingham, using the most efficient method currently in use on the GB Distribution System (cable and circuit breaker upgrades).	Quantification of the typical cost of mitigating Fault Level issues in Birmingham using new technologies.

Base Case Costs

Description	Quantity	Unit
Number of feeders	19	feeders / substation
Switchgear		
Number of 11kV feeder circuit breakers (CBs)	1	per feeder
Number of 11kV ring main units	7	per feeder
Number of 11kV transformer incomer, bus-section and bus-coupler CBs	10	per substation
Amount of 11kV switchgear	162	per substation
Cost of 11kV switchgear upgrade from 250MVA to 500MVA	30	£k / switchgear
Cost of switchgear replacement for Fault Level mitigation	4,860	£k / substation
Cable		
Length of 11kV cable	725	m / feeder
Total length of 11kV cable to be replaced	13,775	m / substation
Cost of upgrade of 11kV cable per m	350	£ / m
Cost of cable replacement for Fault Level mitigation	4,821	£k / substation
Switchgear and cable upgrade		
Cost of switchgear and cable replacement per substation	9,681	£k / substation
Number of substations in project	5	substations
Cost to business	**48,406**	**£k / project**

Method Costs

Description	Quantity	Unit
Cost of Fault Level Mitigation Technology	2,000	£k /substation
Number of substations in project	5	substations
Cost to business	**10,000**	**£k / project**

Projected Savings

Description	Quantity	Unit
Savings in WPD West Midlands (1 city)	38,406	£k
Savings across WPD (4 licence areas - 1 city per licence area)	153,625	£k
Savings across UK DNOs (14 licence areas - 1 city per licence area)	537,688	£k
Savings across UK DNOs (5 years - 1 city per licence area)	**537,688**	**£k**
Savings across UK DNOs (10 years - 2 cities per licence area)	**1,075,375**	**£k**

K1 - Fault Level monitoring: The business case and literature survey

Introduction
This appendix provides a detailed review of literature to date that has informed the need case for the proposed trials in Method Beta. The review intends to provide a brief synopsis of the literature, summarising key points that inform the development of the Method. Where relevant, a critical analysis of the literature is presented to assess its limitations and identify the benefits of further Fault Level monitoring trials through the Low Carbon Networks Fund. The anticipated benefits of the trials have been summarised at the end of this appendix together with concluding remarks.

The need for Fault Level monitoring trials
The increasing requirement to connect new distributed generation (such as renewable, micro CHP or CHP) to GB's distribution networks will impact on the operation of the network in a number of areas including voltage levels and Fault Levels. In general all new distributed generation contributes to fault current. In some cases this could result in the Fault Level exceeding the design limit of the network equipment unless actions are taken to mitigate this issue [1].

The contribution of induction machines to short-circuit currents can be significant and must be considered when evaluating system Fault Levels. Standard procedures for calculating short circuit currents of induction machines require detailed machine data, which may not be available. The results obtained using standards may lead to conservative design and unnecessary expense [2].

At present, industry standards use assumed 33kV fault in-feed values of 1 MVA per MVA of aggregate low voltage network connected winter demand and 2.6 MVA per MVA of aggregate winter demand connected at 11kV. These values relate to a complete loss of supply voltage to the motors[3]. The industry currently uses conservative models to calculate Fault Level. Little work has been done in the past to justify the calculated values of short circuit currents and there is some belief that the values obtained are unduly pessimistic[4]. Calculations in IEC60909 tend to include a safety margin of up to 10%.

The integration of low carbon technologies within distribution networks increases the need for accurate Fault Level assessments, so that appropriate costs can be attributed to customers' connections. However, it is not practical to apply a full short circuit in order to measure the fault current. Therefore, at present, there is limited visibility of true network Fault Level and how this changes on a real-time basis.

Summary of the state-of-the-art
Fault Level monitors can generally be categorised as passive devices, active devices or hybrid devices. Passive devices use naturally occurring system disturbances to estimate the Fault Level. Active devices create temporary but reduced short circuit currents on a periodic basis or inject harmonic currents around the frequency band of the fundamental frequency. Hybrid devices use artificial and controlled network disturbances, potentially supplemented with natural disturbances, to measure the Fault Level and minimise the effect of Fault Level measurements on the distribution network and connected customers.

---

[1] KEMA, "The Contribution to distribution network fault levels from the connection of distributed generation", 2005.
[2] Williamson, Jenkins, Cornfield, "Use of naturally occurring system disturbances to estimate the fault current contribution of induction motors", 1996.
[3] ENA "Engineering Recommendation G74 – Procedure to Meet the Requirements on IEC 909 for the Calculation of Short-Circuit Currents in three-Phase AC Power Systems", 1992.
[4] Cornfield, "Estimating system fault level from naturally occurring disturbances", 1993.

Passive devices

'EATL Fault Level Monitor'

The need to develop instrumentation to measure Fault Level was identified by EA Technology two decades ago [4]. In conjunction with the ENA and UMIST, a Fault Level monitor was developed, using natural disturbances to estimate network Fault Levels, including the downstream contribution from induction motor loads. The algorithm was embedded on a disturbance recorder with extended software capabilities. The performance of the device was examined using simulation studies and comprehensive field tests at two industrial substations and a wind farm. Results showed that the Fault Level monitor was within 8% of the simulation results and 15% of the field tests [2]. The results of the test carried out on the Fault Level Monitor (FLM) show that it is capable of delivering an assessment of both the source and motor in-feed elements of Fault Level. During the study it was identified that the EATL FLM was based on a hardware platform which is obsolete and no longer supportable. Stage 2 of the work carried out in conjunction with University of Strathclyde was intended to develop a new FLM. To progress to Stage 2 of the project, as originally defined, the results obtained from Stage 1 had to support a statement that it was technically feasible to develop a Fault Level Measuring Instrument capable of deriving answers within ±5% of the actual in-feed values. Following the work carried out it was not possible to make such a statement. The algorithm validation work cast some doubt over the achievability of that goal. As the results of Stage 1 did not support an unequivocal statement that it was technically feasible to develop a Fault Level Monitor with the required degree of accuracy this project concluded at Stage 1. The report produced by EATL recommended that a new platform to collect and analyse the disturbance data should be developed. No further ENA collaboration work is anticipated on the EATL FLM.

'Electrical network Fault Level measurement for distributed generation and other applications'

Through the IET's Power Networks Research Academy, research continued with EATL, University of Strathclyde, Central Networks and EDF Energy to overcome the hardware platform issues. A Fault Level meter has been developed using a digital signal processing chip. The first stage of this work, published in 2010 was to implement the calculation of fault contribution caused by the network source impedance in a single-phase system in near real-time. The second stage of this work is the development of near real-time Fault Level meter, which will determine both the source impedance and motor contributions to Fault Level in a three-phase system [5]. Key conclusions from this work were the need for accurate measurement transducers and the implementation of the algorithms on a more powerful microprocessor to reduce errors in the calculation of the source impedance.

Building on these conclusions, the initial development of an algorithm has taken place, which can be used alongside a digital signal controller (a Texas Instruments TMS320F28335) to calculate in near "real-time" the fault level at a specified point on the distribution network [6]. Using short-term Fourier transfer analysis, system transients are detected. Further work is scheduled to focus on the transient area of the signal to extract information for fault level estimates. This work is still at the feasibility / technology development research stage.

'Short circuit impedance measurement'

The Technical University of Denmark (DTU) developed algorithms to measure the short circuit impedance of 400kV, 132kV and 400V electricity networks, based on natural disturbances [7]. A key conclusion of the work is that there are different issues with impedance estimations at different network voltage levels. To overcome this, the DTU proposes that the statistical treatment of results can be necessary to extract the measured short circuit impedance. The proposed measurement method includes the contribution to short circuit impedance of different kinds of customers connected to the grid. The present status of this work is unknown.

---

[5] McIlvenna, Cruden, "Implementation of a Fault Level Meter using a Digital Signal Processing chip", 2010.
[6] Conner, Cruden, "Development of an Algorithm utilising a Digital Signal Controller to accurately determine in near 'Real-Time' the Fault Level in DG", 2012.
[7] Pedersen, Nielsen, Poulsen, "Short-circuit impedance measurement", 2003.

'Algorithm development for electricity supply Fault Level monitor applied in distribution generation'

Warwick University, in conjunction with the Chengde Electric Power Corp developed algorithms for a fault level monitor and carried out simulations, laboratory tests and field trials [8]. Simulation results confirmed the accuracy of the fault level monitor to be in the range 2.15% - 1.72%. Lab tests also demonstrated good agreement between the predicted and measured Fault Level. 110kV field tests predicted the three-phase fault level to within 3.7% of the power system analysis software package. The key conclusions from this project were (i) to select accurate CTs and VTs and set them up properly; (ii) select appropriate threshold values for the Fault Level. This work has not yet been progressed further.

'Outram Fault Level Monitor'

The "Outram Fault Level monitor" has been developed by Scottish Power and Outram Research Limited through IFI funding as a portable instrument that can successfully measure Fault Level on a distribution network with repeatability and reliability [9]. The developed instruments measure upstream and downstream Fault Level contributions [10] and will be deployed at various locations where there is uncertainty in Fault Level in low voltage, 11kV, 33kV and 132kV groups on the network. It is proposed that the instrument could provide a viable alternative for Fault Level assessment to extensive modelling or at locations where upstream and downstream Fault Level can vary drastically over a period of time making traditional Fault Level analysis complex.

The expected timescale to adoption is less than 2 years. During 2010 – 2011, the technology readiness level of the product progressed from TRL4 to TRL 6. Trial results have shown the Fault Level monitor is within 2 – 10% of the modelled Fault Level and Scottish Power have reported a 75% chance of the project's success.

Active devices

Fault Level monitors based on natural disturbances are potentially adequate for planning processes. However, these types of devices have limited application in the real-time management of Fault Level. This is because the occurrence of natural disturbances within the electricity network is unpredictable and, on this basis, insufficient to guarantee the regular Fault Level measurements that would be needed in a real-time monitoring system. This limitation is overcome by active or hybrid Fault Level monitoring devices.

'Experimental measurements of Fault Level for SCECO West, Kingdom of Saudi Arabia'

In Saudi Arabia, research has been led by King Abdulaziz University in conjunction with the Saudi Consolidated Electric Company (SCECO) to determine Fault Levels through thyristor pulse measurements [11]. In this project, a simulated prototype was developed for the measurement of short-circuit current arising from a controlled connection from a substation busbar to ground. The simulation utilised a power electronic thyristor module (modelling an anti-parallel thyristor configuration) to create a path for a small quantity of fault current to flow. The firing angle of the thyristor combined with the voltage on the busbar and the measurement of the short-circuit current provided suitable parameters for an algorithm to determine the Fault Level. The concept was implemented in laboratory environment, giving reasonably realistic results. Due to limited funding, the research and development of this device has not progressed.

---

8 Yang, Yang, "Algorithm Development for Electricity Supply Fault Level Monitor Applied in Distributed Generation", 2009.

9 Scottish Power, "IFI Report 2010/11", 2011.

10 ORL, Patent appl. WO 2012/025722 http://patentscope.wipo.int/search/en/WO2012025722, 2012.

11 Ibrahim, "Experimental Measurements of Fault Level for Sceco West, Kingdom of Saudi Arabia", 2004.

Hybrid devices

'Passive agent system impedance monitoring station and method'
EPRI has developed a hybrid device to measure and calculate fault currents on an energized system [12]. The EPRI method is less intrusive than techniques such as inserting faults or injecting harmonics to make Fault Level measurements on energized systems. The device uses capacitor inrush, typically found in power electronic loads. This allows the fault current calculation to be made based on time series and harmonic measurements. The device uses a method of monitoring impedance of an electrical system, including the steps of providing an impedance monitoring station adapted to test and monitor system impedance; solving for system impedance in a time domain; solving for system impedance in a frequency domain; and determining a time domain driving point impedance and a frequency domain driving point impedance to identify the impedance of the system. The Electric Power Research Institute (EPRI) has recently filed a patent for the real-time Fault Level monitoring device. The existing device measures single phase Fault Levels and has not yet been developed for deployment above domestic voltage levels.

'Implementation of an active Fault Level management scheme'
A real-time Fault Level monitoring device has been developed under the WPD LCNF Tier-1 project "Implementation of an Active Fault Level Management Scheme" (see Appendix K2). This project builds on Scottish Power's IFI work to assess the upstream and downstream Fault Level contributions that can be actively obtained through artificial network disturbances. Fault Level was successfully predicted to within 4.5% of the measured three-phase faults applied to the system, in an 11kV, 50Hz, laboratory network, with a variety of network running arrangements. The voltage and harmonic distortions created as part of the Fault Level prediction process were consistently within required voltage and harmonic planning limits.

Conclusion
The integration of low carbon technologies within distribution networks increases the need for accurate Fault Level assessments, so that appropriate costs can be attributed to customers' connections. For example, as the network configuration changes (with generator connection / disconnection or motor load connection / disconnection) then the Fault Level itself will change and the exploration of novel commercial contracts will require much a greater temporal resolution of Fault Level. Fault Level monitors based on natural disturbances are potentially adequate for planning processes. However, these types of devices have limited application in the real-time management of Fault Level. This is because the occurrence of natural disturbances within the electricity network is unpredictable and, on this basis, insufficient to guarantee the regular Fault Level measurements that would be needed in a real-time management system. This limitation is overcome by active or hybrid Fault Level monitoring devices.

For a successful project, the maximum acceptable measurement error of the Fault Level monitoring device is deemed to be ±5% of the actual in-feed values. The solution proposed by WPD for active Fault Level monitoring demonstrated an accuracy of ±4.5% in laboratory tests. This provides a reasonable basis on which to progress to scaled field trials through the Low Carbon Networks Fund. The integration of the PM7000 FLM and IntelliRupter within 11kV networks represents a novel step, which provides the total fault current contribution, without necessarily needing the exact detail of the elements which contribute to this total. The equipment overcomes the drawbacks associated with other passive and active devices.

High precision VTs and CTs will allow the PM7000 to monitor voltage and current wave forms with a high degree of accuracy. The fully supported PM7000 hardware platform provides powerful processing capability, allowing the three-phase fault contribution from both upstream and downstream sources to be monitored. The IntelliRupter provides the PM7000 Fault Level monitor with controlled non-customer-affecting disturbances that overcome the sole reliance on naturally occurring system disturbances. Scaled trials through the Low Carbon Networks Fund could allow the accuracy of the Fault Level monitor to be determined for different DG types, which exhibit differing fault current contribution characteristics.

---

[12] EPRI, Patent appl. 20100085065, http://appft1.uspto.gov/netahtml/PTO/search-bool.html, 2010.

K2 – 'Implementation of an Active Fault Level Management Scheme' Test Report

Summary

This report forms part of the factory acceptance test (FAT) output from the WPD Tier-1 project 'Implementation of an Active Fault Level Management Scheme', registered with Ofgem on 17/04/2012. In this project, two existing products (S&C Electric's IntelliRupter and Outram Research Limited's PM7000 Fault Level Monitor) have been combined to provide Fault Level predictions in real-time. The system is expected to deliver Fault Level Monitoring capability for HV electricity networks without affecting the quality of supply delivered to customers.

The Fault Level prediction functionality of the combined devices was tested at S&C Electric's laboratories in Chicago during July 2012.

For the 11kV, 50Hz tests, conducted at a variety of system Fault Levels and network running arrangements, the Fault Level was consistently predicted to be within 4.5% of measured three-phase faults applied to the system.

Overview of Real-time Fault Level Monitoring System

Two existing products (S&C Electric's IntelliRupter and Outram Research Limited's PM7000 Fault Level Monitor) have been combined to provide Fault Level predictions in real-time. An IntelliRupter is an electricity network switching device that, in normal operation, is used to detect and isolate faults. The PM7000 is an electricity network device that monitors power quality. The PM7000 provides a hardware platform for Fault Level Monitoring and prediction algorithms.

Using the control functionality of the IntelliRupter, an artificial change in network operating conditions is created. This switching operation has the same effect on the electricity network as a motor or generator connecting to the network and being switched on / off. The change in network running conditions is detected by the PM7000 Fault Level Monitor and the Fault Level is predicted. The system is expected to deliver a Fault Level Monitoring System for HV electricity networks without affecting the quality of supply delivered to customers.

Test Procedure

Factory acceptance tests were carried out at the S&C Electric laboratory facility in Chicago during July 2012. A diagram of the test set-up is given in Figure 1.

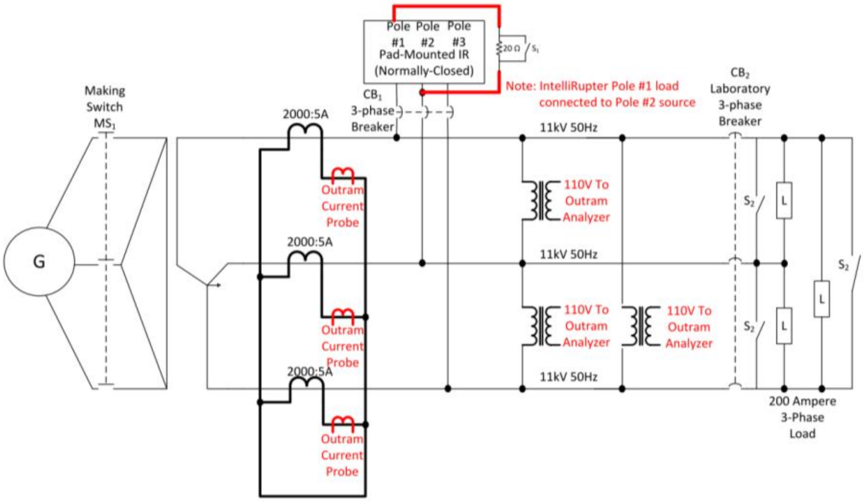


Figure 1. Laboratory Test Set-Up

(G = generator, S = switch, L = load).

For a range of X/R ratios (13.3 – 30.0) and with / without 200A load connected, a series of tests were conducted. The Fault Level Monitoring system, with the IntelliRupter and PM7000 combined, was used to predict the Fault Level of the system. In order to validate the accuracy of the Fault Level Monitoring System predictions, for each test a three-phase fault was applied to the network and the results of the Fault Level Monitoring system were directly compared to the measured Fault Level.

Test Results
A selection of test results are summarised in Table 1, representing inclusion of a 20Ω inductance in the IntelliRupter circuit. The greatest difference between measured and predicted Fault Levels was 4.5%. This result occurred for the break Fault Level prediction, when the test network was configured with an X/R ratio of 30 and with 200A load connected to the system. Across a range of test conditions, the average % difference for both make and break Fault Level predictions was 2.7%.

Measured Fault Current		**X/R Ratio**	**Switching Operation**	**Predicted Fault Current**		**% Difference**	
Make @ 10ms (kA)	Break @ 90ms (kA)	(No unit)	(No unit)	Make @ 10ms (kA)	Break @ 90ms (kA)	Make @ 10ms (kA)	Break @ 90ms (kA)
13.83	5.10	30.00	With 200A load connected	13.37	4.87	3.33	4.46
13.83	5.10	30.00	Without 200A load connected	13.50	5.24	2.37	-2.70
12.88	5.09	13.30	With 200A load connected	13.27	4.95	-2.99	2.79
12.88	5.09	13.30	Without 200A load connected	13.38	5.03	-3.88	1.32
31.34	13.10	23.00	With 200A load connected	30.40	13.5	3.01	-3.38
31.34	13.10	23.00	Without 200A load connected	31.02	12.87	1.01	1.74

Table 1. Laboratory Test Results

Voltage and waveform distortion considerations are given in Appendix K3.

Conclusion
The laboratory tests have demonstrated that the IntelliRupter and PM7000 devices can be successfully combined and used to provide a Fault Level prediction within 4.5% of the measured Fault Level for the test cases considered. Using control functionality of the IntelliRupter to provide a non-customer-affecting disturbance, there is the possibility of predicting the Fault Level in real-time.

Since there is limited capability, at present, to monitor HV Fault Levels in UK electricity networks, the results are considered to be highly encouraging.

The Tier-2 project allows the developed Fault Level Monitoring System to be tested extensively in a variety of substation environments, with various network running arrangements.

K3 – Supplement to AFLMS Test Report (Waveform distortion and voltage considerations)

Summary

This report supplements the 'Implementation of an Active Fault Level Management Scheme' Test Report (Appendix K) and explicitly considers the potential effect on customers' quality of supply, due to voltage and waveform variations, as a consequence of providing network Fault Level predictions in real-time. Two existing products (S&C Electric's IntelliRupter and Outram Research Limited's PM7000 Fault Level Monitor) have been combined to provide Fault Level predictions in real-time.

The Fault Level prediction functionality of the combined devices was tested at S&C Electric's laboratories in Chicago during July 2012.

For the 11kV, 50Hz tests, conducted at a variety of system Fault Levels and network running arrangements, both voltage and harmonic distortions are such that they are consistently within required planning limits.

Test Results

Voltage

A selection of test results are summarised in Table 1. The greatest voltage step change without the presence of any additional impedance was 23.41%. When a 20Ω impedance was included in the system the voltage step change was reduced to 2.76%. Figure 2 illustrates the effect on the voltage at the point an artificial change in network operating conditions is created.

Fault Level	X / R Ratio	Switchging operation	Impedance	Maximum Voltage	Minimum Voltage	Voltage fluctuation
Make @ 10ms (kA)	(No unit)	(No unit)	(Ω)	(kV)	(kV)	(%)
13.83	30.00	With 200A load connected	0	6.534	5.373	17.77%
13.83	30.00	Without 200A load connected	0	6.548	5.015	23.41%
12.88	13.30	With 200A load connected	0	6.357	5.658	11.00%
12.88	13.30	Without 200A load connected	0	6.477	5.775	10.84%
31.34	23.00	With 200A load connected	0	6.346	5.619	11.46%
31.34	23.00	Without 200A load connected	0	6.555	5.871	10.43%
13.83	30.00	With 200A load connected	20 (inductive)	6.417	6.353	1.00%
13.83	30.00	Without 200A load connected	20 (inductive)	6.447	6.384	0.98%
12.88	13.30	With 200A load connected	20 (inductive)	6.289	6.193	1.53%
12.88	13.30	Without 200A load connected	20 (inductive)	6.453	6.298	2.40%
31.34	23.00	With 200A load connected	20 (inductive)	6.298	6.150	2.35%
31.34	23.00	Without 200A load connected	20 (inductive)	6.451	6.273	2.76%

Table 1. Voltage fluctuation results

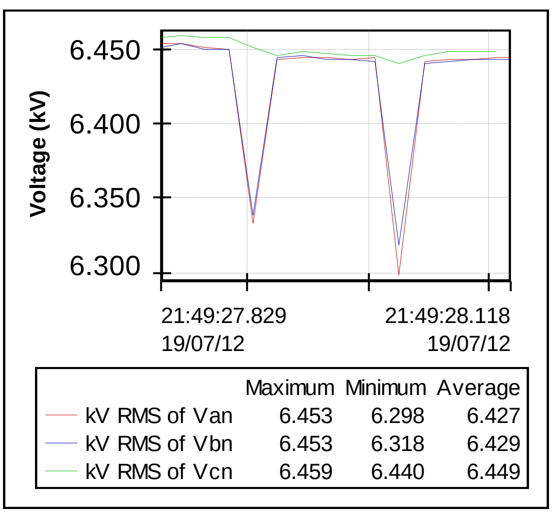


Figure 2. Voltage fluctuation for FL 12.88kA and X/R 13.30

The percentage voltage fluctuation with zero additional impedance ranges between 10.84% and 23.41%. The complete range of percentage figures are in excess of the recommended acceptable network limits, as prescribed in P28. Through the introduction of a 20Ω impedance (inductance) the voltage fluctuation seen on the system was limited to a range between 0.98% and 2.76%. P28 recommends a general limit of 3% on the allowable magnitude of voltage changes. The average percentage voltage deviation was 1.84%, which is P28 compliant.

Harmonic

Figures 3 and 4 illustrate the change in total harmonic distortion (THD) due to the artificial change in network conditions. The instantaneous THD range for a system with no additional impedance is between 22.6% and 54.9%. For a system with a 20Ω impedance included the THD range is between 2.2% and 4.7%.

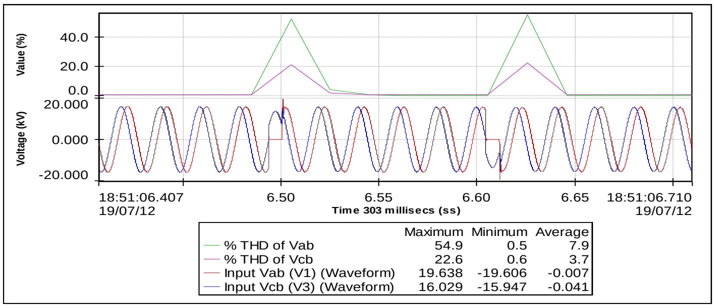


Figure 3. THD with zero additional impedance

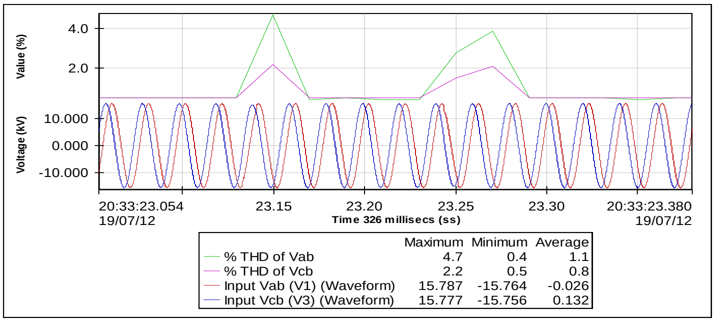


Figure 4. THD with 20 Ω impedance

The THD values represented in Figures 3 and 4 are instantaneous values extrapolated from sub-cycle disturbances. G5/4-1 indicates that THD values are to be derived over 10 minute average values, where 4% is the limit at 11kV. Therefore, dependent on the frequency of disturbance repetition, THD values, both with and without 20Ω impedance included, would be acceptable to the 11kV distribution system.

Conclusion

The laboratory tests have demonstrated that a device to provide Fault Level predictions in real-time could be successfully integrated in to an 11kV distribution network, in terms of acceptable harmonic and voltage network distortion. The inclusion of a suitable impedance, demonstrated by a 20Ω inductor in the laboratory tests, is required to ensure that the effects on harmonic and, more critically, voltage distortion are retained within planning recommendation limits.

Repetition rates for Fault Level monitoring are yet to be considered in detail, however, using calculations as prescribed in P28, with the worst case voltage fluctuation, 2.76% and assuming background levels to be at 50% of the limit, the acceptable repetition rate would be 360 seconds. The repetition rate is limited by the acceptable Long term severity value (P_{lt})

The THD values calculated and presented in Figures 3 and 4 are instantaneous values, if considered over 10 minutes, as detailed in G5/4-1, the effect on THD would be negligible.

L - Overview of Fault Level Mitigation Technologies

Technology	Description	Discussion
Fault current limiter	Normally invisible to the network (no effect). Reduces fault current in the instance of a fault.	• Several methods of actively limiting fault current exist, with individual merit. • Minimal voltage drop during normal operation.
Higher impedance transformers	Reduces fault current through increasing the operational impedance of the network.	• No additional space requirements. • Considerable voltage drop during normal operation. • Relatively small amount of fault current reduction achievable. • Expensive and time-consuming installation.
Inductive reactor	Device comparable to a transformer, with additional operational impedance on the network to minimise fault current.	• High on the technology readiness level (TRL) scale and has been deployed in a number of locations. • Considerable voltage drop during normal operation. This can be mitigated by only switching equipment into the network when generation and load increases. • Switching reactors into the network relies on the healthy operation of control signals and switching equipment.
Real-time network switching and software solution	Solution that adapts the configuration of the network to prevent fault current exceeding equipment ratings.	• System-wide Fault Level Management is possible. • Fault current is not actively reduced. The solution cannot be used if Fault Levels exceed equipment ratings when the network is run split. • The solution would require complete system monitoring and/or modelling and relies on the healthy operation of control signals and switching equipment.
Soft normally open points	Control of power flow between two points and reduction of fault current.	• Actively limits fault current with no voltage drop during minimal operation. • Technology can also provide voltage control. • Technology proven at transmission level.
Uprating of switchgear	Switchgear with higher fault level ratings.	• No additional space requirements. • Fault current is not actively reduced. The fault current may still exceed equipment rating downstream of the substation. • Expensive solution if equipment over a wide area needs replacing, and time-consuming installation.

M – Overview of Substations and Suitability for Technology Inclusion

Substation Selection Procedure

Eighteen 132/11kV grid substations in the Birmingham region were assessed for the deployment of Fault Level Mitigation Technologies. This assessment was based on the following criteria:

- Fault Levels already near existing switchgear/equipment ratings
- Presence of suitable 11kV switchgear
- Proximity to the centre of Birmingham (Commercial Business District)
- Likely requests for the connection of distributed generation
- Available space for Fault Level Mitigation Device installation
- Available space for additional 11kV switchgear associated with Fault Level Mitigation Technologies
- Any consequential benefits arising from reduced Fault Levels

As a result of this assessment, five substations were selected as suitable for the installation of Fault Level Mitigation Technologies. These five substations are referred to as Substation A, B, C, D and E later in this appendix.

Fault Levels and Switchgear Capability

Power system analysis studies were undertaken on each of the chosen substations to assess Fault Levels under existing operating conditions and after the addition of incremental amounts of Distributed Generation (DG), from 5% up to 50% of substation firm capacity. These increased Fault Levels were compared with existing grid substation equipment ratings to identify where reinforcement due to Fault Level constraints would normally be required.

Fault Levels are not reduced to any great extent by the impedance of interconnecting cables, and it is expected that very similar Fault Levels will exist at 11kV/LV substations close to the grid substation. It follows that these 11kV downstream substations will require a Fault Level assessment to ensure switchgear is not exposed to fault currents in excess of their ratings. As mentioned elsewhere in the project proposal, there are particular issues with ensuring the rating and general condition of customer-owned switchgear under increased Fault Level scenarios.

The cost of any necessary grid substation, network cabling, and 11kV/LV substation reinforcement due to DG connections represents the base case or business-as-usual scenario against which each of the Fault Level Mitigation Technologies can be compared during the project.

Fault Level Mitigation Technology Initial Evaluation Procedure

In readiness for the Tier 2 project, Request for Information (RFI) enquiries were sent to nine prospective product suppliers requesting details of equipment suitable for Fault Level mitigation in electric distribution networks. The RFI responses received will form the basis of the Tier 2 project Fault Level Mitigation Technology assessments as part of a detailed procurement process. RFI responses were received for a range of technologies:

- Active Fault Decoupler
- Magnetic Fault Current Limiter
- Shielded Inductive Superconducting Fault Current Limiter
- Dynamic Fault Current Limiter
- High Temperature Superconductor Hybrid
- MgB2 Superconducting Fault Current Limiter
- Resistive Superconducting Fault Current Limiter
- Pre-saturated Core Fault Current limiter
- Superconducting Pre-saturated Core

From these RFI responses, the potential Fault Level reduction available using each technology was assessed. A Fault Level reduction factor was established for each of the technologies and will be used for comparison purposes during procurement.

Fault Level mitigating equipment space and weight requirements were compiled and compared to available accommodation in each of the five substations. The results are summarised in Table 1 below:

Fault Current Limiter Technology	Substation				
	A	**B**	**C**	**D**	**E**
Active Fault Decoupler	Yes	No	Yes	Yes	Yes
Magnetic	No	No	No	Yes	No
Shielded Inductive Superconductor	No	No	No	Yes	No
Dynamic	Yes	Yes	Yes	Yes	No
High Temperature Superconductor Hybrid	No	No	No	Yes	No
MgB2 Superconductor	No	No	No	Yes	No
Resistive Superconductor	Yes	Yes	Yes	Yes	No
Pre-saturated Core	Yes	Yes	Yes	Yes	No
Superconducting Pre-saturated Core	No	No	Yes	Yes	No

Table 1 - Equipment Requirements versus Substation Suitability

Summary

The initial substation selection process has identified five suitable 132/11kV grid substations in or near to Birmingham's Central Business District. Substations have been selected on suitability to accommodate a range of Fault Level Mitigation Technologies and because they are expected to be involved in Distributed Generation schemes in the near future.

Further detailed analysis will be undertaken during the Tier-2 project to select the appropriate Fault Level Mitigation Technology for each of the selected substations.

N – Learning from IFI, ETI and LCNF Projects

Projects involving Fault Current Limiters

There are 3 UK projects involving the installation of superconducting fault current limiters (SFCLs) on distribution networks. In total these projects involve 6 fault current limiters being installed on 5 distribution networks, including one to be installed on Western Power Distribution's network.

- **Innovation Funding Incentive – 'Superconducting Fault Current Limiter'**

  This project involves the trialling of three SFCLs on three different UK distribution networks. The participating DNOs are Electricity North West (ENW), Scottish Power (SP) and Northern Power Grid (NPG). The aim of the project is to develop, understand and address the issues associated with the connection of 11kV fault current limiting devices to the network, where successful trials will result in the development of commercially available fault current limiters. Three fault current limiter applications are to be trialled; transformer tails, bus section and interconnected network connection.

  - SP estimated probability of success at 25%
  - ENW estimated probability of success at 75%
  - Technology provider: Applied Super Conductors Ltd
  - The project is due to report results by 2014

- **Energy Technologies Institute– 'Pre-saturated Core Superconducting Fault Current Limiter' and 'Resistive Superconducting Fault Current Limiter' (including IFI 'Active Fault Current Management' funding)**

  This project involves the development and demonstration of a pre-saturated core SFCL at UK Power Networks and a resistive SFCL at Western Power Distribution.

  During the trial the SFCL's performance will be monitored and the impact on existing equipment and operational procedures will be assessed. The demonstration will also contribute to the drafting of standards (specifications, manufacturing requirements, type testing, routine testing etc.) and knowledge will be gained on the whole system losses, allowing improvements to be made.

  The device to be developed for installation on the Western Power Distribution network uses novel superconducting material, which aims to reduce capital costs.

  - WPD(CN) estimated probability of success at 25%
  - R&D providers: AREVA T&D, University of Palermo and E.ON Engineering
  - The project commenced in Q2/2011 and is due to report results by 2014

- **Low Carbon Network Fund Tier 1 – 'CET1001 – 33kV Superconducting Fault Current Limiter (33kV SFCL)'**

  This project involves the trialling of a single superconducting 33kV fault current limiter on the Northern Power Grid network. Fault current limiters at this voltage level have not yet been trialled in the UK.

  The key learning to be delivered by the project is the understanding of the circumstances under which the SFCL can be used to mitigate fault level issues, specifically the circumstances where use of the SFCL could be used to mitigate distributed generation connection issues. Other learning includes identification of the control and operational issues, assessment of the actual carbon benefits and assessment of the impact on policies, codes of practices and section level procedures.

  - Technology provider: Applied Superconductor Ltd
  - The project installation is scheduled for 2012 and is due to report results by 2013

Projects involving Fault Level Monitors

- **IFI DNO/ENA Collaborative 'EATL Fault Level Monitor'**

  The results of the test carried out on the Fault Level Monitor (FLM) show that it is capable of delivering an assessment of both the source and motor in-feed elements of Fault Level. During the study it was identified that the EATL FLM was based on a hardware platform which is obsolete and no longer supportable. Stage 2 of the work carried out in conjunction with University of Strathclyde was intended to develop a new FLM.

  To progress to Stage 2 of the project as originally defined the results obtained from Stage 1 had to support a statement that it was technically feasible to develop a Fault Level Measuring Instrument capable of deriving answers within ±5% of the actual In-feed values. Following the work carried out it is not possible to make such a statement. The algorithm validation work has cast some doubt over the achievability of that goal. As the results of Stage 1 do not support an unequivocal statement that it is technically feasible to develop a Fault Level Monitor with the required degree of accuracy this project will conclude at Stage 1.

  The report produced by EATL recommended that consideration should be given to the need to carry out further development of a new platform to collect and analyse the disturbance data. No further ENA collaboration work is anticipated on the EATL FLM.

  - Technology provider: University of Strathclyde, EA Technology Ltd

- **IFI Central Networks 2009/10 PNRA 'Electrical Network Fault Level Measurement for Distributed Generation and Other Applications'**

  The project will develop an electrical instrument (a Fault Level Monitor) that is capable of calculating the network source impedance, the X/R ratio of this impedance and the fault contribution of connected rotating plant. The preferred solution is an instrument that processes signals obtained from measuring network disturbances caused by load changes, network switching or other natural transient events in near real-time. Ideally any generated network Fault Level information will be time tagged to permit temporal profiling of Fault Level as the network generation, loads and topology change.

  The meter is intended to measure network Fault Level to support results from IEC 60909 calculations. This will aid in evaluating the network for new entrants and providing more detailed temporal data on network Fault Levels.

  - CN estimated probability of success at 25%
  - Technology provider: Strathclyde University
  - The project commenced in 2010 and is due to report results by 2012

- **IFI SPEN 'Outram Fault Level Monitor'**

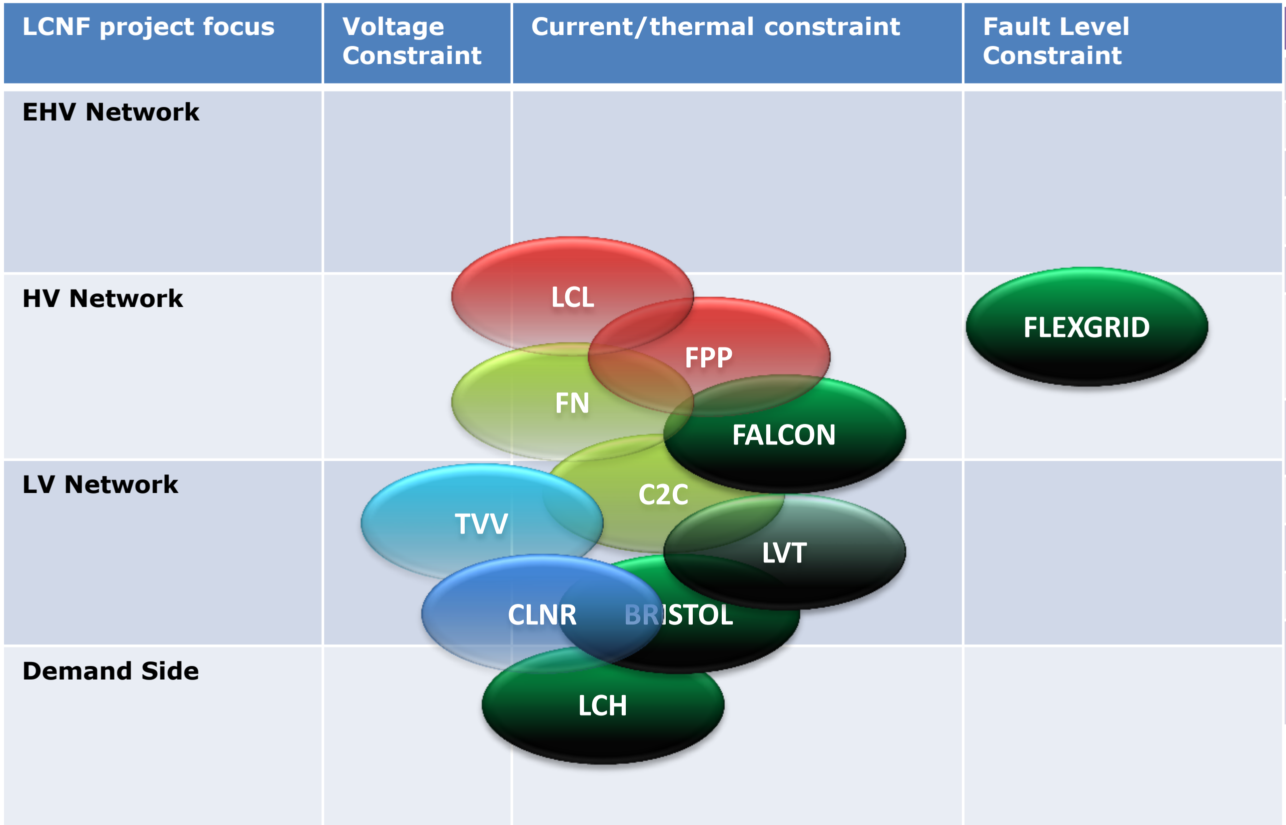
  The aim of this project is the development of a portable instrument that can successfully measure Fault Level on a distribution network with repeatability and reliability. The developed instruments will be deployed at various locations where there is uncertainty in Fault Level in Low Voltage, 11kV, 33kV and 132kV groups on the network.

  - SP estimated probability of success at 75%
  - Technology provider: Outram Research Ltd
  - The project is due to report results by 2013

Appendix O – Differentiators from previous LCNF projects

O - Differentiators from previous LCNF projects

FLEXGRID's focus on Fault Level issues is unique among Tier 2 projects.



KEY:	
FLEXGRID	This project
TVV	Thames Valley Vision 2
C2C	Capacity to Customers
FPP	Flexible Plug and Play
FN	Flexible Networks
BRISTOL	Buildings Renewables and Integrated Storage / Tariffs
CLNR	Customer Led Network Revolution
LCL	Low Carbon London
LVT	LV Templates
LCH	Low Carbon Hub
FALCON	Flexible Approaches for Low Carbon Optimised Networks

NB: Indicative only

P1 - Carbon Emission Savings

The quantity of carbon emission savings is dependent on the type of generation that customers choose to connect to the network. The expected primary source of carbon emissions savings from this project will be as a result of the increased amount of facilitated CHP installation. CHP is becoming increasingly prevalent, particularly in the application of district heating, as highlighted in Councils' strategic planning documents.

To evaluate the carbon emission savings from potential CHP installations five scenarios have been considered; the first three consider the savings that could be achieved in the Birmingham area, the fourth and fifth consider the carbon savings if the project was rolled out nationwide.

Scenario 1: The connection of 10% of the homes (41,000) in Birmingham to district heating. This is in line with 'Birmingham: Climate Change Action Plan 2010+', which documents that Birmingham aims to have 10% of the homes in Birmingham connected to district heating by 2015 [1].

Scenario 2: The connection of CHP generation (50% of the substation firm capacity) at the five Birmingham substations to be installed with Fault Level Mitigation Technologies. This results in an installed CHP electrical generation capacity of 214MW, connecting 123,379 homes to district heating schemes.

Scenario 3: The connection of 50% of homes (205,000) in the Birmingham area to district heating.

Scenario 4: The connection of 50% of homes (13,258,500 [2,3 and 4]) in the UK to district heating. This is in line with the 'Higher CCS, more bioenergy' scenario of the Carbon Plan [5] .

Scenario 5: The connection of CHP generation at 50% of the substation firm capacity at 140 substations in the UK with Fault Level Mitigation Technologies installed. This is based on 5 substations per city, in 2 cities of each of the 14 DNO licence areas.

In scenarios 1, 3 and 4 the total heat energy consumption for the number of homes to be connected to CHP schemes is calculated. This is based on calculating the average heat energy consumption per home, using energy consumption data for space heating and hot water in the UK [6].

In scenarios 2 and 5 the total electricity to be generated by the CHP scheme is calculated. This is based on the total electricity generation capacity that can be installed, where each substation with Fault Level Mitigation Technology is expected to be able to facilitate CHP generation up to 50% of the substation firm capacity.

---

[1] Birmingham City Council, 'Birmingham: Climate Change Action Plan 2010+', Mar 2010

[2] Office for National Statistics, '2011 Census – Population and household estimates for England and Wales, March 2011', Jul 2012

[3] National Records of Scotland, 'Estimates of households and dwellings in Scotland, 2010', May 2011

[4] Northern Ireland Statistics and Research Agency, 'Northern Ireland housing statistics 2010/2011,' 2011

[5] Department of Energy and Climate Change (DECC), 'The Carbon Plan: Delivering our low carbon future', Dec 2011

[6] Department of Energy and Climate Changes (DECC),'Great Britain's housing energy fact file 2011', Sept 2011

For combined cycle gas turbines the heat energy to electricity ratio is 1.6:1 [7]. This is the most common type of CHP currently installed [8]. It is expected that this would be the type of CHP used for the majority of district heating schemes.

In scenarios 1, 3 and 4 the heat energy to electricity ratio is used to calculate the total electricity to be generated by the CHP scheme. In scenarios 2 and 5 the heat energy to electricity ratio is used to calculate the total heat energy to be generated by the CHP scheme.

In all scenarios the total carbon emissions for the CHP scheme are calculated, based on the total electricity generated by the CHP scheme. For combined cycle gas turbines the total carbon emissions of electricity generated is 610g/kWh(e) when natural gas is used as the primary fuel source [9].

The carbon emissions for producing the equivalent amount of electricity are calculated based on the UK average generation mix, which has carbon emissions of 428 g/kWh(e) [10]. The carbon emissions for producing the equivalent amount of heat energy are calculated based on using gas boilers, which is the assumed method of heating the home which CHP will replace. The average UK boiler emissions is 206 g/kWh(h) [11]. The total emissions for conventional energy sources to supply the equivalent amount of energy as CHP, is the sum of equivalent electricity emissions and equivalent heat emissions.

The total carbon emissions for the CHP scheme are compared with the total equivalent emissions for conventional energy sources. The installation of CHP schemes results in carbon emissions savings in all scenarios, which is detailed in Table 1.

CHP generally supplies local load. The actual carbon emissions savings for CHP may therefore be higher than those tabulated in Table 1, due to the fact that the transmission and distribution losses would not be applicable. The average transmission and distribution losses are 5% [12].

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 (Mt)
Scenario 1: 10% of homes in Birmingham	0.6	0.4	71.2	41,000	0.06
Scenario 2: Trial Fault Level Mitigation Technology substations	1.95	1.22	214.5	123,379	0.18
Scenario 3: 50% of homes in Birmingham	3.3	2.0	356.4	205,000	0.30
Scenario 4: 50% of homes in the UK	210	131	23,051	13,258,500	19.37
Scenario 5: 140 substations in the UK with Fault Level Mitigation Technologies	54.7	34.2	6,006	3,454,601	5.05

Table 1: Summary of Emissions Savings

[7] Department of Energy and Climate Change (DECC), 'CHP Emission Reductions', 2012, http://chp.decc.gov.uk/cms/chp-emission-reductions/

[8] Department of Energy and Climate Change (DECC), ' CHP Focus CHP database', http://chp.decc.gov.uk/app/reporting/index/viewtable/token12

[9] Department of Energy and Climate Change (DECC), 'CHP Emission Reductions', 2012, http://chp.decc.gov.uk/cms/chp-emission-reductions/

[10] Department of Energy and Climate Change (DECC), '2011 UK Greenhouse Gas Emissions', Jul 2012

[11] The Carbon Account, 'Carbon calculation methodology', Mar 2008

[12] Ofgem, 'Electrical distribution system losses: non-technical overview', Mar 2009

P2 - Carbon Emission Savings Calculations

	Scenarios					
	Scenario 1: 10% of homes in Birmingham (41,000 homes) supplied by CHP	**Scenario 2: CHP installed at substations trialling Fault Level Mitigation technology**	**Scenario 3: 50% of homes in Birmingham (205,000 homes) supplied by CHP**	**Scenario 4: 50% of UK homes supplied by CHP**	**Scenario 5: CHP installed at 140 UK substations with Fault Level Mitigation technology**	**Units**
(1a) Energy Use (based on a number of homes supplied by the CHP scheme)						
Total UK energy use for space heating	3.35E+11	n/a	3.35E+11	3.35E+11	n/a	kWh(h)/yr
Total UK energy use for hot water	8.50E+10		8.50E+10	8.50E+10		kWh(h)/yr
Total UK energy use for heating (space heating + hot water)	4.20E+11		4.20E+11	4.20E+11		kWh(h)/yr
Number of homes in the UK	26520000		26520000	26520000		
Average energy use for heating per home	1.58E+04		1.58E+04	1.58E+04		kWh(h)/yr
Number of homes to be heated by CHP	41000		205000	13260000		
Total heat energy to be generated by CHP	6.49E+08		3.25E+09	2.10E+11		kWh(h)/yr
Typical CHP heat to electricity ratio	1.6		1.6	1.6		
Total electricity to be generated by CHP	4.06E+08		2.03E+09	1.31E+11		kWh(e)/yr
Running factor of CHP scheme	65		65	65		%
Total electricity generation capacity required for the CHP scheme	71,273		356,363	23,050,580		kW
(1b) Energy Use (based on an amount of generation that can be accommodated)						
Total electricity generation capacity that can be accomodated	n/a	214500	n/a	n/a	6006000	kW
Running factor of CHP scheme		65			65	%
Total electricity to be generated by CHP		1.22E+09			3.42E+10	kWh(e)/yr
Typical CHP heat to electricity ratio		1.6			1.6	
Total heat energy to be generated by CHP		1.95E+09			5.47E+10	kWh(h)/yr
Number of homes to be heated by CHP		123,393			3,454,992	
(2) Emissions from CHP						
CHP emissions per kWh(e) of electricity (assuming all CHP emissions are assigned to the production of electricity)	610	610	610	610	610	g/kWh(e)
Total CHP emissions for the scheme	2.48E+11	7.45E+11	1.24E+12	8.01E+13	2.09E+13	g
(3) Equivalent emissions using other energy sources						
Standard UK boiler emissions per Kwh(h) of heat energy	206	206	206	206	206	g/kWh(h)
Emissions if the heat energy provided by the CHP scheme was to provided from gas boilers	1.34E+11	4.03E+11	6.69E+11	4.33E+13	1.13E+13	g/yr
Average emissions for UK electricity generation per kWh(e) of electricity generated	428	428	428	428	428	g/kWh(e)
Emissions if the electricity generated by the CHP scheme was to be provided by the average UK generation mix	1.74E+11	5.23E+11	8.68E+11	5.62E+13	1.46E+13	g/yr
Total emissions for the scheme if heat energy came from gas boilers, and electricity generated came from the average UK generation mix	3.07E+11	9.25E+11	1.54E+12	9.94E+13	2.59E+13	g/yr
(4) Emission savings						
Emissions savings using CHP compared to providing the same amount of energy using gas boilers and electricity based on the UK average generation mix (Mt)	**0.06**	**0.18**	**0.30**	**19.37**	**5.05**	Mt/yr
% Reduction in emissions savings using CHP compared to providing the same amount of energy using gas boilers and electricity based on the UK average generation mix	**19.48**	**19.48**	**19.48**	**19.48**	**19.48**	%

Formatting key

(green)	**Values associated with heat**
(yellow)	**Values associated with electricity**
(lavender)	**Values associated with heat and electricity combined**
(peach)	**General values**

P3 - Other Benefits

Customer Benefits

- **Customers wishing to connect distributed generation** will benefit from lower costs of connection and shorter times to connect.

- **Customers who wish to install DG will gain from earlier access to DG benefits**. An uptake in distributed generation is already underway with large consumers of energy opting to install CHP schemes with direct long term cost benefits and increased security of supply. In the case of the Solihull hospital tri-generation scheme annual financial savings of £293,000 and carbon savings of 1,920 tonnes per year are forecast[1].

- **All customers will benefit from an improved quality of supply**. This project will also increase the network's capacity to be run in parallel which will reduce customer minutes lost (CMLs) and customer interruptions (CIs)[2].

- **All customers will benefit from lower than predicted DUoS charges** as a result of the use of lower cost alternatives to conventional reinforcement and a reduction in distribution losses due to the ability to install generation closer to load.

- **Customers in city centre areas may also benefit from reduced heating bills** through the introduction of CHP district heating schemes which are facilitated by this solution; this would assist the Government in addressing fuel poverty.

Direct Benefits

- We do not expect to deliver Direct Benefits during the course of the project and there will be no change to WPD's existing DR5 business plans.

- If the solution moves to 'business-as-usual' during RIIO-ED1, we would expect DNOs to benefit from reductions in network reinforcement costs together with any improvement in CIs and CMLs.

---

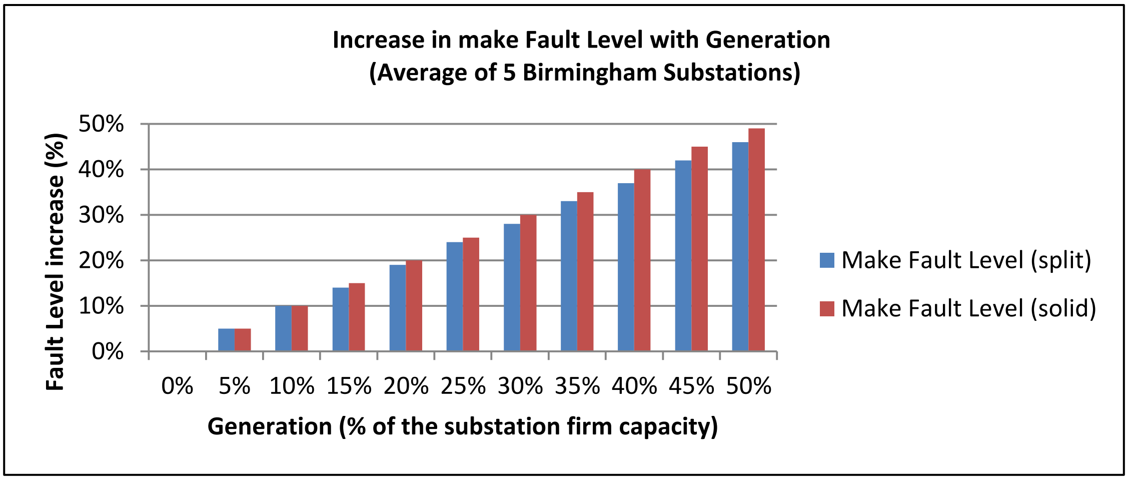
[1] Press Release: "Solihull Hospital Celebrates Low Carbon Award Success", December 2010

[2] DTI: "The Performance of Networks Using Alternative Network Splitting Configurations", August 2004

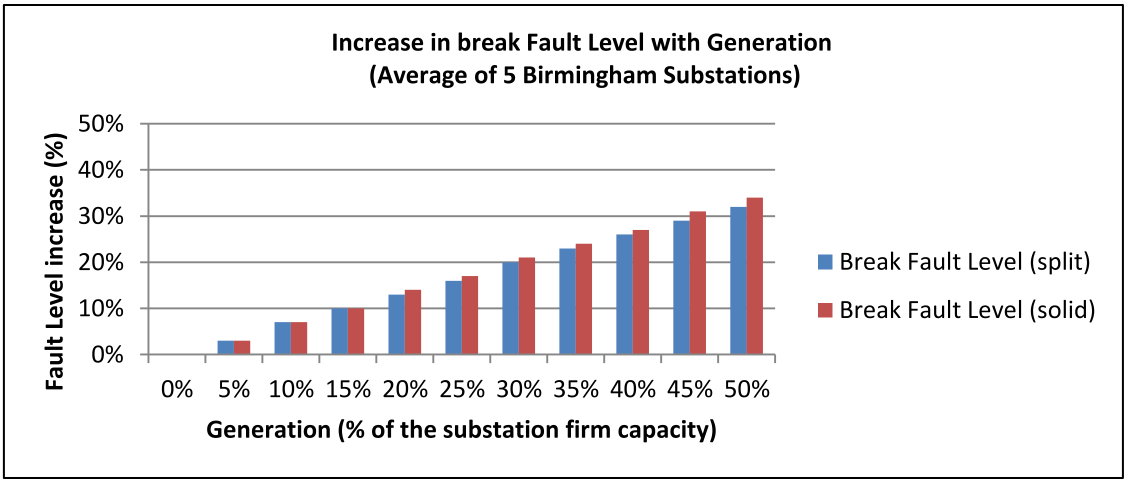
Q - Generation Effect on Fault Level

Preliminary studies have been conducted in a power system modelling tool to investigate the impact of proposed generation connections, within the 11kV network, on the Fault Level. Fault Level studies have been undertaken for five substations in Birmingham, for both split and solid configurations. The percentage increase in make and break Fault Level for generation network integration between 0% to 50% of the substations' firm capacities has been modelled.

The average increase in make Fault Level and break Fault Level for generation network integration of 50% of the substation firm capacity for solid configuration is 49% and 34% respectively. Fault Level increase for split configuration is marginally lower than for solid configuration.



a) Average increase in make Fault Level with generation



b) Average increase in break Fault Level with generation

R - Glossary of Terms

Asset Replacement	Replacement of distribution network assets (e.g. transformers and circuit breakers).
Automatic Switching Sequences	Automated switching to optimise electrical network running conditions.
BaU	Business as usual.
Break Fault Level	Fault current that the circuit breaker interrupts.
Capital Expenditure	Expense to acquire or upgrade network assets.
Central Business District (CBD)	Area of high value land and the commercial, office, retail and cultural centre of the city.
Circuit Breaker	Protection device that interrupts the flow of current in an electric circuit in the event of a fault.
Combined Heat and Power (CHP)	Simultaneous generation of usable heat and power (usually electricity) in a single process.
Connection Assessment Process	A series of technical and commercial steps by which the impact of a demand or generation connection to the electricity network is quantified.
Customer Interruptions (CI)	The number of customers whose supplies have been interrupted per 100 customers per year, where an interruption of supply lasts for 3 minutes or longer.
Customer Minutes Lost (CML)	Average duration of interruptions to supply per customer, per year, where an interruption of supply lasts for 3 minutes or longer.
Demand Side Management (DSM)	Actions undertaken by distribution network operators to influence customers to change their electricity use, in terms of quantity and/or time of use.
Distributed Generation (DG)	Generation connected directly into the distribution network, as opposed to the transmission network. This generation typically supplies local demand.
Distribution Network Operator (DNO)	The owner and/or operator of an electricity distribution system and associated assets.
Distribution Use of System (DUoS) Charges	Use of system charges for demand and generation customers which are connected to and utilising the distribution network.
District Heating	Supply of heat to a number of building or homes from a central heat source through a network of pipes carrying hot water or steam. The source of heat is typically CHP.
Electricity Miles	Representation of the physical electrical distance between generation and demand. The greater the distance, the greater the electrical losses associated with the electricity network.

Emergency Return to Service (ERTS) plan	Strategy to restore supply to customers within a set time frame in the case of an emergency during a planned outage. For customers with more than one supply, the actions set out in the strategy would be used if the customer was to lose their alternative supply.
Energy from Waste (EfW)	Burning of waste, which would otherwise go to landfill, to produce heat and/or electricity.
Energy Technologies Institute (ETI)	Partnership between global industries and the UK Government to accelerate the development of technologies that will help the UK to meet their climate change targets.
Enhanced Fault Level Assessment	Assessment of Fault Level by probabilistic quantification rather than by standard Fault Level calculations.
Flexible AC Transmission System (FACTS)	Power electronics based system designed to enhance controllability and increase power transfer capability. These devices are available for use on both transmission and distribution networks.
Fault Current	Current which flows during a fault.
Fault Level Mitigation Technology	Device that detects the flow of fault current in an electricity network and ensures that the fault current remains within network switchgear and network ratings.
Fault Level	Measure of electrical stress when faults occur within electricity networks.
Fault Level Capacity	Maximum Fault Level limit.
Fault Level Headroom	Capacity to increase the Fault Level without exceeding the Fault Level limit.
Fault Level Indices	Ranking based on the fault current as a percentage of the equipment rating or network limit.
IEC 60909	Standard produced by the International Electrotechnical Commission (IEC) on short-circuit currents in three-phase a.c. systems.
Innovation Funding Incentive (IFI)	Ofgem incentive mechanism to encourage DNO innovation.
Interlocking	Method of protection against incorrect power system operation. This can be 'electrical interlocking' or 'mechanical interlocking' in the form of locks and keys.
Islanding	Use of distributed generation to provide network supply during loss of mains generation provision.
Long Term Development Statement (LTDS)	Statement published annually by DNOs to make network information available to the public domain. This enables anyone interested in connecting generation or load to the network to identify opportunities or constraints on the network.

Appendix R – Glossary of Terms

Make Fault Level	Fault current that the circuit breaker closes onto.
MoU	Memorandum of understanding.
Nuisance Tripping	Unwarranted tripping of circuit breakers.
Open-loop	Control system that does not have a feedback loop.
PowerOn Fusion	Distribution Management System by General Electric (GE).
Protection Relays	Device that analyses power system voltages and currents to detect faults.
RAID Log	Risk, Assumption, Issues and Dependencies Log
Real-time Fault Level Modelling	Assessment of Fault Level by the use of computer simulations and inputs that vary in real time.
Real-time Fault Level Monitoring	Method which measures the Fault Level on a periodic basis.
Real-time Fault Level Measurement	Measurement of fault current on inception of a fault to calculate the Fault Level at a particular instant in time.
RfI	Request for Information.
Solid Configuration	Configuration where transformers are run in parallel (defined in Appendix C1).
Split Configuration	Configuration where transformers are run separately (defined in Appendix C1).
Static Synchronous Condenser (STATCOM)	FACTS device to maintain voltage magnitude (shunt compensation).
Substation	A point on the network where voltage transformation occurs.
Switchgear	Device for opening and closing electrical circuits (including circuit breakers).
Technology Readiness Level (TRL)	Method of assessing and defining maturity of technology.
Transformer	Device that changes the voltage of an a.c. current, without changing the frequency.
UoW	University of Warwick.
Voltage Conditioning Unit	Device that controls the electricity network voltages.