Enhanced Frequency Control Capability (EFCC)

National Grid

July 2014

Electricity Network Innovation Competition Full Submission Pro-forma

Contents

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Section 1: Project Summary

1.1 Project Title:

Enhanced Frequency Control Capability

1.2 Funding Licensee:

National Grid Electricity Transmission

1.3 Project Summary:

Meeting UK carbon reduction targets will result in a significant increase in the volume of **renewables**. This will reduce **system inertia**, giving rise to an increase in the volume and speed of frequency **response** requirements. Under existing arrangements this increased response requirement is anticipated to see the cost of controlling frequency increase by **£200m-£250m** per annum by **2020**. To mitigate this increase in cost to the end consumer it will be necessary to develop new, significantly faster response solutions utilising renewables, demand side resources, and other new technologies in a coordinated manner. The successful implementation of this project can result in **savings of £150m-£200m per annum by 2020.**

The objective of this project is to develop and demonstrate an innovative new monitoring and control system which will obtain accurate frequency data at a regional level, calculate the required rate and volume of very fast response and then enable the initiation of this required response. This system will then be used to demonstrate the viability of obtaining rapid response from new technologies such as solar PV, storage and wind farms. The new system will also be used to demonstrate the coordination of fast response from demand side resources (DSR), and fast start up from thermal power plants. Utilising the output of this trial, a fully optimised and coordinated model will be developed which ensures the appropriate mix of response is utilised. This will support the development of an appropriate commercial framework prior to full roll out.

New generation technologies are required to facilitate the carbon agenda. EFCC will enable these to contribute to resolving the challenges associated with the change in the generation mix, without imposing increased risk on the security of the system. This will provide commercial incentives and ensure these new technologies can effectively compete with existing technologies in the ancillary service market. There is no provision for trialling the EFCC concept as business as usual.

1.4 Funding

1.4.1 NIC Funding Request (£k): £7,239

1.4.2 Network Licensee Compulsory Contribution (£k): £823

1.4.3 Network Licensee Extra Contribution (£k):

1.4.4 External Funding - excluding from NICs/LCNF (£k): £1,371

1.4.5 Total Project cost (£k): £9,603

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Section 1: Project Summary continued

1.5 Cross industry ventures: If your Project is one part of a wider cross industry venture please complete the following section. A cross industry venture consists of two or more Projects which are interlinked with one Project requesting funding from the Electricity Network Innovation Competition (NIC) and the other Project(s) applying for funding from the Gas NIC and/or Low Carbon Networks (LCN) Fund.

1.5.1 Funding requested from the LCN Fund or Gas NIC (£k, please state which other competition): N/A

1.5.2 Please confirm if the Electricity NIC Project could proceed in absence of funding being awarded for the LCN Fund or Gas NIC Project:

☐ **YES – the Project would proceed in the absence of funding for the interlinked Project**

☐ **NO – the Project would not proceed in the absence of funding for the interlinked Project**

1.6 List of Project Partners, External Funders and Project Supporters:

Project partners

- Alstom - Technology provider - Contribution £450k
- Belectric - Battery storage and PV power plant response - Contribution £349k
- Centrica - Wind and large-scale thermal response - Contribution £37k
- Flexitricity - Demand side response provider - Contribution £285k
- The Universities of Manchester and Strathclyde - Academic partners - Contribution £250k

Project supporters

SP Energy Networks, Western Power Distribution, Ecole Polytechnique Federale De Lausanne, Technische Universitat Dortmund, Idaho Power, Quanta Technology

1.7 Timescale

1.7.1 Project Start Date:	**1.7.2 Project End Date:**
January 2015	March 2018

1.8 Project Manager Contact Details

1.8.1 Contact Name & Job Title:	**1.8.3 Contact Address:**
Dr. Vandad Hamidi SMARTer System Performance Manager	B3 – Network Strategy – Transmission Network Services National Grid House – Warwick Technology Park – Gallows Hill Warwick – CV34 6DA
1.8.2 Email & Telephone Number: Vandad.Hamidi@Nationalgrid.com +44-(0)7962-827267	

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Section 2: Project Description

This section should be between 8 and 10 pages.

2.1 Aims and Objectives

2.1.1 The problem which needs to be resolved

The concepts and problems presented here are explained in more detail in Appendix 5, Detailed Project Description.

The GB electricity system

The Great Britain (GB) electricity system is undergoing huge change, with decarbonisation resulting in increasing volumes of renewable and small-scale generation. To achieve carbon reduction targets it is vital that these sustainable generation sources are encouraged and able to connect to the grid. National Grid has identified the challenges arising from this increase in renewable and small-scale generation [1, 2]. One of the key areas highlighted is the impact on the ability to control **system frequency.**

System frequency

System frequency is a measure of balance between electrical power generated and consumed. The system frequency in the UK is 50Hz. The bands of frequency variation are shown in Figure 2.1. This figure also illustrates the timeframes involved in response following an in-feed loss, such as a power station trip: primary response provider units must reach full response after 10 seconds and sustain this for 30 seconds; secondary response units reach full response after 30 seconds and sustain this for 30 minutes. Frequency drops after the in-feed loss but then recovers as response is brought on.

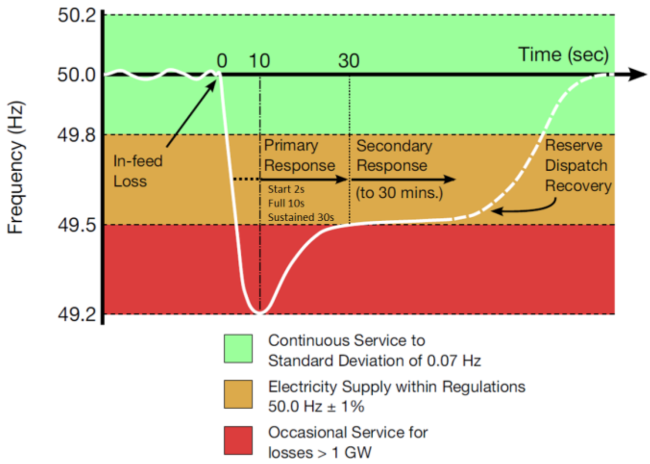

Figure 2.1 – System Frequency Limits

National Grid, as the system operator, has a licence obligation to control system frequency within acceptable limits around 50Hz. Significant deviations in frequency can affect the whole power system and, in the worst case, result in cascading events leading to partial or total system blackout. Figure 2.2 shows an event in 2008 during which the cascading loss of generation resulted in undesirable demand disconnection. The cost of managing this event was £12m. To achieve stable system frequency, National Grid ensures that sufficient generation and / or demand is held in automatic readiness to manage all credible circumstances that might result in frequency variations.

[1] Chapter 5 (System Operation) - Electricity Ten Year Statement 2013, National Grid November 2013.
[2] System Operability Framework (SOF) – National Grid – July 2014

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Project Description continued

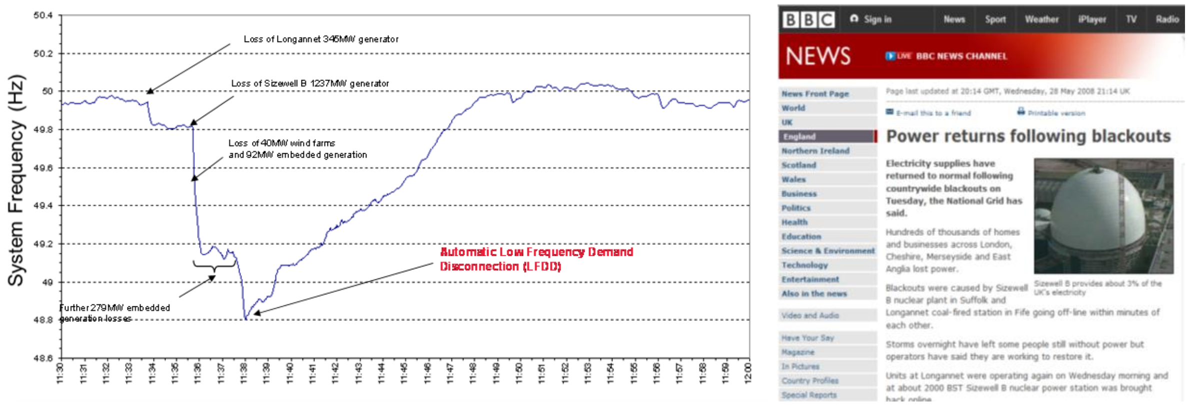

Figure 2.2 – Real Example of System Frequency Deviation and Undesirable Demand Disconnection in May 2008

System inertia

Traditionally, an important natural aid in achieving frequency stability has been system inertia. This is provided largely by thermal power plants, which use rotating synchronous generators. These turbo-generator sets contain stored kinetic energy and therefore provide system inertia, which acts to resist any change in system frequency. In the case of frequency deviations, system inertia **limits** the rate of change of frequency. This results in frequency deviations being more manageable. The more inertia the system has, the more time will be available to respond to fault events (e.g. power plant outages), enabling National Grid to deliver suitable mitigation services.

Renewable units, notably converter-connected wind turbines and solar PV, do not provide inertia. New wind turbines are connected by power electronics that effectively de-couple the rotating masses of the turbine and generator from the system and solar PV generation has no rotating elements at all. HVDC interconnections (i.e. interconnectors to mainland Europe) have the same characteristics. As a result of this, as the level of renewable generation and interconnection connected to the system increases there will be a corresponding **decrease** in the level of system inertia and therefore frequency behaviour following system events will be more **dynamic** than is presently the case.

Moreover, depending on the level of the penetration of converter-connected generation, the system inertia will become increasingly **variable** over time, as the generation mix will consist of a far wider variety of technologies with distinctly different levels of inertia.

Further, the reduction of inertia is **not uniform** across the grid. Areas with high renewable generation will show greater frequency deviations during disturbances (within the first few seconds) than areas where rotating plants are concentrated. The regional variations in frequency changes are important in system stability, and an accelerated frequency response service is proposed that will address both the overall inertia change and the geographic variations.

The impact of reduced/variable system inertia

We discuss the impact of reduced system inertia, and the corresponding increase in costs, in Section 3, Business Case. System inertia is forecast to decrease significantly under both National Grid's future energy scenarios. These changes will cause **significant challenges** for the transmission system operator (TSO).

Currently, on average, thermal plant starts to provide primary response two seconds after an event such as a power station trip. Within these two seconds, however, synchronous

Project Description continued

plant is providing a "natural" inertial response. <u>This natural inertial response avoids frequency dropping too quickly and enables the TSO to manage the situation.</u>

Under low system inertia conditions, however, RoCoF is higher and the natural inertial response is less. The frequency excursion will be faster and larger, quickly reaching dangerously low levels. A greater volume of response is required to arrest frequency decline.

This increased level of response brings a **significant increase in costs**. Response forecasts suggest that the cost of managing the system will increase to around £200m- £250m in 2020. These figures are explained and justified in Section 3, Business Case and Appendix 6; Cost Benefit Analysis.

In summary, ensuring system frequency stability under conditions of low system inertia requires a **large volume** of normal (**slow**) response. This is the **business-as-usual** approach, outlined below in Figure 2.3, and response will be provided largely by thermal generation units. This approach will become increasingly expensive and will have a significant and negative effect on the UK's carbon and environmental targets.

Figure 2.3 – Summary of business as usual approach

We propose here an **alternative approach**, outlined below in Figure 2.4. EFCC provides a **smaller volume** of **rapid** response which can act very quickly after a system event. This offers significant cost savings and environmental benefits.

Figure 2.4 – Summary of EFCC approach

We develop these arguments further in Section 3, Business Case, and Section 4, Evaluation Criteria.

There are a number of **further problems** related to high levels of RoCoF, which we explain further in Appendix 5.

<u>It is these challenges, and the recognition that the dynamic properties of the GB electricity system will experience fundamental changes, that make EFCC a timely and essential project.</u>

2.1.2 The methods being trialled

Current response planning methods are largely based on the historic electricity supply delivered largely by thermal power plants with high inertia. To reflect the reality of the modern GB electricity system, EFCC will trial a method of monitoring and instructing response from a range of resources: Demand Side Response (DSR); Large-scale, thermal generation; PV power plants (solar); Energy storage; and wind power.

A new Monitoring and Control System (MCS) will be developed and used, alongside existing and additional Phasor Measurement Units (PMUs), to monitor the electricity system and instruct response from these resources as required. This response will use local and wide-area frequency, phase angle and RoCoF to initiate the appropriate frequency response.

The methods being trialled will enable the development of new balancing services and additional response capability in the grid. These will mitigate the reduction of system inertia and allow effective management of system frequency.

2.1.3 The Development or Demonstration being undertaken

There are three streams of development and demonstration being undertaken. These streams will largely run simultaneously, with a high level of interaction as all partners work together.

Figure 2.5 – Outline of Streams

Stream 1

Development of a new Monitoring and Control System (MCS) capable of initiating frequency response in proportion to the rate of change of frequency at a regional level. Alstom will develop this technology, working closely with our other partners.

This stream is explained further in Appendix 5, Detailed Project Description and Appendix 10, Wide Area Frequency Control. Currently, most response is based on the absolute level of frequency. Corrective responses are initiated automatically as frequency crosses certain thresholds. However, the conventional approach has inherent delays to avoid spurious triggering and over-response.

The MCS will make use of local and wide-area frequency, angle and RoCoF to trigger a response as **early** as possible after an event, without spurious triggering. It will concentrate the response close to the **region** of the disturbance source, such that the extent of the system disturbance is minimised. The response will be **proportionate** to the disturbance, using frequency and RoCoF to define the extent of response required. This approach is designed to be self-limiting and not over-respond. The MCS will include facilities to co-ordinate both fast-acting short-term response and slower-acting services, and will interact with local control where appropriate. The MCS will be demonstrated with its control actions in the Strathclyde Power Networks Demonstration Centre (PNDC) and/or in a Hardware-in-the-Loop environment, and also to the extent feasible in the real power system.

The MCS demonstration will continue through the project, observing and logging control actions over an extended period. A performance review will be carried out, identifying improvements and further infrastructure requirements for prospective roll-out.

Stream 2

We will demonstrate the frequency response capability of the selected response providers (partners) and connect with the newly-developed MCS.

The developed MCS will be used to record measurements from the electricity system and instruct response from distribution- and transmission-connected providers listed in 2.1.2. The characteristics of different forms of response will be investigated and demonstrated. One type of response, for example, may provide a very fast but short response, whereas another may be slower but longer lasting. Testing and understanding the capabilities of different providers is a key aspect of the project. This will be ensured through extensive system studies focused on different scenarios and dynamic properties of different providers.

Streams 1 and 2 will be started in parallel, and partners will collaborate to ensure that the MCS and response provision are co-ordinated.

Stream 3

Demonstration of the coordination of the frequency response from different providers.

Having assessed the capabilities of different response providers individually during Stream 2, we will demonstrate how they can be coordinated to provide an optimal response to system events. This optimisation will build on the results of Stream 2. We will optimise the response in order to provide the most economic and efficient rapid frequency response under different system conditions. The reliability of the proposed control strategy must also be assessed, due to the key role this fast response must play in ensuring the stability of power systems in a low carbon future. This activity will lead to the development of a new service for rolling out EFCC as business as usual.

2.1.4 The Solution which will be enabled by solving the problem

EFCC will enable the provision of new **frequency response** from a range of technologies. The response capabilities of these technologies are not currently being fully harnessed, if at all. As the amount of renewables connected to the GB electricity system increases it is vital that renewables and other resources are able to contribute to system stability.

A key deliverable of the solution is the development of a commercially viable **balancing service**. This will define a commercial framework for response from different resources, allowing such technologies to access the response market. This will provide an important new revenue source for renewables and a vital new tool for National Grid as we continue to manage the GB system. Through **diversifying** the rapid frequency response market, EFCC will also enable a more **economic** and **efficient** way of delivering system requirements.

EFCC is a vital step in preparing for a future electricity system in which a large proportion of generation is provided by renewable sources.

2.2 Technical description of the project

This section provides a technical description of the project, broken down into work packages (WPs). For each WP the innovation being delivered is highlighted. A more detailed technical description is included as Appendix 5. The work packages are outlined in Figure 2.6 below.

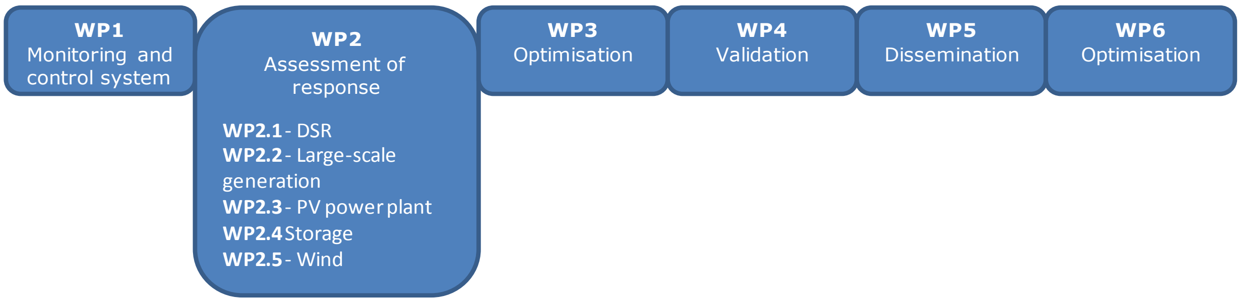

Figure 2.6 – Outline of work packages

WP1 – Monitoring and Control System

Central to this project is the development of an innovative Monitoring and Control System (MCS) that will monitor the transmission and distribution networks at a regional level and instruct response from a range of resources. We have engaged Alstom as a partner on this project and they will supply this technology.

This MCS will use available and additional phasor measurement units (PMUs) to monitor the network and a central control agent to instruct response from the frequency service providers. A control platform will be developed for the project, and deployed as a demonstration system. The system will interface with the service providers and communicate control signals to them.

Purpose

- Develop an MCS to measure regional frequency, angle and RoCoF, and instruct a proportionate response with regional prioritisation

Innovation

- A world-first grid scale frequency response service taking advantage of non-conventional resource capability
- Fast real-time triggering of frequency response service using wide area signals
- Instructing a response proportional to the triggering disturbance, without the inherent delays in conventional frequency response
- Co-ordination of diverse frequency response capabilities and providers, including short-term fast-acting and long-term slower response, thus facilitating a more flexible frequency response service market
- The control system will monitor and instruct at a regional level and operate across both the transmission and distribution networks

WP2 – Assessment of the response of different providers

The frequency control resources will be trialled in order to measure the response capabilities, such as the speed of response, time sustained, and predictability. Both local control and external input mechanisms will be investigated.

WP2.1 – DSR

DSR resources will be assessed with local and external control in order to test and demonstrate response.

Purpose

- Develop and demonstrate the operation of real industrial and commercial aggregated DSR resources to support system inertia in a variety of categories, potentially including:
    - RoCoF control – DSR assets providing rapid deloading to the network in response to signals corresponding to high rate of change of frequency
    - Simulated/synthetic inertia – assets providing autonomous increases and decreases in consumption using variable speed drives in a manner analogous to real inertia
    - Real inertia – synchronising additional small generation and load at times of low demand in order to add real rotating mass in aggregated form

Innovation

- DSR resources will provide new categories of fast response services
- The potential contribution of individual assets, and the scalability of that contribution through aggregation, will be quantified
- Challenges associated with simulated inertia, RoCoF and aggregated inertia will be identified and potential solutions investigated
- The best match between the different DSR resource types and the different ways in which they can provide EFCC will be identified
- Economic and technically feasible means of deploying DSR for EFCC purposes will be

clarified through testing and modelling

WP2.2 – Large-scale generation

Following upgrades, both South Humber Bank-2 and Langage power stations will have much wider operating envelopes than previously available. This will enable them to provide key services to National Grid.

Purpose

- To demonstrate that large-scale generation (CCGTs) can respond to RoCoF input/signal. This response could be proportional, possibly with a dead band and/or a wide-area un-blocking signal, to RoCoF. The possibility may exist for a block response triggered when a given RoCoF is exceeded or a central instruction issued. The RoCoF-triggered response should be available across a range of loading points.

Innovation

- This project will involve modifying the CCGT DCS to respond to machine speed, which is not currently the case. This is considered the optimal way of measuring rate of change of frequency for a synchronous generator.

WP2.3 –PV power plant

The capabilities of solar PV resources will be tested and demonstrated with local and external control.

Purpose

- Demonstrate an output power curtailment in accordance with frequency and/or by direct communication with the NETSO
- Demonstrate a positive frequency response by operating the power plant below MPP and reserving the difference to frequency response
- Demonstrate the provision of reactive power for the purpose of voltage stabilisation control, e.g. to enable fast power swing without voltage violation

Innovation

- Implementing a continuous relation between grid frequency and power
- Operating a PV power plant outside the usual MPP, thus realising a possible positive frequency response by providing positive reserve power
- Provision of reactive power to support accelerate power ramping

WP2.4 – Storage

The capabilities of storage resources will be tested and demonstrated with local and external control.

Purpose

- Demonstrate the principle operability of a frequency control battery on the network
- Demonstrate different reaction speeds
- Demonstrate emulation of rotating generators and their inertia by implementing a very high response rate (milliseconds or tens of milliseconds)
- A direct connection to an external entity (i.e. the NETSO) shall be established, so

definition of working points, response statistics or direct command and control may be done from a central point outside the unit

- Procedures to practically measure and financially account for energy input/output from a PV plant combined with storage need to be agreed and practically tested

Innovation

- First time a battery will be used as a standalone frequency response unit in GB
- Innovative command and control schemes will be implemented that enable the battery to act similar to rotating machines, providing grid inertia and short-circuit power capacity, and respond to external control signals
- The challenges of incorporating batteries in network regulation (SoC, etc.) and their advantages will be studied and evaluated
- The financial benefits of operating a battery in the plant will be studied and a future financial compensation policy for battery operation will be outlined.

WP2.5 – Wind

The capabilities of wind farms – Lynn or Inner Dowsing and Lincs - will be tested and demonstrated with local and external control.

Purpose

- To demonstrate that a large, multi-turbine, wind farm can respond to a rate of change of frequency input and/or an external control signal. The wind farms under consideration for this project are Lincs and Lynn or Inner Dowsing. Working with Siemens as OEM, modifications will be required.

Innovation

- Wind farms to offer frequency response based on RoCoF signal
- Lynn and Inner Dowsing are not obligated to offer any services to National Grid (as it is DNO connected). This will give access to innovative services from a new provider
- The response output from the wind farms (expected to be around 25% of turbine capacity) will be tested and demonstrated
- Demonstration of the length of time that a response can be sustained

WP3 – Optimisation

The response provided will be optimised. EFCC will trial the coordination of different response resources in order to provide the optimal response. Our academic partners will play an important role in this work package by proposing proven and robust supervisory control strategies for our case, and working with Alstom to further develop and tune the control implementation. System studies and simulations will be carried out in order to aid in the proper coordination of the disparate technologies. These studies will reflect the importance of providing a smooth response and protecting against the threat of improper coordination or failed instructions, creating by this a second, and possibly more threatening, disturbance. Studies will also investigate regionality in generation technology and RoCoF.

Purpose

- Understand the ways in which the selected resources can be coordinated in order to provide optimised response

- Understanding the requirements of the communication infrastructure necessary to support the proposed supervisory control strategy from its latency and bandwidth requirements perspective

Innovation

- Coordination of response from selected resources to enable effective response to rapid changes in frequency, optimised at both a local and national level
- A new operation scheme, i.e. Wide Area Control System, which is a typical Smart Grid application at the transmission system level

WP4 – Validation

All results will be validated to ensure accuracy. Our academic partners will take particular responsibility during this WP. Anticipated results and simulated performance will be validated using flexible hardware-in-the-loop (HiL) testing facilities (the largest UK RTDS at Manchester) and the Power Networks Demonstration Centre (PNDC) in Glasgow, and field trials at selected locations.

Purpose

- To convert the proposed new control schemes into a flexible hardware in the Loop environment, offering its full testing and assessment. The scheme will be simulated using RSCAD software for RTDS testing, and tested at the PNDC
- Ensure that anticipated and simulated results are accurate
- Assist with de-risking of solutions and provide detailed learning of the performance of individual controllers and wide-area monitoring and control schemes
- To enable any in-service issues to be identified and remedied prior to wider roll-out
- To be used as an aid in dissemination and demonstration to a wider audience

Innovation

- Validity and accuracy of the solution will be confirmed
- Use of extensive HiL and unique testing and demonstration facilities at PNDC
- Increase of the confidence in unproven and innovative Smart Grid technology, in this case a new Wide Area Control System

WP5 – Dissemination

Results and learning from the project will be disseminated to interested parties.

The academic partners will assist significantly in dissemination. A project website, events and traditional dissemination channels (newsletters, white papers, advertorials, conference and industry event presentations and journal publications) will all be used. In addition to these activities, the laboratory and demonstration facilities at both academic institutions will provide unique opportunities for intensive "hands-on" dissemination to all interested parties and stakeholders.

Purpose

- Ensure that learning from the project can be fully utilised

Innovation

- Dissemination of innovative knowledge
- Use of academic facilities to provide "hands-on" dissemination

WP6 – Commercial

A new balancing service product, and the value of the response, will be assessed and defined. National Grid will work with our partners to achieve this. Our academic partners have particular experience in the economic assessment of the value of services to a power system operator.

Purpose

- Create new balancing service allowing immediate roll out of the enhanced frequency control capability, and achieving the savings envisaged on frequency response cost

Innovation

- A new commercial balancing service will be developed and rolled out
- Renewables will have a new source of revenue, encouraging their growth
- New technologies such as

2.3 Description of design trials

Ensuring the results are statistically sound and sufficiently robust is a priority of EFCC. A number of processes will be followed in order to achieve this:

- A **wide range** of technologies will be included in the trials. This will allow the project to capture learning from different response providers.
- Trials will be carried out under different system **conditions**. The GB electricity network copes with a variety of conditions, including high and low demand. To capture sufficient data the trials will take place at different times and in different generation, demand and RoCoF conditions.
- The characteristics of the GB electricity network differ by **location**. Trials will be carried out in different regions in order to expand the usefulness of the results.
- Use of a pre-defined set of trials (e.g. frequency excursions to pre-determined magnitudes with a range of RoCoF values) will enable the performance of the control schemes to be fully investigated, demonstrated and disseminated prior to actual field implementation. Validation and testing will go beyond the anticipated rates of RoCoF in the future – therefore allowing schemes to be fully validated and effectively "future proofed". In addition to the response instructed when frequency deviations are experienced, the operation of the schemes under other network transients (voltage perturbations, unbalance, short circuits, harmonic distortion) can also be tested in an accelerated fashion using hardware-in-the-loop (HiL), Real Time Digital Simulator, (RTDS) and Power Networks Demonstration Centre (PNDC).

All tests and scenarios will be fully defined in the competed Work Package descriptions in the project plan.

2.4 Changes since Initial Screening Process (ISP)

The scope of EFCC is largely consistent with the submission for the Initial Screening Process (ISP). However, the following changes have occurred:

- Given the level of preliminary work carried out so far, we intend to start the project in January 2015
- We have removed HVDC links from the list of resource technologies being trialled
- The total cost of the project has been revised downwards from £10.3m to £9.6m and the NIC funding requested has been reduced from £9m to £7.2m

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Section 3: Project Business Case

This section should be between 3 and 6 pages.

3.1 Context

EFCC is focused on meeting the challenges posed by the UK's carbon reduction targets. As the generation mix changes to include significantly more renewables, the amount of system inertia will be reduced. This will result in an increase in the volume of frequency response required. Without innovative solutions the operating cost is anticipated to increase by £200m-£250m per annum by 2020.

EFCC will enable response to be provided by a range of technologies (DSR, large-scale generation, PV power plants, storage and wind).

A monitoring and control system (MCS) will monitor the system and instruct fast, proportionate response, based on factors including RoCoF, from these technologies. This fast response will reduce the need for slower, traditional response. This will reduce the overall response requirement for the grid and result in the development of new commercial balancing services.

Through reducing the overall level of frequency response required to manage system frequency, the successful development and implementation of this project may result in a **saving to the end consumer of £150m-£200m per annum**.

The cost figures quoted in this section are explained in Appendix 6, Cost Benefit Analysis.

3.2 Overview of the case for EFCC

As increasing amounts of renewables lead to reductions in system inertia, National Grid faces clear challenges in managing the GB electricity network safely and efficiently.

Our **business case** for EFCC is based on:

- The continued increase in non-synchronous generation connected to the GB electricity network and the corresponding reduction in system **inertia**
- The subsequent requirement for increasing levels of **response** to manage frequency (and the increasing risk that higher RoCoF leads to more frequent loss of load through under-frequency load shedding)
- The significant **cost** increases resulting from this increased response requirement and the increasing carbon output

EFCC is **suitable** for NIC funding for a number of reasons:

- Previous NIA/IFI **projects**, detailed further in Appendix 9, Previous Projects, as well as substantial in-house work, have established the feasibility of the project
- The trial requires new **infrastructure** to be built for the purpose of the demonstrations. Additional PMUs will be required and modifications required to the response technology
- The trial involves **risks** relating to network monitoring and the instruction of response which could not be included in National Grid's normal operational activities. Our primary aim is to deliver electricity safely and reliably; therefore, we cannot introduce into our operations any techniques or processes which risk our ability to do

this

- There is currently no **commercial** incentive to encourage grid users to provide very fast frequency response services; therefore there is no business-as-usual route to justify investment. Also, there is no international reference case for fast acting frequency response services

3.3 Previous work

National Grid has carried out **significant research** into the impact of low inertia on system frequency. This research has sought to better understand the level of inertia, how it impacts the system and certain features, such as regionality.

One particular area of research has been the **regionality** of RoCoF. Following a system event, RoCoF varies significantly by location. One of the key aims of EFCC is to develop a system that can respond proportionately to regional RoCoF.

In one study RoCoF measurements at six different PMUs across the network were taken following system events. Clear differences were seen.

For example, an incident on 08/08/2011 occurred at 00:28 hours. A bipole at the IFA interconnector, connected at Sellindge substation, which has a capacity of 1,000MW (operating in import mode), tripped. At the time of the trip the total system demand was 21,900MW. The generation pattern was dominated by synchronous generation of 20,910MW. Transmission connected wind was 990MW. The trip occurred with system frequency at 49.98Hz.

Figure 3.1 below shows frequency levels at different points on the network following the trip.

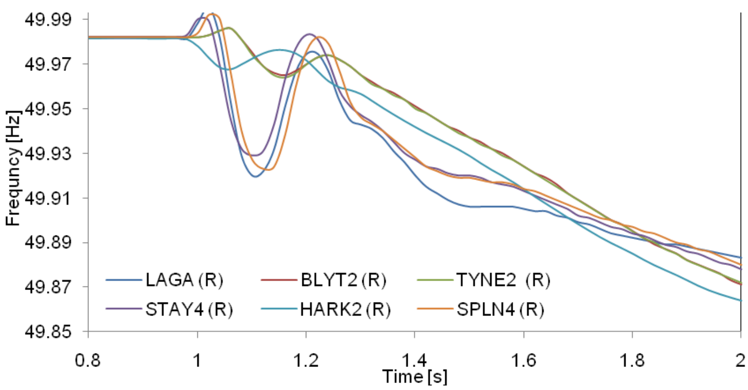

Figure 3.1 - Investigation into variations of RoCoF at different parts of the network during a frequency incident

The different levels of frequency recorded by the different PMUs can be seen. It is clear that the regionality of RoCoF is an important problem for EFCC to consider. Appendix 9 includes further details of this work.

Related NIA projects have also established the need for EFCC and provided knowledge to build on:

- Assessment of Distributed Generation Behaviour during Frequency Disturbances

NIA_NGET0142 - 04/2014 - 02/2015

The work is providing a comprehensive view of distributed generation types and susceptibility to RoCoF for the entire GB synchronous network. The feasibility and implications of using revised protection settings to avoid coincident distributed generation losses during loss of in-feed events will be established.

- Co-ordinated Intelligent System Protection Against Frequency Collapse in Future Low Inertia Networks

  NIA_NGET0037 - 10/2011-10/2014

  This work has researched and created a new adaptive protection concept that is capable of guarding against frequency collapse in future energy networks incorporating significant amount of inverter-interfaced energy sources and loads.

- Frequency Sensitive Electric Vehicle and Heat Pump Power Consumption

  NIA_NGET0138 - 04/2014-10/2015

  An investigation of the potential to use system frequency to control the power consumption of electric vehicles and heat pumps, and an exploration of the value of making these technologies frequency sensitive, through testing the associated commercial, technical and logistical challenges.

Further details on this work and additional examples are included in Appendix 9.

National Grid has also performed **stakeholder engagement** to seek industry's view on how to resolve these challenges. National Grid has engaged Distribution Network Operators (DNOs) via the Energy Networks Association (ENA), supplier and service providers via commercial services, and universities and research institutes via direct contact over the course of the last few months proposing this project. This engagement provided assurance that a sufficient market exists to ensure that the solutions proposed by the project can be delivered in the most economic and efficient way, delivering value for the consumers. This process will continue as part of future procurement for this project.

This project will significantly help with facilitating more economic and efficient frequency control of the GB power system. In addition there are substantial opportunities as part of developing this approach for suppliers, demand side aggregators, embedded generators, and renewable generators. These benefits will ultimately increase the competition, lowering the cost of delivering the product, by creating more opportunities in the electricity market.

3.3 Business as usual baseline

We have carried out a thorough cost benefit analysis, a summary of which is included as Appendix 6. Low system inertia is an increasing problem for National Grid. Increasing amounts of renewables are connecting to the network and this is forecast to continue.

Table 3.1, below, presents the reduction in system inertia against National Grid's Slow Progression and Gone Green scenarios and the increasing RoCoF and response rate required.

RoCoF (Hz/s)	Slow Progression	Gone Green	Inertia GW/s	Action Time (to reach 49.2Hz)	Response Rate (MW/s)
0.125*	2013/14	2013/14	360	9	185
0.2	2019/20	2018/19	225	4	400
0.22	2022/23	2019/20	205	3.4	489
0.25	2023/24	2020/21	180	2.4	679
0.3	2024/25	2021/22	150	1.2	1148

Table 3.1 - Future Ramp Rate Requirements with decreasing System Inertia

Ensuring system frequency stability under conditions of low system inertia requires either:

- A **large volume of non-rapid response** which, together, can provide the response required. This is the business-as-usual approach and response will be provided by thermal generation units. This will have a significant and negative effect on the UK's carbon and environmental targets.
- A **smaller volume of rapid response** which can act very quickly after a system event. This is the EFCC approach and response will be provided by a range of resources. This will have a significant positive effect on the UK's carbon and environmental targets.

<u>EFCC will allow National Grid to replace a large volume of standard response with a smaller volume of rapid response.</u>

3.4 Financial benefits of EFCC

EFCC will provide significant financial savings. The base case scenario will see the cost of response rise by £200m-£250m per annum by 2020. EFCC will mitigate much of this increase by allowing National Grid to utilise rapid response from a range of technologies. This rapid response will significantly reduce the overall level of response required.

National Grid has identified and published the future reduction in the level of system inertia in the Electricity Ten Year Statement. [3]

At present, system frequency is economically and optimally managed by providing the required level of response for the largest loss. When system inertia is high, a lower level of response is required. Figure 3.2 shows how the reduction in inertia will feed through into a greater amount of response being required. In this figure it is shown that such high ramp rates will be required for a significant proportion of time (i.e. more than 800hrs in just 2020).

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[3] ETYS: http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-ten-year-statement/Current-statement

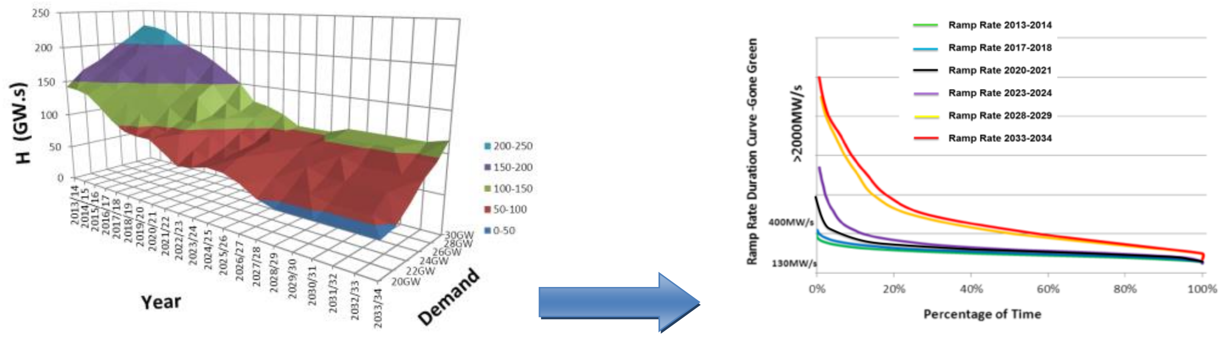

Figure 3.2 - Reduction of System Inertia and Percentage of Time Higher Ramp Rates are required

To mitigate this challenge, three conventional options may be considered by the system operator. Here we consider these and compare the annual financial cost with that of EFCC in 2020 (assuming an implementation by 2018):

(a) Constrain the largest generation/demand (including interconnectors) to a level where conventional solutions can manage the existing system capability

Cost: **£131m** per annum by 2020 (and increasing to **£268m** in the following year when the number of large infeeds increases)

Compared to EFCC: **£121m** extra per annum by 2020 (and **£258m** by 2021)

Pursuing this option in the long term will be extremely expensive. The extra cost associated with this (the constraint cost) will be £268m per annum by 2020. Given the ongoing reduction of system inertia, and corresponding increase in response requirement, this cost will increase further year by year.

(b) Constraining generators (i.e. synchronise more generators to increase the level of inertia)

Cost: **£600m** per annum by 2020

Compared to EFCC: **£590m** extra per annum by 2020

By increasing the level of system inertia, the rate of change of frequency will be slower. The costs associated with this option are calculated based on the extra payments to synchronous generator to stay synchronised for the number of hours the service is required.

(c) Increase the volume of response by carrying response on more power stations

Cost: **£210m** per annum by 2020

Compared to EFCC: **£200** extra per annum by 2020

Increasing the volume of response from conventional frequency response providers (i.e. power stations) with inherent >2s delays increases the cost significantly. The cost increase is due to holding more response (and the extra cost associated with utilisation which will be relatively less). The response requirement as shown in Figure 3.2 will be much higher for a significant period of time by 2020. Assuming a linear increase in the cost of holding more response (in reality it may increase exponentially resulting in much higher cost), the cost of frequency response will increase by an estimated £210m per annum by 2020.

Through developing the new capabilities proposed within EFCC, we aim to provide the additional measures required to avoid holding larger volumes of response or having to constrain generation or demand. This demonstration will also increase the **diversity** of response providers, add more **competition** and bring the incremental **cost** of controlling the frequency down.

By eliminating the need for carrying extra response, balancing costs will reduce, resulting in **savings in the region of £150m-£200m per annum for consumers**.

3.5 Links to National Grid's business

EFCC deals with challenges National Grid is facing right now and which will worsen in the future. As a result, it **links directly with our business plan for the next five-to-ten years**.

Operating the GB electricity transmission network safely and efficiently is National Grid's primary aim. Dealing with the challenges posed by low system inertia is a priority and was covered extensively in our November 2013 Electricity Ten Year Statement.

We have already adopted new operational strategies, taking into account the potential impacts of embedded generator trips as a result of high RoCoF. We are also working collaboratively with the industry in a joint Grid Code and Distribution Code working group to find solutions to help reduce this risk in the longer term. Ideas under consideration include changing the setting of RoCoF relays to a higher level (i.e. to 1Hz/s) in order to avoid the risk of cascading trip of embedded generators.

National Grid are involved in ongoing consultations with Ofgem and industry stakeholders regarding the problem of reduced inertia (RoCoF based loss of main, and Frequency Change after Large Disturbance).

These ideas, however, are not enough to fully mitigate the effects of low system inertia. For that, innovation and investment are required.

<u>EFCC offers a solution to a problem that is central to National Grid's current thinking and forward planning.</u>

3.6 Business plan summary

We believe there is a clear business case for EFCC. The project **tackles the problem** of managing the electricity system under increasingly low system inertia conditions. This is a real problem facing the GB electricity system and dealing with it is a priority for National Grid. The problems it deals with are largely the result of the increasing amount of renewables on the GB network, and EFCC will enable the move to renewables to continue. There are clear **environmental benefits** to EFCC. The **financial benefits** are significant and demonstrable and require action to be taken soon. Any delay in dealing with these problems will see the related costs escalate. These benefits are explained further in Section 4, Evaluation Criteria. EFCC is linked closely to National Grid's current business planning. The project, however involves an innovative, unproven solution and the risks involved mean that the cost of the project fall outside business-as-usual activities.

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Section 4: Evaluation Criteria

This section should be between 8 and 10 pages.

(A) Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/or existing Customers

For a low carbon energy sector to develop it is vital that renewable energy sources are able to connect to the grid.

National Grid is committed to increasing environmental sustainability, supporting the UK's transition to a low-carbon economy and reducing our own carbon footprint.

Through numerous initiatives **we have worked to make it easier for new, renewable energy sources to connect to the grid**. We have reduced up-front costs, helping small, independent developers with renewable generation projects. Our Connect and Manage programme has cut the average time for connection to the GB transmission network by up to 10 years, benefitting large-scale wind farms. And we continue to find innovative ways to connect generation as early as possible, by, for example, allowing 1.5GW of wind generation to connect in Scotland ahead of specific local network reinforcement works being completed.

As we have explained in this document, however, this increase in the penetration of renewables creates **significant challenges**.

<u>EFCC plays a vital role in allowing us to continue to securely and efficiently run the GB system as we connect increasing volumes of renewable energy.</u>

EFCC provides a number of environmental benefits:

- Low inertia and the related problems threaten to act as a **barrier** to the high penetration of low-inertia renewables. EFCC removes this barrier by creating a new technical approach and market for diversified frequency response services.
- Reducing inertia and frequency response services using conventional approaches may result in a **ceiling** on the proportion of renewable energy operated which can severely impact the low carbon targets.
- Alternatives of must-run constraints for maintaining inertia, and/or large-scale expansion of reserve requirements are very expensive and have negative environmental effect. Relying on current techniques will effectively **subsidise** the operation of old fossil fuel units by creating a high value market for a service only they can provide. Without ways of mitigating the effect of low system inertia, some synchronous (thermal) generation may have to be preferred over some non-synchronous (including solar PV and wind) generation when National Grid is balancing the GB system.
- By contrast EFCC makes use of latent capability of existing plant, and is inherently a **cost-effective** solution, avoiding inertia constraints and high frequency reserve costs.
- EFCC proposes **incentives and mechanisms** for all stakeholders (supply and demand) to deliver cost-effective frequency response services, and receive appropriate financial reward. Rather than subsidising fossil fuels this will provide a new market and potential source of revenue for renewables.
- By providing the capability in the grid for a range of resources to help with grid frequency control, new entrants are encouraged to compete with existing participants.

This makes the frequency response market more **competitive** and reduces the cost and carbon impact of frequency control methods.

- The reduction in carbon production at operational timescale is further achieved by the ability of thermal plants to run at **more efficient** operating modes. Without EFCC, increasing volumes of thermal generation will be ran at inefficient half-load levels in order to provide response where required by increasing generation.

Successful implementation of EFCC removes the technical challenges facing the grid in managing the increasing penetration of non-synchronous generation. Existing measures cannot provide a means of managing the high penetration of wind and solar with regard to frequency control. EFCC achieves this and uses renewables as a key part of the solution.

Reduction in Carbon

EFCC directly facilitates the **Carbon Plan**'s key aim of moving to low-carbon electricity generation: "The Government is committed to dramatically increasing the amount of renewable electricity generation in the UK. Meeting the 2020 renewables target is likely to require renewables to provide over 30% of electricity generation in 2020. Making use of some of the best wind and marine resources in Europe will help to lower emissions and the demand for fossil fuels." [4]

For these targets to be met it is vital that renewables can connect to the GB network. Without EFCC the costs of response will rise significantly as more renewables come online. The stability of the network will be challenged unless measures are taken, potentially limiting the amount of renewables that can be connected. Further details regarding the carbon savings can be found in Appendix 1 (Benefits Table).

Financial Benefits

Section 3, Business Case, and Appendix 6, Cost Benefit Analysis, explain the financial benefits of EFCC. Based on implementation of EFCC by 2018, the annual savings as of 2020 provided by EFCC compared to three possible business-as-usual approaches are:

(a) Constrain the largest generation/demand

Saving from EFCC: **£121m -258m** per annum by 2020/21

(b) Constraining generators (to increase the inertia)

Saving from EFCC: **£590m** per annum by 2020

(c) Increase the volume of response

Saving from EFCC: **£200m** per annum by 2020

These savings will be passed directly on to consumers.

[4] The Carbon Plan, p.79
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf

Evaluation Criteria continued

(B) Provides value for money to electricity transmission Customers

EFCC will **directly impact** on the network and on National Grid's operations. Low system inertia is a key challenge we face and it will become an increasingly important problem as the amount of renewables connected increases.

Dealing with the challenges posed by low system inertia is a priority and was covered extensively in our November 2013 Electricity Ten Year Statement. We have already adopted new operational strategies taking it into account and are working collaboratively with the industry to find solutions to help reduce this risk in the longer term.

EFCC aims to offer a commercially viable balancing service which, when taken up by response providers, will have a direct impact on our operations. It will provide a new way for us to manage system frequency and significantly reduce the costs we incur in this area (as outlined in Section 3, Business Case).

We recognise that we are requesting is a significant amount of money. We believe, however, that this represents real value for money and the cost of the EFCC project is **entirely appropriate** when balanced against the solution offered.

Delivering the project at a **competitive cost** is a priority and a number of processes are being employed to ensure this. We have engaged National Grid's procurement and finance departments to ensure that best practice is followed and we have engaged as partners all the key stakeholders in the project. This ensures we fully understand the costs involved in implementing EFCC. Our stakeholders have all made significant contributions to the project and they are committed to ensuring its success.

This project is targeted at improving the electricity network. As such, the main bulk of the **potential benefits** of the project will accrue to the electricity transmission network and then through to National Grid's customers.

We believe the **learning** experienced during this project will greatly outweigh the cost. The cost savings have already been described, and these represent a significant return on the project investment. The first beneficiary of these cost reductions will be the licensees who provide grid stability and maintain reserve power. Ultimately, however, the main beneficiary will be customers.

Identification and Selection of Project Partners

We recognise the importance of **engaging partners** for a complex project such as EFCC. Partnerships build cooperation, align aims and encourage successful delivery.

National Grid sought project proposals for EFCC with a view to submitting a developed NIC proposal. The process began in September 2013, when the priorities for innovation on design and operation of the transmission system were identified and subsequently published as part of Electricity Ten Year Statement (ETYS) in November 2013. We began a process of engagement to gather ideas from our stakeholders and better understand the solutions they can offer, and then sought agreement across the business on 2014 NIC projects. We formally invited expressions of interest, requesting from those interested the solutions they could offer and their level of engagement with EFCC. The publicly available EFCC briefing note outlined broad issues that National Grid wished to address and the timelines involved.

Expressions of interest, along with qualifying information (proposals for solution description, relevant experience, project budget proposals, indication of external funding/contribution, compliance with NIC terms and conditions, etc.), were requested from all interested candidates within a specified time frame. We received over 20 proposals. We then spoke to all the interested parties in order to better understand their offers and to clarify their understanding of EFCC.

National Grid's innovation team, procurement team, and the SMARTer System Performance Manager oversaw the process, which is outlined in Figure 4.1 below.

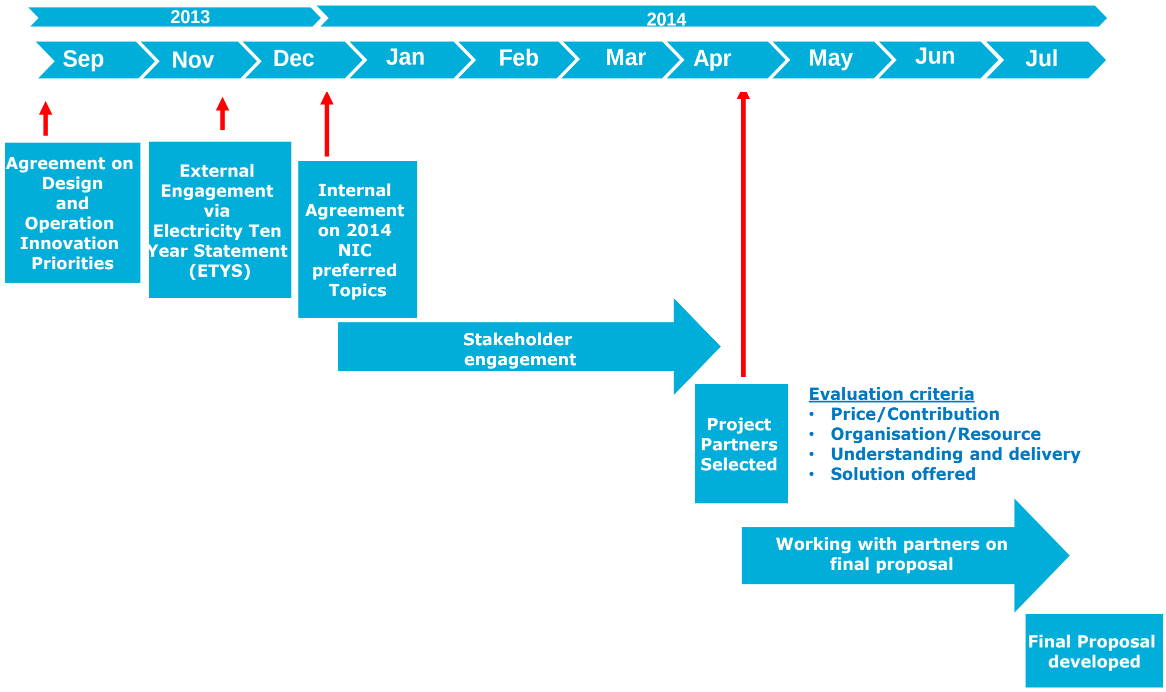

Figure 4.1 Partner selection and development of EFCC timeline

Rationale for Partner selection

Selecting the correct project partners is crucial to the successful delivery of a complex, innovative project such as EFCC. By applying the criteria outlined below we were able to rank the potential partners. We were then extremely pleased to form partnerships with all of our preferred partners. The partners selected bring extensive experience to EFCC, which creates more value for consumers and reduces risk.

The proposals were scored against set criteria:

- Price/Contribution

  Ensuring value for money is a key aim and so we considered the price of the different offers, along with the level of contribution offered.

- Organisation/resources

We rated the reputation and track record of the organisations interested, along with the expertise of their people. EFCC is a complex project requiring specialist skills and knowledge and we ensured we partnered with the best organisations.

- Understanding and delivery

  We specifically rated interested parties in terms of their understanding of the project requirements and their ability to deliver on their ideas. We considered criteria including the level of detail and realism of the plan, governance processes and willingness to partner.

- Solution offered

  When assessing the proposed solutions we focused on Ofgem's criteria (innovative, low carbon, value for money, customer benefits and knowledge sharing) and ensured that all project partners shared these aims.

We explain why our partners were selected and are appropriate for EFCC under (E).

(C) Generates knowledge that can be shared amongst all relevant Network Licensees

EFCC generates important knowledge that can be shared amongst, and will be of benefit to, all relevant Network Licensees. The problem of low system inertia is increasing and the results of the trials, and the solutions offered, will be of great interest to all Network Licensees.

Some of the key learning aspects of the project include:

- **Develop** an innovative Monitoring and Control System that is able to detect and distinguish system disturbances and frequency events to trigger reliable response
- Understand the fastest reliable approach to **detecting** a disturbance that merits a response and the extent to which wide-area signals improve differentiation
- Increase **understanding** of the response capabilities of a range of technologies
- Demonstrate that faster frequency response is possible, while identifying fundamental **limitations** and improvement **opportunities**. Modelling will allow full understanding of the resource capabilities
- Demonstrate how different technologies can best be **coordinated** to provide an optimised response
- Provide **guidance** and learning around frequency response services
- Identify the best **infrastructure** for frequency control, centralised or decentralised
- Demonstrate how to add effective **redundancy** to control schemes
- Determine the relative benefits of wide-area, local or hybrid control approaches
- EFCC will provide **capability** within the demand side to widen their participation in

grid frequency control. As electricity flows at the transmission and distribution level become more diverse and volatile, licensees will need to play a more active role in managing the network by encouraging consumers to participate in technologies such as DSR, Solar PV, and other micro-generation projects, which contribute to a reduction in carbon emissions.

- The **integration** of the learning of this project into the economic decision making of operating the system and optimising the balancing services required to run the system in the most economic and efficient way.
- Specific **education** on the capability of batteries and PV power plants in deliverance of grid services on different levels. This will incorporate frequency control, voltage control, reactive power control, frequency-build-up (black-start capability) and delivery of short circuit power up to the provision of grid inertia. This will provide valuable knowledge for future planning and operation of Transmission Systems.
- Emerging and maturing technologies will **maximize** the use of the transmission system, **strengthen** the safe and reliable operation of the grid, **improve** overall market efficiency, **increase** the provision of frequency response, and **advance** environmental policy objectives.

(D) Is innovative (i.e. not business as usual) and has an unproven business case where the innovation risk warrants a limited Development or Demonstration Project to demonstrate its effectiveness

The measures currently available to deal with frequency control are designed to provide a cost effective way of optimising frequency response in a system with high inertia. EFCC is an innovative project which deals with the increasing problem of low system inertia.

There is no provision for trialling new services as part of Business-as-usual, particularly those which require new infrastructure to be built for the purpose of demonstration.

There are various risks associated with trialling new services, such as:

Technical risks

- Communication – The monitoring and control system will communicate with the various response providers. Where rapid response is being provided, the speed, reliability and accuracy of this communication will be vital.
- Measurement quality – Fast-scan measurement of frequency and RoCoF must be accurate and timely.
- Control systems – A new monitoring and control system will be developed and deployed. This presents clear risks in terms of specifications, reliability of the technology and integration of the system into the network.
- Response from providers – It is not clear to what extent, and how reliably, the different types of technology will be able to provide response. Trials are required to establish the capabilities.

Operational risks

- System stability – National Grid's primary aim is to manage the GB electricity network safely and reliably. EFCC will introduce new operational practices. This cannot be done until we are satisfied that there is no risk to system stability.

- Risks of ability to successfully measure the disturbances on the grid, and determine which events require frequency response.
- Risk of sending command signal and signal latency.
- Risk of service providers having to respond to such signals rapidly and the impact on the devices.

Commercial risks

- Balancing service – EFCC will deliver a new commercial service. This must be trialled and analysed before it can be introduced. There are risks around definition and requirements.
- Risk of service providers having to operate at sub-optimal level to provide response.

Regulatory risks

- Existing business standards such as The National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS), Grid Code, and Distribution Codes may not be aligned with future network development project such as EFCC. Whilst there are well defined processes around required modifications to these codes and standards, the knowledge and evidence for such changes can only be obtained via demonstration projects such as EFCC.

These risks, until mitigated as part of this project, prevent us from defining new services and being able to procure them in the most economic efficient way, which will be of benefit to consumers and the industry.

The EFCC project requires funding from the Electricity NIC as it does not form part of business as usual activities for transmission system operators or players in renewables. The risks are significant and deployment is yet to be introduced. Renewable generators are not able to provide the above defined grid services on a business-as-usual basis, since there is no sufficient financial model for grid service compensation. This business model will be developed during this project. Once in place, investment decisions will be taken by various players and services will be offered. Before that, the level of risk involved makes investment difficult.

(E) Involvement of other partners and external funding

We have taken a **number of steps to make potentially interested parties aware of EFCC**.

Following identification of NIC 2014 project candidates, National Grid engaged with a range of external stakeholders to develop the ideas. This was achieved through a request for project proposals. Briefing notes outlining the project candidates were made available on the NationalGrid.com website within the Innovation section. Direct contact with relevant customers, suppliers and partners was made to raise the awareness of these briefing notes. In addition, National Grid used a number of forums such as ENA and Commercial Operation, and directly contacted potential university partners to share the 2014 NIC project candidates.

The responses received provided a deeper understanding of the capability available to successfully take forward the NIC 2014 project candidates.

By starting to define the services required with our partners it will provide more time for suppliers that are not involved in the project to adapt their technologies beforehand and join the market immediately after it is created.

All of our partners are making a significant contribution to EFCC.

- **Alstom** has committed to contribute **£450k** to the project through reduced labour rates and equipment.
- **Belectric** has committed to contribute **£349k** to the project through reduced labour rates and the use of patents.
- **Centrica** has committed to contribute **£37k** to the project through reduced labour rates.
- **Flexitricity** has committed to contribute **£285k** to the project through the use of patents.
- **The Universities of Manchester and Strathclyde** have committed to contribute a combined **£250k** to the project through the use of their specialist facilities.

We selected these partners based on the criteria described in (B) and believe they are the right partners for EFCC.

ALSTOM

Alstom – Technology provider

Alstom is a global leader in the world of power generation and transmission and sets the benchmark for innovative and environmentally conscious technologies. In the UK, Alstom is active in the rail, power and electricity transmission sectors, operates from 30 sites and employs more than 6,500 people across the country. Alstom's generating kit powers half of the UK's power stations and the company has been at the forefront of engineering developments since the 19th-century and continues to produce cutting edge technology for projects across the world.

Alstom will develop the monitoring and control system (MCS). Alstom has a strategic interest in the field of wide area measurement and control, and recognises the value of the EFCC project.

BELECTRIC™

Belectric – Solar PV and storage

Belectric provides utility-grade PV power plants that enable safe, reliable, and efficient power generation from the sun. The company has more than 10 years of experience and within this time has installed over 1GW of solar power across the world. Belectric is the technology leader due to a focus on research and innovation. Belectric employs 1,500 employees in 21 countries with 500+ construction workers worldwide and has a portfolio of

100 patents since 2001.

Belectric will provide response from their PV power plants and storage facilities. Belectric will provide knowledge and practical solutions to realise the project objectives concerning battery- and PV-based frequency regulation, virtual inertia, collaboration of different response providers and others.

centrica

Centrica – Large-scale generation and wind

Centrica is one of the UK's largest utilities and is active in every stage in the energy chain, from sourcing energy to saving it.

Centrica has an excellent track record in understanding the needs of the system operator and offering services to meet these needs. By doing so, Centrica has been pioneering in offering its power plants to meet National Grid's needs – most noticeably the conversion of four older CCGTs to OCGT operation and offering them into the STOR market in response to signal from National Grid that additional STOR volumes are required. They have also offered extremely flexible CCGT plants into the BM with short minimum run times.

Centrica will play a dual role in EFCC, providing response from both large-scale generation (Langage and South Humber Bank CCGTs) and wind farms (Lincs and Lynn or Inner Dowsing). The company is very experienced in both of these areas.

flexitricity
Unlocking smart grid revenue

Flexitricity – DSR

Flexitricity runs the largest live, open-market smart-grid operation in the UK, supplying reserve services to National Grid. It has been established for ten years and has built a leading position in the field of DSR. Flexitricity has particularly useful experience in delivering similar innovation projects. The company has a wide range of customers we can work with and understands the process of including these customers in providing services.

Flexitricity is a world leader in bringing industrial and commercial electricity users into balancing services. Flexitricity's innovative Frontline and Footroom services provide the groundwork – and, potentially, the example sites – through which the ability of DSR to provide EFCC can be demonstrated.

Flexitricity will recruit example customers from industrial and commercial sectors for the DSR trial, largely from its current extensive customer base. Flexitricity will also deploy its proprietary control and communication solutions, providing local interface points for the MCS on customers' sites, and will monitor and operate the DSR trial from its 24-hour DSR control centre.

MANCHESTER 1824
The University of Manchester

University of Strathclyde Glasgow

The Universities of Manchester and Strathclyde – Academic support

Together, the universities provide world-leading academic knowledge and facilities. The Manchester RTDS is the largest HiL simulator in the UK and the second largest in Europe. It can perform electric power system simulations continuously in real time. Strathclyde's PNDC allows any equipment connected to the PNDC's network to be tested under a wide range of transient situations. In EFCC, the PNDC will be used to fully test and demonstrate the innovative technology that has been developed by EFCC project partners.

The universities will provide academic support as well as testing facilities, system studies and expert knowledge. A focus will be validation and knowledge dissemination.

(F) Relevance and timing

EFCC is both relevant to current operational and environmental challenges and a timely solution to these. The key **environmental** challenge EFCC solves is how to continue to manage the GB electricity system safely, reliably and cost-effectively as renewables are connected and the level of inertia decreases. This is a necessity if renewables are to continue growing and the UK is to meet its carbon reduction targets.

As previously explained, the proposed solution is strategically necessary and highly innovative. It comes at a time when the share of renewable generation is rising sharply. In addition to increased levels of renewables, more and more energy is transmitted from continental Europe via HVDC lines. They also feed into the grid via inverters and therefore do not provide inertia. The share of synchronous generations is dropping dramatically. In order to prevent this from inhibiting further expansion of renewable generation, a clear and robust concept for dealing with these upcoming problems needs to be developed quickly. For these reasons, EFCC is highly relevant.

Frequency reserve cost is already **rising** because of the increasing penetration of renewables. This rise in costs cannot be reversed overnight and EFCC, therefore, needs to be implemented as soon as possible. It will take time to develop a new incentive mechanism and encourage stakeholder take-up. Further, response providers will need to develop capabilities to participate in the market. For the mechanism to be in place as Business-as-usual, with stakeholders using it by 2018/19, it is critical to start now. By 2018/19 under National Grid's Gone Green scenario, inertia is reduced by 37% and the time to reach 49.2Hz is less than half today's level.

There is, therefore, **urgency** to starting the project now, so that there is a functioning diverse frequency response service market before costs significantly escalate.

EFCC will have a **direct impact** on our future business planning. Balancing the system and ensuring system stability are key drivers of our day-to-day operations. As renewables and other response resources are able to provide response, and the problem of low system inertia is lessened, we will adapt our planning approach. This will reflect the lowered requirement for response. These changes will be reflected in our business plan submissions in future price controls.

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Section 5: Knowledge dissemination

This section should be between 3 and 5 pages.

☐ Please cross the box if the Network Licensee does not intend to conform to the default IPR requirements.

Knowledge dissemination is a priority of EFCC. The significant learning EFCC offers is described in Section 4 (c). In order to ensure that this knowledge is shared a number of processes will be put in place.

The project will form a working group with industry representation (manufacturers, academics, suppliers, aggregators, generators, and network licensees) to monitor the progress at different stages and ensure the deliverables are challenged and reviewed. This will also ensure continuous knowledge sharing with the industry to accelerate service and technology developments in this area. As part of this, we will set up a knowledge sharing hub (in the public domain) to also allow the use of data and learning of this project by academic institutes, as well as showing leadership in this important area internationally.

5.1 Learning dissemination

Knowledge sharing is a key enabler for rolling out improved frequency control services. Providing response to control system frequency requires a range of service providers, and the more providers there are, the better. It is, therefore, important that the learning of this project is shared regularly throughout the project life-cycle. This will allow all interested parties to prepare for the roll-out of future commercial arrangements, and ensure timely and efficient development of grid services.

5.1.1 During control development and demonstration activities

National Grid is conducting this trial to develop the capability for better control of system frequency, not only by improving the control systems, but also by diversifying the service providers. Therefore, the learning from this project will be captured and shared at different stages accordingly in the following areas:

- **New control systems:** The development of control systems capable of initiating the optimum response. This dissemination of knowledge with manufacturers, service providers (generators, demand side aggregator, storage providers, etc.), transmission and distribution companies is essential in commercialisation of this approach.

- **System resilience and response to loss of generation or demand:** The ability to detect and distinguish disturbance from frequency events in the grid will result in better studying the system behaviour particularly in an era which grid faces significant change in system characteristics as a result of change in generation mix. The "regional system response" will be shared with academic institutes providing invaluable data for further research and development in this area. This learning will also be shared with generators, and transmission and distribution companies for discussions around system restoration (black start) to decide on future restoration plans.

- **Rapid response profile of demand and storage and interaction with other services:** demand and storage are the two technologies which are currently used for a wide range of commercial services (i.e. STOR service by National Grid) and demonstration projects. Both technologies are also capable of providing very fast acting response as demonstrated before. The provision of enhanced frequency control capability from these technologies, and how they interact with other services during the trial (i.e. conflicting actions) are important lessons which will be shared with the stakeholders.

- **Rapid response profile of non-synchronous generation:** Non-synchronous generation technologies such as solar PV and wind may contribute to significant volume of demand in the future, and it is important to enable them to provide the support the grid requires. Sharing the trial results with the key stakeholders in the context of GB requirement for new balancing services and addressing the key challenges is required for the roll-out of such service from non-synchronous generation technologies.

- **Technology capability portfolio:** The trial of response delivered to the grid from a range of technologies in this project will ultimately lead to gaining the knowledge of how different technologies are capable of responding in proportion to the rate of change of frequency, for how long, etc. Such information will be shared for future balancing services development, and for technology advancement.

5.1.2 Post-project completion

The control system developed for this project will continue remaining live providing opportunity for the following activities:

- **System response optimisation capability:** The balancing services scheduled for day to day system operation will be analysed on a continuous basis based on the information available from EFCC control tools. <u>The ability to optimise the balancing services using the tool developed in this project will save money for the consumers.</u>

- **Real time data access:** It is envisaged the future grid development activities (i.e. generation and demand connection), and research projects require greater access to data and in such a way to allow comparing system behaviour between different parts. The EFCC tool will provide access to such data which enable more economic and efficient transmission and distribution planning, as well as more effective research and developments in this area.

5.1.3 Knowledge dissemination approach

National Grid hosts a number of **forums** such as the Grid Code Working Group, Operational Forum, and Security and Quality of Supply Standard (SQSS) group, which we have used so far to gather ideas on system needs and development of new services. We shall continue to use such forums for on-going discussions around this subject as well as informing the stakeholders regarding the progress made on EFCC.

In addition to these on-going forums, the project will form a **working group** with industry representation (manufacturers, academics, suppliers, aggregators, generators, and network licensees) to monitor the progress at different stages and ensure the deliverables are challenged and reviewed. The workgroup will hold regular web conference updates (every three months) as well as an annual event. This will ensure continuous knowledge sharing with the industry to accelerate service and technology developments in this area. As part of this, we will set up a knowledge sharing hub (in the public domain) to also allow the use of data and learning of this project by academic institutes, as well as showing leadership in this important area internationally.

The project will have an <u>**online portal (EFCC e-hub**</u>) enabling the share of the data, simulations, and results of the trials with wide range of stakeholders. We acknowledge the need for timely dissemination of the EFCC learnings, to enable market participants to provide the service the project envisages to develop at the roll out phase.

Knowledge dissemination continued

There will be significant **academic interest** in studying the response of novel technologies when they are part of a functioning transmission system. There will also be interest in studying variations in frequency (e.g. local frequency discrepancies and propagation of the frequency wave).

The **academic partners will assist significantly** in dissemination. A project website, events and traditional dissemination channels (newsletters, white papers, advertorials, conference and industry event presentations and journal publications) will all be used and contributed to by the academic institutions.

In addition to these activities, the laboratory and demonstration facilities at both academic institutions will provide unique opportunities for intensive "hands-on" dissemination to all interested parties and stakeholders. The facilities at Manchester have already successfully been used for showcasing the very first Wide Area Monitoring System in the UK. Using the recently-commissioned **Manchester RTDS**, the opportunity exists for a broad range of new demonstrations. This simulator is the largest one in the UK and one of largest in Europe. It is a digital system able to perform electromechanical and electromagnetic electric power system transient simulations continuously in real time, covering the frequency range DC to ~3 kHz. It is designed for hardware in the loop testing of physical equipment, such as control and protection devices, or complex solutions involving a large number of intelligent Electronic Devices. As such, it can not only be used for demonstrating the EFCC results, but also as a flexible training facility.

At Strathclyde, the **PNDC** has a large control room for dissemination and demonstration of results. This room can also be used as a classroom and can seat 60 people. The PNDC also has meeting rooms, extensive laboratories and of course the outdoor facility, which provides an excellent vehicle for hosting of dissemination events and offers facilities to showcase and demonstrate project outcomes in a "real world" environment.

The Technology and Innovation Centre at Strathclyde, opening early 2015 will be made available for large dissemination events. This has several auditoria (two main halls seating up to 300 or up to 450 respectively) and has break-out rooms, catering and many other facilities.

Figure 5.1 - New £90m TIC building

5.2 IPR

EFCC will comply fully with the default IPR arrangements. Our partners have been made aware of these arrangements and have agreed to comply. It is not anticipated that the developments carried out in EFCC will fall outside the default Intellectual Property Rights (IPR) arrangements defined by NIC governance document. In addition to the steps described above in knowledge dissemination, this section will make specific reference to the work carried out to ensure full compliance with default IPR. A full review of the section 9 of the NIC governance document has been carried out with EFCC partners, and as well as the agreement on the learnings of each work package (as described in section 2). The following steps will be taken to ensure a full compliance with default IPR:

- National Grid has detailed the expected learnings of each work package. This has been agreed with the partners and all relevant data, models, simulation results, and control system developed as part of EFCC will be publicly available on EFCC e-hub

- It is expected that the technology provider of the project may wish to contribute to development of some of the Solutions (control hard ware and software development, and monitoring hardware) in order to retain the IPR. This will fall under "Foreground IPR" as described in section 9 of the NIC governance document. Any product developed on such basis, will be made available for purchase on fair and reasonable terms. In the collaboration agreement between National Grid and the partners the "Foreground IPR" will be specifically described to ensure the compliance with section 9 of the NIC governance document.

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Section 6: Project Readiness

This section should be between 5 and 8 pages.

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

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

The success of EFCC is dependent on several factors outlined in Figure 6.1 and explained further in this section of the document. We are confident that all these areas have received a sufficient level of attention for the project to commence without delay:

- **Previous Projects:** We have identified work related to EFCC which has provided valuable learning points to both National Grid and our partners.
- **Project Governance:** A strong governance framework has been put in place to ensure the success of the project.
- **Technology readiness**: Our partner, Alstom, has developed the monitoring and control system to be implemented, and this is at an appropriate level of readiness.
- **Inherent Benefits:** The project will deliver valuable knowledge irrespective of the take-up of low carbon technologies.
- **Quality Control:** Steps have been taken to ensure accuracy of all information.
- **Contingency Planning:** Assessments have been carried out to identify and mitigate risks.

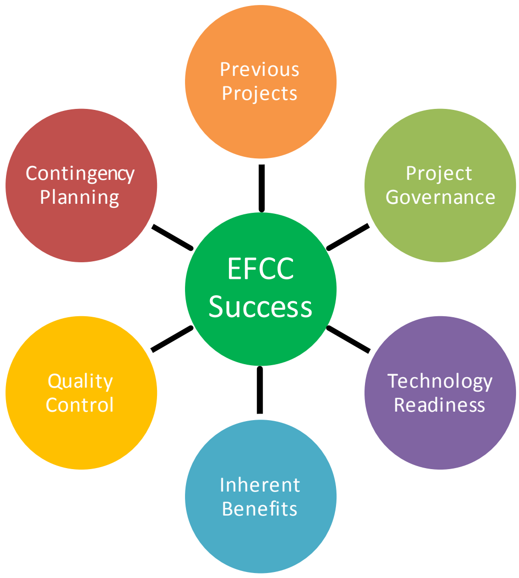


Figure 6.1 – Inputs into EFCC readiness and success

EFCC will start in a timely manner. We are in a position to start the project according to the planned timeframes. National Grid will begin work in January 2015, carrying out initial assessments of existing equipment, and the work of our partners will commence in April 2015.

Further details on timing are found in Appendix 3, Project Plan.

We have established partnerships with all the key parties:

- **Alstom** – Technology provider
- **Belectric** – PV power plants and storage
- **Centrica** – Large-scale generation and wind
- **Flexitricity** – DSR
- **The Universities of Manchester and Strathclyde** – Testing and academic support

These partners have been involved through the proposal process and have helped shape the project. Ongoing discussions between National Grid and all partners have helped to clarify queries, increase understanding and develop the scope. A meeting of all partners took place at National Grid House to encourage this process.

All partners understand their own roles and the wider project. In particular, they recognise the timeframes and are ready to commence at the relevant times. Through establishing these partnerships we have aligned our interests and ensured that the key parties are committed to the success of the project.

National Grid is ready to commence the project in January 2015. We have full support from senior management and across the business.

6.1 Previous projects

Although EFCC is an innovative project both National Grid and our partners have considerable experience and expertise in this area. This experience places it at the appropriate level of readiness and ensures that the project will start in a timely manner.

The background work of National Grid and our partners is outlined below.

6.1.1 National Grid experience

EFCC builds on previous work undertaken by National Grid. We have carried out related NIA and IFI projects and substantial amounts of work in this area (summarised in Section 3, Business Case, and detailed in Appendix 9, Previous Projects) as part of our usual business activities. The problems caused by system inertia are an important, current issue and EFCC represents a highly important area of work. The EFCC project proposed here is the result of our work in this area and reflects the knowledge and experience we have built.

6.1.2 Experience of partners

Our partners have a significant amount of experience that makes them ready to carry out EFCC.

Alstom

There is experience in Alstom relating to real-time wide-area monitoring and analysis and control. Alstom (through its Psymetrix division) delivers the world-leading phasor-based wide-area monitoring platform, which has a long history of use in real-time power system dynamics monitoring. The development and deployment of this technology is vital to the success of EFCC and so Alstom's impressive track record is important. Two areas of experience of particular relevance to this project are detailed below.

System disturbance monitoring application of PhasorPoint, detecting disturbances in real-time, locating triggers and measuring impact of system disturbances. Further enhancement of the location and impact measures, is scheduled to refine the algorithms. It has been found that real-world disturbance sequences and measurements are significantly more complex than simulations; however, appropriate signal processing and experience with real disturbances can be applied.

Wide area stability control has been deployed in Iceland to ride through large disturbances using PMU measurements. The current state includes active prototype schemes for smelter load control and industrial load shedding, with the longer-term outlook for a large-scale integrated deployment of various control schemes including generation ramping, further smelter load control, and controlled islanding. The development of a real-time control platform to host the EFCC project requirements is part of Alstom's contribution to the project. This platform will host the measurement inputs, analysis, logic functions and interfacing required by the EFCC project. Feasibility of developing a controller capable of this task has been proven, and a development team is in place to start the development on approval of the project. Furthermore, the development team brings together experience in power system dynamics and signal processing to address the algorithmic developments required to implement the control scheme.

BELECTRIC™

Belectric

Belectric has gained experience in grid supportive operational management of PV power plants across a wide range of countries and conditions. Belectric has realised more than 1GW of PV power plants in more than 20 countries.

Belectric started enhancing its PV power plants with respect to grid auxiliary services some 5 years ago, enabling adjustable reactive power supply during daytime and meanwhile also during the night. Belectric has built 3MW-scale batteries and conducted numerous tests regarding grid management including demonstrations of frequency control with them.

Belectric developed, planned and built a number of hybrid projects where various energy sources are combined and controlled, including PV, batteries, diesel and water power generators. Belectric's control system is able both to optimize operating costs depending on the available energy mix as well as to ensure stable operation under every condition (e.g. dynamic behaviour during grid outage).

centrica

Centrica

Centrica is committed to offering services to National Grid and sees the current and potential future benefits in them. All of Centrica's existing CCGTs have a proven track

Project Readiness continued

record of offering frequency response with no limitations (e.g. need to be X MW above SEL as other generators sometimes do). Centrica has chosen to invest in Low Part Load capability at Langage power station – the first CCGT in the UK and the first multi-shaft CCGT in Europe to have this technology. This demonstrates Centrica's experience and its willingness to make investment in new and innovative products. South Humber Bank Phase II is the first UK CCGT to be fully fitted with MXL2 GT components. One GT at South Humber Bank Phase 1 had these components installed on a trial/proving basis, further demonstrating Centrica's approach in this respect.

Centrica is committed to developing renewable technology and is keen to be an innovator in this area.

flexitricity
Unlocking smart grid revenue

Flexitricity

Flexitricity has ten years' worth of experience in bringing industrial and commercial electricity consumers into electricity balancing activities. Since launch, Flexitricity's live DSR control centre has operated the largest and most diverse DSR portfolio in the GB market. Using a team of engineers, Flexitricity designs a DSR solution for each customer and deploys it using well-established methods. The portfolio includes banks, data centres, event venues, horticulture, water treatment works, cold stores, distribution centres, semiconductor manufacturing, small hydro, district heating networks and others.

Flexitricity's history of innovation is unmatched in the sector. It was the largest contributor of DSR to Low Carbon London, a major project under the Low Carbon Networks Fund, and pioneered the use of DSR despatch through Automated Network Management, a feature which went beyond the original scope of the project. Flexitricity's most recent innovation was the launch of Footroom, a service which uses the demand side to reduce the need to turn down wind farms during periods of low demand.

MANCHESTER 1824 The University of Manchester
University of Strathclyde Glasgow

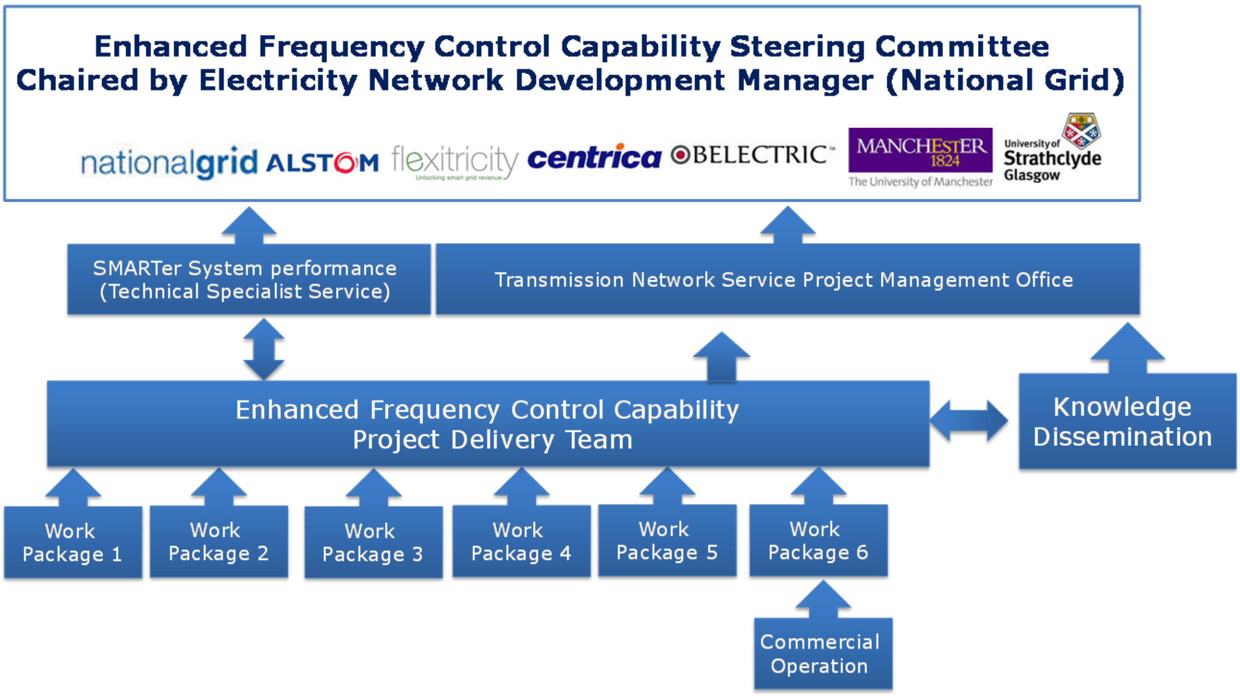
The Universities of Manchester and Strathclyde

Our academic partners bring great experience in system studies and world-leading academic knowledge and facilities. These facilities – including the Manchester RTDS and Strathclyde's PNDC – will be of great benefit to the project. The universities' expertise will provide a foundation for the project and enable a timely start.

6.2 Project governance

Strong governance is vital to the successful delivery of a complex project such as EFCC. A clear governance structure has been put in place to lead the project. National Grid's Head of Network Strategy will chair the EFCC Steering Committee, with the ongoing involvement of senior management at our project partners.

Project Readiness continued



A project team will be put in place to run the project day to day. This team will be led by National Grid and will provide regular feedback and updates to senior management.

National Grid's involvement will be led by

- **Dr. Vandad Hamidi** – SMARTer System Performance Manager

Further information on the key people involved in EFCC is included in Appendix, 7, Organogram and Team.

6.3 Technology readiness

The Technology Readiness Level of the MCS is currently around **6-7**, as advised by Alstom. The concept of using PMU information for disturbance characterisation is well established, and a substantial body of experience has been gained through monitoring many systems worldwide. The key intention of this project is to develop the infrastructure from current prototype to a robust real-time control solution for demonstration, ready for rapid transition to business-as-usual rollout after the project.

6.4 Inherent benefits

EFCC offers inherent benefits and will deliver **learning** irrespective of the take up of low-carbon technologies and renewables. The key areas of learning (outlined in Section 4, Evaluation Criteria) are not dependent on the take up of such technologies.

Importantly, low system inertia is already a problem. Even a moderate future uptake of renewables will see the effects on, and costs of, managing the system increase significantly. Further, the EFCC project is not restricted to one area and does not rely on a certain rate of renewables take up in a specific area.

At the moment, there is no mechanism for non-conventional resources to be used as frequency response. Regardless of the future changes to inertia, there is great value in understanding the contribution that non-conventional resources can provide for frequency response, as this can potentially provide cost savings over conventional service delivery. Assessing the potential for greater competition in frequency response service provision will be a valuable outcome. Learning delivered in this area will be applicable to other Licensees.

EFCC generates important knowledge that can be shared amongst, and will be of benefit to, all relevant Network Licensees. The problem of low system inertia is not unique to National Grid and the results of the trials, and the solutions offered, will be of great interest to all Network Licensees.

Benefits will increase with greater take up of renewables, but still exist at lower levels

6.5 Quality control

We have taken a number of steps to accurately **estimate** the costs and benefits of the project. A tender process was followed to identify potential partners. By identifying partners for key positions we have been able to better understand the project's costs. Our partners have provided detailed cost estimates which we have fed into the project costs. The costs of partners make up a significant proportion of project costs and so forecasting them accurately is vital.

We have **verified** all information included in the proposal. Our proposal has gone through a thorough internal review process and has been signed off by all our partners. We have thoroughly interrogated our partners' costs to ensure they are accurate and appropriate. Further, we have used internal departments (procurement, finance) to ensure we follow best practice and receive expert advice.

6.6 Contingency planning

We will employ a number of measures to minimise the possibility of cost **overruns** or shortfalls in Direct Benefits. National Grid has used its considerable experience in managing similar projects to guide the process. Procurement processes have been used to assess the costs of inputs. We are confident our estimates of the costs and benefits of EFCC are accurate. National Grid possesses expertise in project management. We have significant experience in delivering complex, high-value projects.

We have developed a comprehensive risk register with associated control measures. These risks have been categorised between general risks and work package specific risks. Our partners have provided their own input into this, based on their experience. This risk register is included as Appendix 4.

Processes are in place to identify circumstances where the most appropriate course of action will be to **suspend** the project (pending permission from Ofgem).

Success of EFCC is dependent on identifying and managing risks appropriately. We recognise that certain situations could arise which could lead, in the worst-case scenario, to the suspension of the project.

The project will be closely monitored allowing us to quickly identify potential problems and to deal with these in a timely manner. In the unlikely event of a situation which results in the most appropriate course of action being to suspend the project, we have clear processes in place. At the first opportunity, the EFCC Steering Committee will be advised by the EFCC

Project Readiness continued

project manager. The Steering Group will then consult and make a decision. Any decision to suspend/delay the project will be discussed with the authority with proposed recommendations in line with NIC governance document sections 8.30-8.42

We are, however, confident that given the significant volume of preliminary work carried out so far, combined with the breadth of experience of the project partners will ensure smooth delivery of the project.

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Section 7: Regulatory issues

This section should be between 1 and 3 pages.

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

It is not expected that EFCC will require any derogations, consents or changes to the regulatory arrangements in order to implement the project.

7.1 Balancing and Settlement Code

As part of Work Package 6 - Commercial, the services developed will be assessed in conjunction with existing services (i.e. Balancing Services, Short Term Operating Service) to ensure any areas which may conflict with the existing arrangements are identified and modification of the service, or the codes will be proposed.

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Section 8: Customer impacts

This section should be between 2 and 4 pages.

It is not expected that EFCC will have any adverse impact on customers or require access to customers' premises. The partners in this project are selected carefully so they provide the necessary response to the EFCC project. The nature of trials and demonstration carried out as part of EFCC means there is no adverse effect on day to day operation of the grid.

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Section 9: Successful Delivery Reward Criteria

This section should be between 2 and 5 pages.

Criteria 9.1

Formal Memorandum of Understanding and Agreement in Place with Project Partners

In order to achieve the project objectives, it is crucial that all project partners are committed to deliver allocated tasks. At the early stages, establishing this agreement with the project partner is the first measure of success for EFCC.

Evidence

- Formal memorandum of understanding, and agreement signed by all project partners by the end of May 2015.
- Where appropriate, partners to have agreements in place with customers

Criteria 9.2

Control System Developed Successfully

One of the key deliverables of the project is to enhance frequency monitoring capability enabling the measurement and comparasion of rate of change of frequency at regional level, and distinction between disturbance, from a real frequency event

Evidence

The following component should be delivered for success at this stage:

- Development of validated control platform enabling access to PMU devices and receiving data from the PMU, and indicating the rate of change of frequency at different locations (at least 5 zone).

Criteria 9.3

Response Initiation Tool Developed Successfully

Following the development of the control system enabling the measurement of rate of change of frequency at regional level, the new control tool must enable the initiation of response (communication to service providers).

Evidence

The following component should be delivered for success at this stage:

- Development of the response initiation tool, tested and validated enabling frequency response initiation from service providers
- The capability of the response initiation tool has been demonstrated in PNDC
- Appoporiate models (validated against the tool's performance) to be developed and made available to analysis and further development.

Successful Delivery Reward Criteria Continued

Criteria 9.4

Response Analysis from Service Providers

In this project, we will demonstrate how different technologies will respond to frequency events and their capability to provide response in proportion to rate of change of frequency.

Evidence

- Report detailing the result of the demonstration of the response from:
  - Windfarm
  - Solar PV farm
  - Demand Side Response (aggregated response)
  - CCGT Power Stations

The demonstrations must include the following system states

- Conditions when the windfarm was at different operating modes and evaluation of response capability
- Conditions when the solar PV outputs (individual farm) was at different output level and evaluation of response capability
- Trials must be carried out at different system inertia levels (at least 20% bandwidth)

Criteria 9.5

Successful Validation of Response

The project must deliver technology that is effective in reducing the overall response requirement for the grid. To achieve this, it must be demonstrated that response can be optimised to provide the most economic and efficient rapid frequency response. This requires the trails carried out in as part of Criteria 9.4, to be validated against the representative models.

Evidence

- Successful delivery of representative models and validation of trial results using the models

Criteria 9.6

New Enhanced Frequency Response Service Developed Successfully

The roll out of the EFCC requires a new balancing service to be developed to ensure the savings envisaged are achieved.

Evidence

- Successful development of the new enhanced frequency response service as part of new balancing services

- Report to recommend the implementation of the new service by 2018

Criteria 9.7

Successful Knowledge Dissemination

Successful dissemination of knowledge generated by EFCC within National Grid, to other transmission owner, DNOs, and industry stakeholders will be carried out to ensure the learnings are communicated at different stages of the project to enable timely roll out of the new balancing serice

Evidence

- Knowledge sharing e-hub developed
- All non-confidential data, and models developed as part of EFCC to be shared on the e-hub
- Work package reports delivered at the end of each work package and made available on the e-hub
- Annual knowledge dissemination event (at least one per year) organised

Criteria 9.8
Project close and knowledge dissemination

The project is planned from January 2015 until March 2018. The project is well organised to satisfy all pre-set objectives and deadlines. Eventually the new control of system frequency and provision of frequency response in proportion to range of change of frequency is demonstrated and the relevant commercial services are developed. The new approach to control the system frequency will be commercially rolled out at the end of the project.

Evidence

- The project is assessed against its initial goal and objectives.
- All reports and findings are disseminated as appropriate and the final report is sent to authority.
- Project close down by March 2018.
- locations and system conditions
- Results of trial to be published and disseminated

Section 10: List of Appendices

Appendix	Item and short summary
1	Benefits Table
2	Costs Sheet Provided Separately
3	Project Plan
4	Project Risk Register, Risk Management and Contingency Plans
5	Detailed Project Description
6	Cost Benefit Analysis
7	Organogram and Partners
8	Letters of Support
9	Previous Projects
10	Wide-area Frequency Control

KEY

Method	Method name
Method 1	EFCC
Method 2	[Insert method names here]
Method 3	[Insert method names here]

Electricity NIC – financial benefits

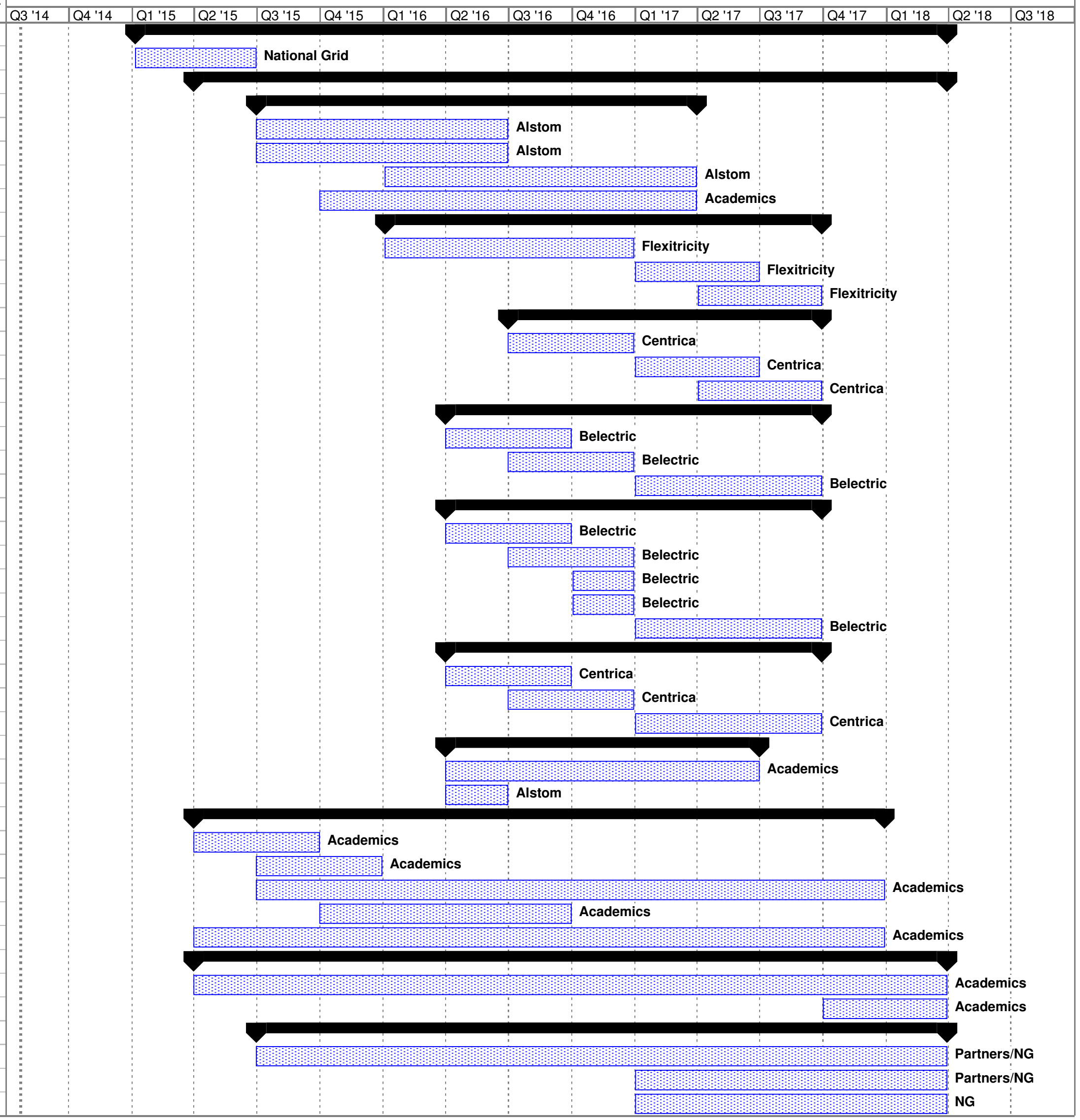
Financial benefit (£m)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**Benefit**			**Notes**	**Cross-references**
				2020	**2030**	**2050**		
Post-trial solution *(individual deployment)*	EFCC	£9.6	£210	£200.4	£807	£807*	It is anticipated that the post-trial savings associated with the EFCC include year by year reductions in Balancing Services Cost (Frequency Response) - The post-trial scale benefits are the same as GB scale as the new balancing services developed will enable all GB Participants to provide the new services to the grid. * The level of system inertia for 2050 is hard to estimate due to unavailability of any ranking order – Therefore we have assumed the 2030 figure for 2050. This will in reality give a very conservative saving level as with expected increase in the volume of non-synchronous generation such as solar PV and Wind post-2030, the reduction of system inertia is expected to continue.	Our figures are explained and justified in Appendix 6, CBA.
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	EFCC	£9.6					*(Number of sites:___)* NA	The licensee scale has not been entered as the project will be rolled out at the GB scale – Frequency Management's cost + benefits are GB Scale.
GB rollout scale *If applicable, indicate the number of relevant sites on the GB network.*	EFCC	£9.6	£200	£214	£807	£807*	GB Scale – fully implemented as part of ancillary services.	Our figures are explained and justified in Appendix 6, CBA.

Electricity NIC – carbon and/or environmental benefits

Energy saved (kWh)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**2020**	**2030**	**2050**	**Notes**	**Cross-references**
Post-trial solution *(individual deployment)*	EFCC	£9.6m	£200m	19x10^9	72x10^9	72x10^9	The energy saved on this project is calculated based on the avoided curtailed energy from clean energy sources as a result of reduction of system inertia. Similar to financial benefits, we have assumed the 2050 figures remain as 2030 which gives a very conservative figure.	The Appendix 6 includes the details of how these figures are calculated.
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	EFCC	£9.6m					*(Number of sites:___)*	The licensee scale has not been entered as the project will be rolled out at the GB scale – Frequency Management's cost + benefits are GB Scale.
GB rollout scale *If applicable, indicate the number of relevant sites on the GB network.*	EFCC	£9.6m	£200m	19x10^9	72x10^9	72x10^9		Our figures are explained and justified in Appendix 6, CBA.
If applicable, indicate any carbon and/or environmental benefits which cannot be expressed as kVA or kWh.	**Post-trial solution:** [Explain any carbon and/ or environmental benefits which cannot be expressed as kVA or kWh]							
	Licensee scale: [Explain any carbon and/ or environmental benefits which cannot be expressed as capacity or kVA or kWh]							
	GB rollout scale: [Explain any carbon and/ or environmental benefits which cannot be expressed as kVA or kWh]							

Appendix 3 - Project Plan

ID	Task Name	Duration	Start	Finish	Resource Names	Pred
1	**EFCC High Level Plan**	**844 days**	**Tue 06/01/15**	**Fri 30/03/18**		
2	Adaptation of existing communication platform for EFCC	126 days	Tue 06/01/15	Tue 30/06/15	National Grid	
3	**Project Management**	**783 days**	**Wed 01/04/15**	**Fri 30/03/18**		
4	**WP1 - Monitoring and control system**	**458 days**	**Wed 01/07/15**	**Fri 31/03/17**		
5	Application development	262 days	Wed 01/07/15	Thu 30/06/16	Alstom	
6	Control platform development	262 days	Wed 01/07/15	Thu 30/06/16	Alstom	
7	Demonstration	325 days	Mon 04/01/16	Fri 31/03/17	Alstom	
8	Academic testing	392 days	Thu 01/10/15	Fri 31/03/17	Academics	
9	**WP2.1 - DSR**	**455 days**	**Mon 04/01/16**	**Fri 29/09/17**		
10	Engage with users	260 days	Mon 04/01/16	Fri 30/12/16	Flexitricity	
11	Establish and test MCS communication	130 days	Mon 02/01/17	Fri 30/06/17	Flexitricity	
12	Test and demonstrate response capability	130 days	Mon 03/04/17	Fri 29/09/17	Flexitricity	
13	**WP2.2 - Large-scale generation**	**326 days**	**Fri 01/07/16**	**Fri 29/09/17**		
14	Engineering assessments	131 days	Fri 01/07/16	Fri 30/12/16	Centrica	
15	Establish and test communication	130 days	Mon 02/01/17	Fri 30/06/17	Centrica	
16	Test and demonstrate response capability	130 days	Mon 03/04/17	Fri 29/09/17	Centrica	
17	**WP2.3 - PV power plant**	**391 days**	**Fri 01/04/16**	**Fri 29/09/17**		
18	Site preparation	131 days	Fri 01/04/16	Fri 30/09/16	Belectric	
19	Install equipment	131 days	Fri 01/07/16	Fri 30/12/16	Belectric	
20	Test and demonstrate response capability	195 days	Mon 02/01/17	Fri 29/09/17	Belectric	
21	**WP2.4 - Storage**	**391 days**	**Fri 01/04/16**	**Fri 29/09/17**		
22	Site preparation	131 days	Fri 01/04/16	Fri 30/09/16	Belectric	
23	Install equipment	131 days	Fri 01/07/16	Fri 30/12/16	Belectric	
24	Establish and modify relevant IT systems	65 days	Mon 03/10/16	Fri 30/12/16	Belectric	
25	Establish and test communication	65 days	Mon 03/10/16	Fri 30/12/16	Belectric	
26	Test and demonstrate response capability	195 days	Mon 02/01/17	Fri 29/09/17	Belectric	
27	**WP2.5 - Wind**	**391 days**	**Fri 01/04/16**	**Fri 29/09/17**		
28	Modifications to the assets	131 days	Fri 01/04/16	Fri 30/09/16	Centrica	
29	Establish and test communication	131 days	Fri 01/07/16	Fri 30/12/16	Centrica	
30	Test and demonstrate response capability	195 days	Mon 02/01/17	Fri 29/09/17	Centrica	
31	**WP3 - Optimisation**	**326 days**	**Fri 01/04/16**	**Fri 30/06/17**		
32	System studies	326 days	Fri 01/04/16	Fri 30/06/17	Academics	
33	Develop algorithms for Controller Implementation	65 days	Fri 01/04/16	Thu 30/06/16	Alstom	
34	**WP4 - Validation**	**718 days**	**Wed 01/04/15**	**Fri 29/12/17**		
35	System testing (use of PNDC)	131 days	Wed 01/04/15	Wed 30/09/15	Academics	
36	Demonstration under different conditions	131 days	Wed 01/07/15	Wed 30/12/15	Academics	
37	Co-ordinated supervisory control	653 days	Wed 01/07/15	Fri 29/12/17	Academics	
38	Development of control schemes	262 days	Thu 01/10/15	Fri 30/09/16	Academics	
39	Simulation/validation activities	718 days	Wed 01/04/15	Fri 29/12/17	Academics	
40	**WP5 - Dissemination**	**783 days**	**Wed 01/04/15**	**Fri 30/03/18**		
41	Ongoing dissemination	783 days	Wed 01/04/15	Fri 30/03/18	Academics	
42	Final results shared	130 days	Mon 02/10/17	Fri 30/03/18	Academics	
43	**WP6 - Commercial**	**718 days**	**Wed 01/07/15**	**Fri 30/03/18**		
44	Investigate commercial opportunities	718 days	Wed 01/07/15	Fri 30/03/18	Partners/NG	
45	Valuation of new balancing service	325 days	Mon 02/01/17	Fri 30/03/18	Partners/NG	
46	Develop commercial balancing service	325 days	Mon 02/01/17	Fri 30/03/18	NG	



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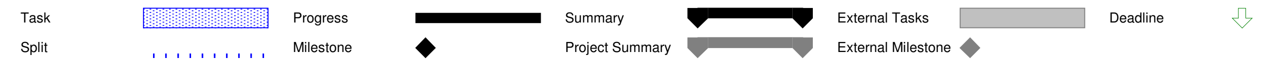


Appendix 4: Project Risk Register, Risk Management and Contingency Plans

Definitions

Impact

1	L
2	M
3	M
4	H
5	H

Likelihood

1	L
2	M
3	M
4	H
5	H

Score	RAG
1 - 6	Green
7 - 14	Amber
15 - 25	Red

Likelihood / Impact

Impact \ Likelihood	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Control Opinion
Effective
Partially Effective
Not Effective

Reputation Impact Ratings

Score	Description	Definition
1	Internal	Internal - minor impact on stakeholders within NGT Group
2	Intra-Group	Internal - major impact on stakeholders within NGT Group
3	Local third party	External - impact on local stakeholders
4	National	External - impact on national stakeholders
5	International	External - impact on international stakeholders

Financial Impact Ratings

Score	£m
1	0 to 5
2	5 to 10
3	10 to 30
4	30 - 50
5	50+

Likelihood Impact Ratings

Score	Description	Frequency of Occurrence	Probability of Occurrence
1	Remote	<Once in 20 years	<10% chance
2	Less Likely	<Once in 15 years	>10% and <40% chance
3	Equally Likely as Unlikely	<Once in 10 years	>40% and <60% chance
4	More Likely	<Once in 5 years	>60% and <90% chance
5	Almost Certain	One or more a year	>90% chance

CONTROL OPINION

Not Effective	Key controls have not been established or are deemed to be ineffective. Action plans to rectify the fundamental weakness have still to be fully implemented
Partially Effective	Key controls are in place but have either not been subject to suitable assurance activity or testing reveals that some control improvements, not deemed to be fundamental, are required
Effective	Key controls are in place, are tested periodically as appropriate and are deemed satisfactory. This testing includes independent challenge where the risk is deemed significant (e.g. from NG Audit or another independent assurance provider)

Appendix 4: Project Risk Register, Risk Management and Contingency Plans

Project: Enhanced Frequency Control Capability

As At: 25/07/2014

Risk No.	WorkStreams / Area	Risk Description	Cause	Consequence	Risk Owner	Likelihood (1-5)	Financial Impact (1 - 5)	Reputational Impact (1 - 5)	RAG	Escalate To	Action Plan	Control Opinion
2	General	Partners leave project before completion.	Decision is taken by partner to leave the project. Reason could be commercial, operational, etc.	Work is lost or unable to commence and the usefulness of the results of project is reduced or project is delayed.	Project Manager	3	2	3	9	Steering Group	Ensure thorough contracts in place. Procurement processes have considered ongoing size and reliability of partners. Replacement partners have been considered and could be approached if required.	Effective
3	General	Estimated costs are substantially different to actual costs.	Full scope of work is not understood. Cost estimates are not validated. Project is not managed closely.	Potential project funding gap. Alternative funding is required or the project scope is reduced.	Project Manager	1	3	2	3	Steering Group	Ensure cost estimates are thorough and realistic and reflect full scope of work. Validate estimates based on tenders and market knowledge. Appropriate contingency to be included.	Effective
4	General	Material costs increase.	The cost of materials rises for unforeseen circumstances.	Potential project funding gap. Alternative funding is required or the project scope is reduced.	Project Manager	3	2	3	9	Steering Group	Define cost risk owner.	Effective
5	General	Significant changes to the GB electricity system during the life of the project.	Priorities or strategies for planning and managing the GB system may change.	Solution may no longer be suitable. Assumptions may no longer be accurate or appropriate.	Project Manager	1	3	4	4	Steering Group	We have fully considered future developments and scenarios. We have ensured usefulness of solution matches planning of system.	Effective
6	General	Critical staff leave National Grid or our project partners during project lifecycle.	Usual and unavoidable staff turnover results in key staff leaving National Grid or our project partners.	Progress of the project is delayed. The expertise to deliver the project is no longer within the project team.	Project Manager	2	2	3	6	Steering Group	Knowledge of, and rsponsibility for, project to not rely with one person. Ensure documentation and guidance exists to assist anyone joining project team. Thorough handover processes to be in place.	Effective
7	General	Quality of technology is insufficient - the monitoring and control system and/or equipment installed at response sites.	Least cost option taken ahead of quality and reliability considerations; quality control insufficient at suppliers.	The solution offered is not reliable and commercial opportunities will be reduced. Costs are incurred through delays and replacements.	Suppliers	4	2	3	12	Project Manager	All partners have been assessed based on reputation, track record and responses to NG tender. Ensure that price is not the prioritised criteria. Ensure quality control procedures are in place and followed throughout project.	Effective
8	General	Technology cannot be easily upgraded.	Monitoring and control technology and/or response equipment is designed without full consideration for future developments.	Technology is less useful in the future as the electricity system continues to develop. Required upgrades are costly or not possible.	Suppliers	4	2	3	12	Project Manager	Fully consider future requirements and build these into specification. Ensure flexibility is built in.	Effective
9	General	Costs of solution over lifetime are high.	Full cost of solution is not considered and/or understood.	Future usefulness and commercial opportunities of solution are restricted.	Project Manager	3	3	3	9	Steering Group	Full long-term costs of solution have been considered as part of detailed CBA calculations.	Effective
10	General	Academic service providers are unable to recruit appropriate staff to work on the project.	Lack of suitable candidates or interest in the project.	Trials are limited or unable to take place. The suitability and performance of the technology is not established.	Academic Project Manager	3	3	3	9	Project Manager	Academics have a large internal candidate-base of experienced PDRAs that are already interested in working on this project and will advertise widely upon award of project. Reputation and facilities of partners will attract high-calibre candidates.	Effective
11	General	Component failure during project.	Equipment will be run in new ways and therefore may experience problems or failures.	The equipment may require repair or replacement. The tests may be delayed.	Suppliers	3	3	3	9	Project Manager	Thorough checks before tests. Clear understanding of equipment capabilities. Particular stress points identified. Spare parts and repairs lined up.	Effective
12	General	Strategic Spares Policy.	Spares Policy for new technology may not be suitable when taking all risks into account.	If suitable spares are not identified and available, the risks of losing the PMU/Controller in the network may reduce effectiveness of project.		3	3	2	9		Cntingency plans will be drawn up to include potential alternative monitoring locations which could be used in the event of equipment and/or communications failure for continued operation. Off-the shelf products that are readily replaceable are used. The proposed structure will contain a number of PMUs in each zone which should allow continued supervisory actions with the loss of a device. For the controller, redundancy will be planned for to ensure the loss of the controller is suitably backed-up.	Effective
13	General	Maintenance requirements	Manufacturer recommends intensive and regular maintenance activities which do not fit with project owner's expectations.	Regular intensive maintenance requires additional resource of field staff and potentially affecting the network operation thus reduce power transfer levels and potential constraint costs.		3	3	3	9		Seek to work with the manufacturers to understand maintenance requirements and the impact on the design or selection of components. Remote VPN access to controller for remote logging and maintenance, especially for beta release stages.	Effective
14	General	Loss of telecommunications.	Technical fault leads to oss of telecommunications between systems.	Reduced availability and performance.		3	3	3	9		Design scheme for continued operation or graceful degredation in the event of a loss of telecommunications.	Effective
15	General	Inefficient operation of MCS.	MCS not configured correctly which results in spurious tripping or excessive ammounts of control initation commands.	Over-response from resources reducing stability, excessive set-point changes in generators reducing asset lifetime/		3	3	4	12		The scheme will be extensively tested in a laboratory environment before any network deployment. The system will also be evaluated using recorded measurements from the GB systems allowing tuning and configuration in a safe environment. Academic partners will also provide suitable facilities to test response on generators to reduce risk to assets after deployment.	Effective
16	General	High operation and maintenance costs.	Cost for inspection, maintenance, repairs, spares, etc. are higher than expected.	Excessive OPEX costs compared to current alternatives.		2	1	1	2		Maintenance requirements and spares etc identified during Tender evaluation. Further work to be carried out to fully determine OPEX requirements	Effective

17	General	Installation	Supplier of TO/TSO delay on Base Install- Delays in implementing control scheme platforms and comms routes to PMUs/Controllers/controllable resources. Co-ordination of National Grid and supplier staff availability.	Delays in key control scheme component will push back the trialling period and thus reducing the avilable time for reports, tuning dissementation.		3	1	3	9		Select vendor with track record of commercial WAMS installations. Supplier must have experience of deploying in utility environment. Direct support by supplier via VPN for diagnosis. Comprehensive training by Supplier for IT personnel in all 3 partners in IT requirements of WAMS project.	Effective
18	General	Communications	Communication Infrastructure is not fit for purpose.	The existing communication infrastructure may inhibit the speed of response of a control reducing scheme effectiveness.		2	1	2	4		Work closely with National Grid and partners to ensure that new comms links not critical to project success. Ensure that the communications infrastructure is well understood and the chosen control scheme can best work with available infrastructure.	Effective
19	General	Outage required for commissioning	Inability to obtain the relevant outages for commissioning.	Possible delays to commissioning programme, or cost of outage.		2	1	3	6		Outages identified and incorporated in Scheme Requirement Document	Effective
20	General	Commissioning	Commissioning procedures encounter problems.	Delays in commissioning the project.		2	1	3	6		Identify and agree all the commissioning procedures with the supplier for the new technology, and the problems that might be encountered	Effective
21	General	Capital costs	Costs higher than anticipated	Project budget exceeded		2	1	2	4		FIDIC contract, Contractor takes risk. Commodity price to be hedged	Effective
22	Health, Safety & Environmental	New equipment	Lack of experience and knowledge regarding new pieces of equipment	Health and safety risks present as a result of lack of experience. Inefficient working could result. Note that controller is low voltage equipment, and actions are taken through existing standard protection and control equipment.	Project Manager	2	1	4	8	Steering Group	Specialist tools and training required for maintenance activity. Procedures to be developed. Controller to go through rigorous testing.	Effective
23	WP1 - Control System	Technology partner fails to deliver suitable product on time.	Problems with design and build.	Project is delayed.	Alstom	3	2	2	6	Project Manager	Contracts to be put in place to penalise delays. Clear specification requirements in place. Development of technology to be closely managed to identify and resolve potential problems.	Effective
24	WP1 - Control System	Technical specification lacks the clarity required to deliver the technology, or contains errors.	Requirements not fully understood. Quality control processes insufficient.	The technology developed may not match requirements or be suitable.	Alstom	3	2	3	9	Project Manager	Care to be taken over technical specification, with input from all relevant partners. Review process in place and then regular communication with Alstom and other partners to identify and resolve issues quickly.	Effective
25	WP1 - Control System	Flexible embedded real-time controller not commercially available	A controller with the flexibility to employ the required algorithm is not currently available and will require significant development effort. Resources must be in place for a timely start to the platform development	Delays in sourcing suitable resources may extend the development period and delay deployment and trialling of the project	Alstom	3	1	2	6	Project Manager	Source suitable development resources in advance of project start date to ensure that timely start can be made to project.	Effective
26	WP1 - Control System	Event detection and response algorithms not available on embedded real-time controller	The controller will use custom functions which are not currently available on the embedded control platform for determining of appropriate reaction. These functions will require development and testing before deployment. New control approaches need developed.	Extension required for the development period which adds delays to all consecutive elements of the project.	Alstom	2	1	2	4	Project Manager	Staged approach to application development with simple initial target in first year. Allow sufficent resources for all stages of algorithm development to ensure that sufficient effort is dedicated to the project at an early stage to avoid any delays and allow for sufficient resource for modification based on the outcomes of the early testing.	Effective
27	WP1 - Control System	Resource Interoperability	Using distributed resources for frequency response is untested in the UK and the availability of resources when called upon is critical. There must exist a sufficient information exchange between the controller and the individual resources so that resources can be called upon in a timely manner.	Lack of comms path or interoperability issues between the controller and the resources may lead to delayed initiation of response and reduced ability of the central control scheme to halt frequency excursions.	Alstom	4	2	3	12	Project Manager	Agree common standards and offier a simple IO for all controllable components through standard interface protocols which will be agreed upon by all controllable resources. Plan demonstration without critical requirement for communication path to all response providers. Evaluate local control and assess the added benefit that central control brings if made available.	Effective
28	WP1 - Control System	Resource Flexibility	Resources do not offer enough flexibility for control under proposed control scheme, either offering response which is difficult to quantify or response which is difficult to tune	May require redesign of the control scheme adding delays to deployment	Alstom	3	2	3	9	Project Manager	Collaborate closely with project partners through all stages to ensure that control scheme is designed according to limits of operation of various resource types. Especially, collaboration between Alstom and Academic Partners on optimisation.	Effective
29	WP1 - Control System	Control Scheme trial outcome	Due to the innovative nature of the project, the selected control scheme when trialled may yield negative results, or introduce additional problems.	The selected control scheme will be unable to effectively deploy resources to arrest a frequency excursion	Alstom	3	2	3	9	Project Manager	The risk is mitigated by using a number of candidate solutions which will be based on wide-area control, local-control and a hybrid-approach using both. If any problems arise from one candidate solution, other solutions will be readily available	Effective
30	WP1 - Control System	Controller scalability for roll-out	The controller will be developed for trial locations using a limited number of sites and corresponding PMU measurments. The control platform may see reduced performance due to increased amounts of measurement and resource data with larger-scale roll-out. An additional risk stems from exceeding the computational capacity of the controller with complex algorithms and increased inputs, e.g. more resources to optimise.	Timely roll-out of the scheme could be put at risk adding significant delays to full effectiveness of the scheme and putting the learning from the project into action. The risk for this stage of the project is minimal.	Alstom	3	4	3	12	Project Manager	Labaratory testing will allow scalability testing which can be used to test the control platform with a greater number of inputs than will be utilised in trialling. This will both allow the limits of the control platform to be found and define new methods by which to overcome these limits. How to deploy the control system for larger roll-out will then be a learning outcome of the project minimising the risk of delayed roll-out. Controller development path enables easy porting between hardware platforms - if greater performance required, other hardware will be available by end of project.	Effective

31	WP1 - Control System	Additional testing and tuning	The controller may require additional tests and fine tuning based on real system measurements ifrom the UK network to ensure robust operation. Data will need to be gathered over a sufficient period to determine the control scheme performent.	the selected control scheme will be unable to effectively deploy resources to arrest a frequency excursion	Alstom	2	2	2	4	Project Manager	Information gathered from VISOR can provide an extended period of system measurements. This data can be replayed in the laboratory environment to test the control scheme with real measurements from the UK system to validate the behaviour while also allowing a longer capture period for sufficient disturbances.	Effective
32	WP1 - Control System	Data Quality	Inadequate data quality from PMUs due to problems with communications infrastructure, incompatible PMUs or from existing PMUs where experience has shown poor quality data.	Controller Application value and performance reduced	Alstom	4	1	2	8	Project Manager	Require proof of prior installations with good data availability. Use PMUs that have evidence of acceptable practical performance, and standards compliance where possible. Applications to be robust to data packet loss. Review of data quality issues and resolution/improvement to be carried out.	Effective
33	WP1 - Control System	ROCOF Trip Risk	Controllable resources which are called upon to arrest frequency excursion may be conflicted by own Loss of Mains RoCoF settings and trip. Also, risk of fast response rolling off at df/dt=0 when it should be sustained.	Loss of effectiveness of resources - unavailable for frequency support or prematurely returned to normal service.	Alstom	2	1	2	4	Project Manager	For trial purposes, RoCoF should be sufficiently low to avoid conflicts of LoM detection, however studies will be carried out to assess the problem for future roll-out. Project will provide learning outcome which can be used to inform future grid codes. Also, co-ordination of control to ensure smooth transitions between stages of response.	Effective
34	WP2.1 - DSR	Flexitricity is unable to provide participants for planned trials.	Timing, risk and commercial terms makes it difficult to recruit DSR participants.	Trials are limited or unable to take place. The suitability and performance of the technology is not established.	Flexitricity	4	3	3	12	Project Manager	Work with Flexitricity to identify, and begin negotiations with, potential participants as a matter of priority once project commences.	Effective
35	WP2.1 - DSR	DSR recruitment: industrial and commercial electriciy customers unwilling to participate	I&C energy managers' workloads, comprehension of the proposition, duration of trials, uncertainty of long-term commercial service, opportunity cost	Ability of DSR to deliver EFCC not proven	Flexitricity	3	2	4	12	Project Manager	Use Flexitricity's extensive existing customer base and contracting process for recruitment	Effective
36	WP2.1 - DSR	DSR trials prove infeasible	Complex technical interaction with existing commercial site processes	Ability of DSR to deliver EFCC not proven	Flexitricity	2	4	4	8	Project Manager	Pursue three separate technical approaches to spread risk (RoCoF, real inertia, simulated inertia). Investigate technical feasibility for higher risk technical approaches (especially simulated inertia) prior to trials	Effective
37	WP2.1 - DSR	Total delay between detection and action too long for distributed resources including DSR	Long signalling chain including communicating with remote sites	Cannot dispatch certain resources fast enough	Flexitricity	2	3	3	6	Project Manager	Include at least one fast-acting technical approach (RoCoF) for DSR, to compensate for other possible signalling delays	Effective
38	WP2.1 - DSR	Cost of DSR too high for large-scale roll-out	Controls modifications (especially RoCoF and simulated inertia), spark spread (especially real inertia)	Project does not result in economic source of EFCC from DSR	Flexitricity	2	3	4	8	Project Manager	Pursue three separate technical approaches to spread risk (RoCoF, real inertia, simulated inertia).	Effective
39	WP2.1 - DSR	DSR deployment lead time too long	Normal delays in dealing with industrial and commercial energy users	Unable to operate trial for sufficient time; some customers are ready too late for trial	Flexitricity	3	3	3	9	Project Manager	Commence EP recruitment during phase 1; show flexibility on trial dates and durations	Effective
40	WP2.2 - Large-scale generation	Modifications to power stations are not completed in time for project.	Power stations proposed by Centrica are in the process of being upgraded. These upgrades may be delayed.	Participation is limited and scope of project is lessened.	Centrica	2	3	3	6	Project Manager	Centrica to manage upgrade process closely. Timescales to be monitored and communicated to National Grid.	Effective
41	WP2.3 - PV power plant	Bad weather (low irradiation).	Poor weather conditions will mean that trials cannot take place.	Insufficient test conditions will lead to delays in testing.	Belectric	3	1	1	3	Project Manager	Plan tests in summer.	Effective
42	WP2.4 - Storage	Delayed installation and commissioning due to local problems.	Issues around grid connection and accessibility cause delays.	The project is delayed.	Belectric	3	2	3	9	Project Manager	Careful and detailed up-front planning; project plan not too tight	Effective
43	WP2.5 - Wind	Windfarm operators struggle to get relevant technical input from OEM.	Lack of communication or timely response from OEM.	The project is delayed.	Centrica	3	2	2	6	Project Manager	Draw up "heads ot terms" with OEM. Pay OEM (from funding) for relevent technical input.	Effective
44	WP3 - Optimisation	Detailed models of the various technology types are not made available to academic partners for system studies.	Poor communication and project management. Possible restrictions on data.	Without detailed technology models, any optimised control scheme will be based on generic assumptions about technology capabilities which may not be accurate. As such, true performance will not align with simulated performance.	Universities	2	2	3	6	Project Manager	Establish communication channels. Specify data requirements early. Closely manage process and follow-up on any delays.	Effective
45	WP4 - Validation	Unable to model the UK network with sufficient detail using the RTDS facilities in order to thoroughly validate proposed control solutions.	Lack of required data. Lack of expertise on project.	Wide scale rollout may be severely impacted by issues not flagged during the validation phase.	Universities	2	3	3	6	Project Manager	Academic team contains expert knowledge. All data to be provided in timely manner. Problems to be escalated to Project Manager.	Effective
46	WP5 - Dissemination	Knowledge gained from project is not adequately shared with industry and other interested parties.	Lack of resources dedicated to dissemination. Failure to deliver events, website, etc.	A major benefit of, and reason for, the project is lost. Performance of solution and lessons learned are not shared.	Universities	1	2	3	3	Project Manager	Ensure knowledge sharing is a priority of project. Establish formal processes to disseminate results, reports, etc. Use working group, internet, academic partners to facilitate sharing.	Effective
47	WP6 - Commercial	Market for EFCC not taken up by possible resource providers.	Knowledge not disseminated, meaning providers unable to prepare. Commercial arrangements not attractive.	The successful roll out of the solution will be delayed.	Project Manager	2	4	4	8	Steering Group	Ensure that knowledge is shared. Establish clear communication channels with interested parties. Develop commercial terms thoroughly prior to roll out.	Effective

Project Code/Version No:
NGETEN03/v1

Electricity Network Innovation Competition Full Submission Pro-forma

Appendix 5: Detailed Project Description

A5.1 The Move to Renewables

The key driver of EFCC is the continuing move to renewables within the GB electricity industry. Figure A5.1 below, taken from National Grid's Future Energy Supply document [1], illustrates the huge increase expected in renewables under both National Grid's Slow Progression and Gone Green scenarios.

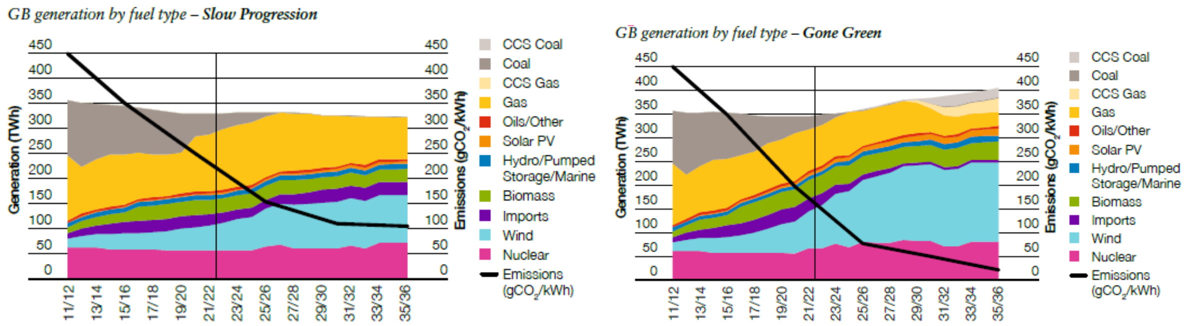


Figure A5.1 - Future Generation Mix as forecasted by Future Energy Scenarios

A5.2 System Frequency

System frequency is a measure of the dynamic balance between energy generated and consumed. It is a continuously changing variable that is determined and controlled by the second-by-second (real time) balance between system demand and total generation.

National Grid has a licence obligation to control frequency within ±1% of nominal system frequency (50.00Hz) except under abnormal conditions. National Grid must therefore ensure that sufficient generation and / or demand is held in automatic readiness to manage all the credible circumstances.

There are two types of Frequency Response:

- Dynamic Frequency Response is a continuously provided service used to manage the normal second by second changes on the system.
- Non Dynamic (Static) Frequency Response is usually a discrete service triggered at a defined frequency level.

National Grid also uses reserves to balance the system. To be able to deal with unforeseen demand increases and/or generation unavailability, National Grid needs to access sources of power variation in the form of either generation or demand. These additional power sources available to National Grid are referred to as reserve and comprise synchronous and non-synchronous sources. Figure A5.2 below depicts the timescales relevant to the different forms of response available.

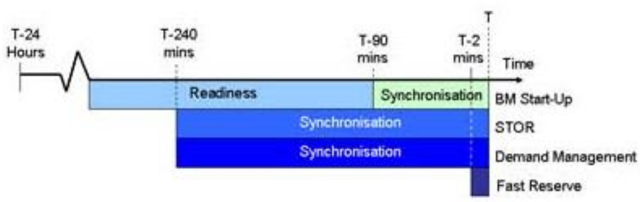


Figure A5.2 - Response timescales

[1] http://www.nationalgrid.com/uk/Electricity/ten-year-statement/current-elec-tys/

BM Start-up

The BM Start-up Service gives National Grid on-the-day access to additional generation BMUs (Balancing Mechanism Units) that would not otherwise have run, and which could not be made available in Balancing Mechanism timescales.

- Short Term Operating Reserve

  Short Term Operating Reserve (STOR) is a service for the provision of additional active power variations from generation and/or demand reduction.

- Demand Management

  Rather than changing generation levels, National Grid can instruct large consumers of electricity (or aggregated pools of smaller consumers) to temporarily reduce their consumption.

- Fast Reserve

  Fast Reserve provides the rapid and reliable delivery of active power through an increased output from generation or a reduction in consumption from demand sources, following receipt of an electronic despatch instruction from National Grid.

EFCC aims to offer a new form of response to assist National Grid in balancing the system in a future system characterised by large amounts of renewables and low levels of inertia.

A5.3 System inertia

Here we build on the explanation of system inertia given in Section 2.

Inertial Contribution: Synchronous Generators

In a synchronous generator, inertia is provided by the turbine shaft and its attachments, comprising the alternator, high, medium and low pressure turbines etc. (see Figure A5.3 below).

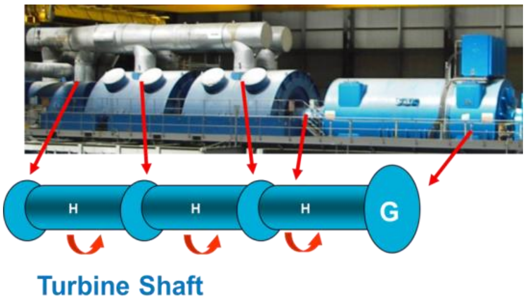


Figure A5.3 - Rotating mass (turbine shaft) of a large synchronous power plant

The physical rotational kinetic energy stored in such a turbine shaft and its attachments in motion is given by $\frac{1}{2} J \omega^2$ where J is its total moment of inertia in kg m^2 and ω is its rotational speed in rad/s.

The per unit "H constant" for rotating machines is defined as the ratio of the above physical rotational kinetic energy and the MVA rating of the machine. Its units are MWs per MVA, or, equivalently, seconds (see Figure A5.4 below).

Large synchronous generators are the main sources of inertia for the transmission system, and as such play the major role both in limiting RoCoF and in the containment of system frequency change following an unscheduled loss (disconnection) of generation or demand from the system.

The inertial requirements for transient (rotor angle) stability are also mainly provided by the inertias of synchronous generating plant.

Inertial Contribution : Wind Farms, Solar PV Installations and HVDC Links

Wind Farms

Except in the case of the older, simpler Induction Generator (or "Danish") design, wind turbines can provide little or no inertia to the system, because in both of the two newer Doubly-Fed Induction Generator and Full Converter designs, the wind turbine with its rotating mass is effectively de-coupled from the transmission system by the AC/DC Converter (see Figure A5.4 below).

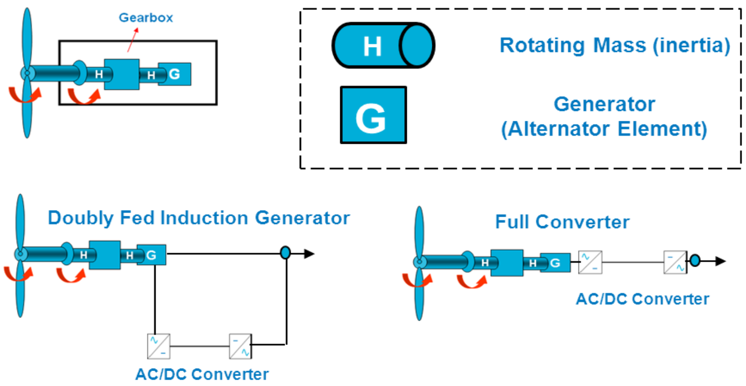


Figure A5.4 - Wind generation technologies deliver low or almost no Inertia

In other words, the two newer wind technologies cannot be used as sources of natural inertia for the purpose of frequency response. They can, however, be made to vary their MW output to give so-called "synthetic" inertia. However, there are certain technical challenges associated with this approach, because the varying of MW output is not a true replacement for "natural" inertia.

Solar PV

Solar PV installations do not contain any rotating parts, therefore have no natural inertia. However, it is possible that they could be made to vary their MW output for frequency response purposes.

HVDC Links

Similarly, this type of plant has no natural inertia. Certain HVDC links, however, are already being used as "static" response: when the system frequency falls below a certain pre-defined level, a change in MW output is triggered which contributes to overall frequency response requirements.

A5.3.1 Summary

The charts below (Figure A5.5) illustrate how system inertia, at different demand levels, will decrease over the next 20 years under National Grid's Slow Progression and Gone Green scenarios. Low inertia is a particular problem during periods of low demand, such as overnight.

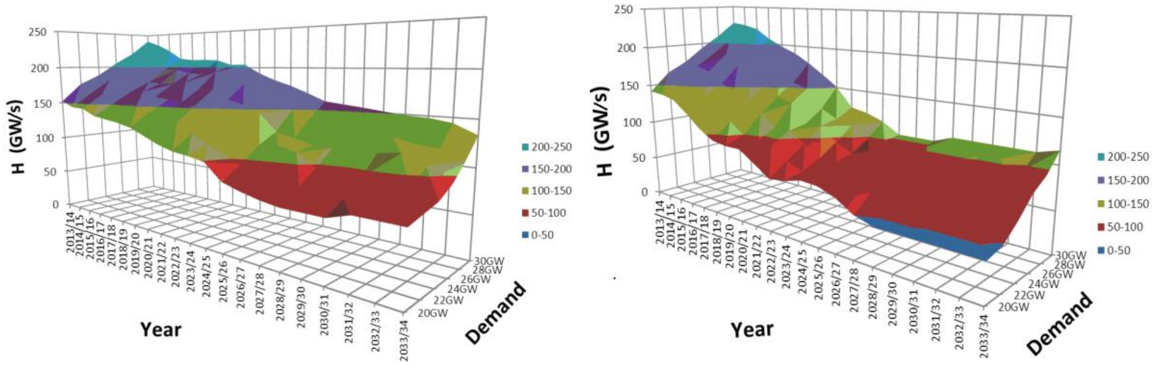


Figure A5.5 Decrease in system inertia under Future Energy Scenarios

A5.4 The impact of reduced/variable system inertia

System inertia is forecast to decrease from the current level of 360GW/s down to 150GW/s by 2025 under National Grid's Slow Progression scenario and 2022 under Gone Green. The rate of change of frequency (RoCoF) following a system event such as the loss of a power station correspondingly increases from a current level of 0.125Hz/s to 0.3Hz/s (similar size of loss).

Figure A5.6 below depicts the effect on frequency of a system event such as the loss of a power station on the system as it is now, with **high inertia and RoCoF of 0.125Hz/s**. On average, thermal plant starts to provide primary response two seconds after the event. Within these two seconds, however, synchronous plant is providing a "natural" inertial response. Frequency has dropped 0.25Hz after two seconds (0.125 x 2). The ramp rate (shown in red) is the rate of response provided, measured in MW/s. The rate of change of frequency in this case is 0.125Hz/s, and the response service is able to avoid a severe drop in frequency (as shown in blue), despite the initial delay in primary response initiation.

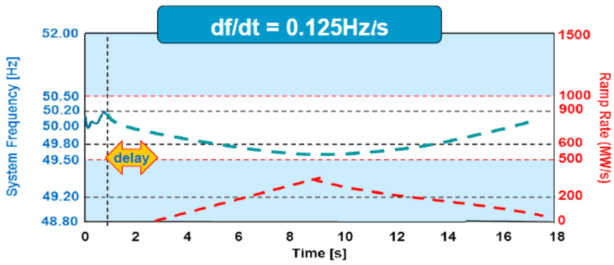


Figure A5.6 Frequency response under high system inertia conditions

Figure A5.7 below shows the effect of the same system event when the level of system **inertia is low and RoCoF is 0.3Hz/s**. The rate of change of frequency is now much higher and the frequency excursion is therefore faster and larger, quickly reaching dangerously low levels. There is the same delay between the event and the response as in Figure A5.6, but now during this time there is limited system inertia available to provide response. Frequency has dropped 0.6Hz after two seconds (0.3 x 2). By the time primary response initiates, a much greater volume of response is required to arrest frequency decline. When system inertia is low the delay between the event and the response becomes more critical.

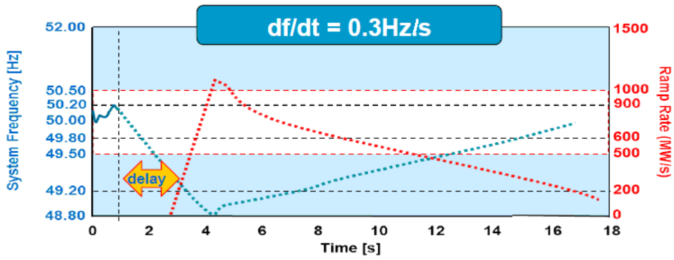


Figure A5.7 Frequency response under low system inertia conditions

A5.5 Related challenges

RoCoF-based relays

The majority of embedded generation is protected by RoCoF-based relays. The purpose of this relay is to detect a localised islanding condition (when the area of the network where the embedded generator connects is isolated from the rest of the grid), and disconnect the embedded generator (to ensure no generation is running so the network can be reconnected to the main grid later without concerns over reconnecting two unsynchronised areas – furthermore, islanded systems may often be unearthed, which represents a very hazardous situation). RoCoF relay cannot always discriminate between loss of mains and system disturbances, particularly when the rate of change of frequency is high. There is a danger, therefore, that embedded generation may be automatically switched off following a system event and corresponding movement in frequency. This can potentially lead to a cascading loss of embedded generation. This becomes an issue with increasing embedded generation penetration.

EFCC will enable rapid response to help control RoCoF. This will help avoid problems with local RoCoF-based relays.

Generator withstand capability

The ability of a generator to withstand a frequency deviation depends on such factors as its inertia, rotor angle, reactance and power factor. Some of these are also relevant to Transient Stability (see below).

Generator tripping

This can be a consequence of a large frequency deviation. A large and rapid system frequency deviation causes acceleration or deceleration of the turbine and governor systems, and consequent stresses. This can lead to generation tripping, particularly in larger thermal units. Generation tripping after the initial disturbance destabilises the system further and can lead to cascading outage. EFCC reduces the extent of frequency deviation and the rate of change, thus reducing risk of further generator tripping.

Power oscillations and recovery post-fault

The larger the disturbance, the larger the initial amplitude of rotor oscillation. There are two types of oscillations involved in the system response to large disturbances:

1. Generator rotor angle oscillations, typically around 0.2-2Hz, risking generator tripping or islanding, and managed by control design for damping.
2. Generator speed governor control oscillations, with the risk of frequency instability increasing with reduced inertia and accelerated proportional control (such as frequency droop).

EFCC reduces the initial disturbance and oscillation amplitude, and introduces a frequency control response without a closed-loop droop characteristic, thus improving both oscillation issues.

Transient stability

This relates to the ability of areas of the system to return to a stable, synchronous steady state following a disturbance. Reducing inertia results in greater deviation of the disturbed region and increased risk of loss of grid synchronism. Regional deviations in inertia are important in the transient stability problem. EFCC reduces the regional deviations of frequency and reduces risk of islanding.

A5.6 Detailed Work Packages

WP1 – Control system

WP1 is explained further in Appendix 10.

The control system development includes:

- Algorithm for identifying a frequency disturbance as quickly as possible, differentiating localised faults and network events from generation/load disturbance
- Method for identifying the area in which the event trigger occurs
- Method for identifying the target proportionate frequency response, where appropriate using an initial controlled action (i.e. a fast-response reserve command) and the observed system response
- Call of reserve from available resources, prioritising fast response in locality of the disturbance event.
- Rules for initiating replacement for time-limited fast response (e.g. battery storage, wind control) with longer-term response (e.g. demand-side response)
- Fast real-time control platform (20ms controller response) on which the control scheme is deployed. This control platform will include PMU inputs, enable flexible control scheme deployment, and provide links to controllable resources

The demonstration includes:

- Building a library of reference events, based on real data from the GB WAMS system and simulated disturbances for testing. Evaluation of control scheme response relative to expected response
- Validating and comparing candidate control schemes based on the reference events above. Software and hardware validation are included
- Deploying control scheme, confirming end-to-end communication from PMUs through the controller to frequency response schemes, in preparation for Phase 2
- Tuning the control scheme on the basis of experience gained in Phases 2&3

WP1 and the sub-tasks are summarised below.

1.1 Applications

Applications on controller to detect frequency events and initiate action

Detection

- System-wide signals including frequency, RoCoF and phase-angle to be collected from zones, aggregated and processed
- Coherency between zonal signals to characterise frequency events
- Fine-tuning with real disturbances captured during project before any network implementation or trialling

Targeted Response

- Determine location and level of response required
- Compare zonal aggregate signals and select zone where frequency / angle move first – the trigger location

Resource Dispatching

- Select available resources in a zone. Resources have diverse time-characteristics which must be considered before initiating the response
- Simple set of rules to govern resources behaviour over time for replacement of depleted resources with new resources
- Accounting for ramp rates with fast, but shorter duration resources
- Rules must be designed to allow for easy addition of new services if they become available in the future.
- Validation of successful resource deployment and transition from wide-area to local control

1.2 Controller Development

- Flexible controller platform developed to implement control application
- Controller must be capable of real-time flexible control
- Provide platform to implement above applications
- Target controller latency <20ms
- Must be scalable to requirements of project
- Capable of receiving direct PMU signals to minimise delays from data concentrators, or PDC data streams to minimise deployment effort.
- Local response providers to make external interface available to link to central controller
- Controller tested and performance validated for use in the project

1.3 Demonstration

Will cover the work specific to GB deployment

- Demonstrate the control approach through:
    - Standalone Controller tests with measured or simulated records
    - Hardware-in-the-Loop (HiL)
    - Strathclyde Power Network Development Centre (PNDC)
    - National Grid real grid deployment
- Develop a control scheme architecture which will allow deployment in the GB system
    - Additional PMUs (especially at EFCC resources)
    - Communications
    - Redundancy
    - Obtaining frequency response services data
- Review measurement availability and data quality, including delays from various components
- Need information on the characteristics of the frequency response services
- Need information on how to share data/control between services and controller(s)
- Planning of scheme deployment, equipment outages, interfaces etc.
- Application tuning based on event review using real measurements – allow for discrepancies between measurements and archival data
- Review of experience, lessons learnt for BaU deployment

Knowledge dissemination

Our academic partners have extensive experience with the development of methods for the measurement of frequency and rate of change of frequency and will support this work as required, either in the form of development of the method or benchmarking of the quality of the method.

WP2 – Assessment of the response of different providers

The control system will instruct response from the selected resources. The selected resources will be trialled to establish their response capabilities and to ensure secure communication with the monitoring and control system.

WP2.1 – DSR

We will demonstrate the use of demand-side technology to provide response. We have engaged Flexitricity as a partner and they will provide access to DSR customers.

RoCoF control

DSR assets capable of RoCoF control are often associated with critical commercial loads such as datacentres, communication and banking sites. Many of these possess equipment capable of disconnecting the site from the distribution network in the event of problems in power quality, and carrying site load using kinetic energy stores or batteries. Such sites should in theory be capable of accepting external signals derived from the EFCC control system and responding extremely quickly.

However, such sites' tolerance for rapid disconnections of this nature will depend on the number of expected events and their anticipated duration. Furthermore, any engineering intervention on sensitive sites must be designed in a highly defensive manner, in order to preserve the continuity of the site's core business activities. This therefore poses technical challenges which EFCC must address.

Certain other less critical site categories may also be able to offer RoCoF control, for example, cooling or pumping sites. While these have a greater tolerance for interruption, their ability to respond in near-instantaneous timescales requires further investigation. For example, sudden shutdown of pumping loads can give rise to surge effects, while disconnection of refrigeration loads can test the limits of expansion vessels. For such loads to participate, these mechanical concerns must be considered.

EFCC will address these issues in the following manner:

- Identifying a small number of real sites with the capability to offer RoCoF control
- Appraising the sites and developing a potential technical approach which should address the specific technical concerns at the sites in question
- Where possible, implementing demonstration installations with the capability to respond to real RoCoF events
- Using the information gained, extrapolating to give a view of the total potential for this type of control in the GB market

Simulated inertia

The class of industrial and commercial load and generator which can offer simulated inertia is very different to that associated with RoCoF control. In this case, continuously-variable power control present on certain electrical loads and generators is the viable resource. These include variable-speed drives on ventilation and certain pumping loads, as well as some continuously-running generators such as landfill gas and CHP.

Again, Flexitricity will seek to identify suitable sites.

Real inertia

Distributed synchronous generators contribute to total system inertia in the same manner as synchronous power stations when running. The total capacity of high load-factor synchronous distributed generators is well in excess of 1GW, and this is the only class of synchronous inertia which is presently growing in capacity in GB. However, owing to the small scale of the individual units, the inertia of such assets is neither measured nor deployed operationally by the system operator. Furthermore, those which are able to respond to electricity prices are more likely to be disconnected at times of low system load, when system inertia is most needed.

Excess capacity

Some embedded generation sites possess excess capacity. For example, a CHP site may, outside the heating season, operate one engine instead of two. The same site could achieve the same heat load by operating two engines, each at reduced output. In doing so, it would double its contribution to system inertia.

Flexitricity will examine the technical and economic implications of re-scheduling generation on a small number of suitable example sites to support system inertia. Where suitable, Flexitricity will operate a trial of inertia-based scheduling in collaboration with site owners and National Grid.

WP2.2 – Large-scale generation

Centrica is our partner for large-scale generation. Two power stations are offered for the project to investigate the types of RoCoF-based response available.

South Humber Bank-2 power station will soon undergo installation of MXL2 gas turbine components – the first such plant (Alstom 13E2) to be fitted with these. The plant will have a much wider operating envelope than previously available, including a much lower Stable Export Level (was 355MW but is now expected to be significantly under 300 MW). It is envisaged that the ability to respond to RoCoF will be available over this new operating envelope.

Langage power station will be the first CCGT in the UK to be fitted with Low Pat Load (LPL) capability. This will dramatically increase the operating envelope of this module, taking the Stable Export Level down from the current 400 MW to a figure significantly under 300 MW. For a 905 MW module this makes it a plant extremely well suited to the changing needs of the power system offering the full range of balancing and ancillary services of three large synchronous generators (two gas turbines and one steam turbine). Like South Humber Bank-2, it is envisaged that the ability to respond to RoCoF will be available over this new operating envelope.

WP2.3 – PV power plant

The MCS will communicate with solar PV resources in order to test and demonstrate response.

Belectric has been selected as the solar PV partner. The company owns a large volume of solar PV generation in the UK and has agreed to provide the necessary resources, depending upon project requirements.

PV power plants only have a limited capacity to provide reserve power, since for economic reasons they are usually operated at the “Maximum Power Point” (MPP) and their reserve provision is limited to times when they produce significant power. Nevertheless in these cases they may be used for negative response, i.e. whenever frequency is too high. An output power curtailment is then possible and shall be demonstrated in accordance with frequency and/or by direct communication with the TNO.

A positive frequency response shall also be realised in this work package by operating the power plant below MPP and reserving the difference to frequency response.

Independent of pure frequency response the PV power plant may be used to provide reactive power to the purpose of voltage stabilisation. This may be done in conjunction with active power provision (out of PV and/or battery) or at times of no active power output (night) highlighting different aspects of reactive power compensation.

Implementing a continuous relation between grid frequency and power (beyond state of the art cut-off-frequency), starting at 50 Hz and upwards (negative frequency response).

A PV power plant will be operated outside the usual MPP, thus realising a possible positive frequency response by providing positive reserve power. This requires an innovative PV power plant model, which is capable of forecasting the MPP power whenever the plant is operated outside of MPP. The difference marks the available reserve power.

Provision of reactive power - especially at night – is currently not an operating scheme of PV power plants. Using this capability will facilitate grid management considerably.

WP2.4 – Storage

Belectric is responsible for investigating response from battery storage.

Renewable power plants do not save "fuel" but lose yield revenue whenever they deliver below their maximum output. They are, therefore, normally run at full power. This is why renewable power plants are usually not preferred to provide frequency response. This opens the field for storage batteries, which are able to compensate for that and provide positive and negative reserve power from a zero power operating point. The combination of renewable power plants and storage is, therefore, an ideal combination, which combines the no-loss-operation of renewable power plants with the reserve power provision of conventional power plants. Furthermore, this combination allows for considerably higher reaction speeds than conventional power plants may provide, up to the simulation of grid inertia at very high reaction speeds.

A Belectric storage battery (EBU 1000) shall be installed in a PV power plant ("Willersey solar farm") and put into operation in frequency control mode. This shall demonstrate the principle operability of a frequency control battery on the electricity network. The inverter used for grid coupling will be a modified PV inverter, thus giving maximum standardisation with PV power plants.

Different reaction speeds (i.e. ramp up and ramp down times) will be implemented into the command and control system of the battery. This shall give physical evidence of which ramp rates are safely achievable without disturbing other response providers on the grid or even inducing oscillations. Corresponding benefits for the TNO due to these high gradients shall be looked at. Tests are to be run with a current-based control mode of the inverter. Power rise times from zero to full power will be in the order of seconds.

In order to emulate rotating generators and their inertia a very high response rate shall be implemented (in the order of milliseconds or tens of milliseconds). In this way a "virtual synchronous machine" will be realized in the command & control system of the battery system. Alternatively a pure voltage regulation – resulting in an inertia-like operation – may also be implemented directly into the inverter as an alternative to the initial experiments.

The combination of different response providers and their characteristics with each other shall be assessed during this work package. The permanent availability of the battery will be secured by substituting it with other response providers on a slower timescale, thus making sure the state of charge (SoC) of the battery will not fall below a certain limit (the battery will be operated between 40% and 100% SoC, having a preferred SoC of 70%).

A direct connection to an external entity i.e. the TNO shall be established, so definition of working points, response statics or direct command and control may be done from a central point outside.

Analysis and testing of inverter behavior between 49.8 and 49.2 Hz will be carried out.

Procedures to practically measure and financially account for energy input/output from a PV plant combined with storage need to be agreed and practically tested.

This is the first time that a battery will be used as a standalone frequency response unit in Great Britain. The realization will be done with modified PV inverters and a specially adapted battery, giving it a very good perspective from the cost side. The inverter will be modified, so – unusually for PV inverters – high power gradients are possible. Compared to all other reserve power providers the battery will provide the highest possible power increase rate.

WP2.5 – Wind

We have engaged Centrica as our partner for wind farms.

Three wind farms are under consideration for this project: Lincs and Lynn or Inner Dowsing.

Lincs is a 270 MW windfarm consisting of seventy five 3.6MW Siemens WTGs. It is currently one BMU but after OFTO transition it will become two BMUs. It is currently controlled by two High Performance Park Pilot (HPPP) controllers and this will continue post OFTO transition.

Lynn and Inner Dowsing are two identical 90 MW windfarms, side by side, each consisting of twenty seven 3.6 MW Siemens WTGs.

Using Lincs plus one of Lynn and Inner Dowsing will give the project exposure to a large, BMU (Lincs) and also a smaller, DNO-connected wind farm (Lynn or Inner Dowsing).

Each site will require modification to the HPPP, working with Siemens as OEM, and these modifications will require logic to cope with issues such as whether the RoCoF initiated response is in addition to or instead of conventional response and how the plant will behave under prolonged frequency instability conditions. Engineering assessment will be required to determine the impact upon drivetrain equipment and the impact of the additional workload this will place on the WTG power convertors.

WP3 – Optimisation

The response provided will be optimised. EFCC will trial the coordination of different response resources in order to provide the optimal response.

Our academic partners will assist with this work package. They will provide a wide variety of valuable system studies, using both PowerFactory and the Manchester RTDS, of a power system with the new technologies and controller models included (as provided by the partners) to aid in the proper coordination of the disparate technologies. These studies would need to reflect the importance of providing a smooth response and protecting against the threat of improper coordination or failed instructions form creating a second, and possibly more threatening, disturbance. *Monte Carlo simulations*, to capture the impact of uncertainties on the performance/stability of the control system, would be a necessity.

PowerFactory simulations will be used to study the regional variations in ROCOF for low/variable inertia systems. This will inform the selection of measurement locations and the regions that the supervisory control scheme will separate the system into. A potential threat to successful regional control in the low carbon future may be the variations in the geographic location of power generation and the distinct differences between the generation technologies, e.g. the power supplied to one area may at one time primarily be supplied from the west by Nuclear and gas generation (making it a strong area closely coupled to the west) and at another from the east by wind (making it a weak area closely coupled to the East). This may cause the regions that present similar frequency behaviour, and as such will be suitable control regions, to vary throughout the day.

WP4 – Validation

Anticipated results and simulated performance will be validated using flexible hardware in the loop (HiL) testing facilities (the largest UK RTDS at Manchester) and the Power Networks Demonstration Centre (PNDC) in Glasgow, and field trials at selected locations.

The Manchester RTDS provides the ability to set up simulations, control, and modify system parameters during a simulation, data acquisition, and result analysis. Using the Manchester RTDS, a full range of different HiL testing relevant for the EFCC project can be undertaken. As a part of the Manchester testing facilities, a sufficient number of precise voltage and current amplifiers will be available. The National Instrument Compact-RIO platform for specific tasks (e.g. data acquisition and further data processing using LabView environment) is a standard kit available for different types of testing.

The PNDC, a £12.5m facility at Strathclyde, allows transients (frequency, voltage, unbalance, short circuits, etc.) to be emulated in a primary HiL environment using a 1 MW motor-generator set and controllable load banks. The PNDC can be used to evaluate the performance of wide-area and local control functions capable of providing improved frequency responses from generation, storage (including pumped storage), DSR (Demand Side Response) and HVDC interconnectors. It has been designed to allow the connection of additional primary and secondary equipment to facilitate rapid and comprehensive demonstration and testing. A number of pre-defined standard disturbances/frequency/RoCoF scenarios will be defined and "replayed" through the HiL and PNDC to investigate the performance of the wide-are instruction scheme and of the responses of individual devices.

The universities have extensive experience with low frequency demand response schemes and the wide variety of such schemes that are presented in the literature. A range of simulations can be performed in PowerFactory (and where necessary using the Manchester RTDS) in an attempt to benchmark these schemes (including the existing National Grid scheme) and the proposed scheme for a variety of operating scenarios. This would provide some insight into the value offered, in terms of improved frequency control, by the complexity involved in the proposed RoCoF based, adaptive, regional supervisory control scheme.

WP5 – Dissemination

Results and learning from the project will be disseminated to interested parties.

Further, detailed information is found on this in Section 5.

WP6 – Commercial

A balancing service market, and the value of the response, will be assessed and defined.

This stage will be based on collaboration between National Grid, our partners and wider stakeholders. National Grid and our academic partners have experience of assessing the economic value of the services available to a power system operator.

Electricity Network Innovation Competition Full Submission Pro-forma

Appendix 6: CBA

A6.1 Frequency Response Cost

National Grid incurs costs in managing system frequency. These costs are made up of a Holding Payment (£/MWh), and a Response Energy Payment (£/MWh).

The level of response required varies depending on a number of key factors such as:

A. Demand level
B. Amount and type of generation running on the system
   - This influences the level of inertia on the system and also the ramp rate amongst the running generation fleet
C. Size of the largest infeed/outfeed which the system is to be secured against

Figure A6.1 below illustrates the difference in response requirements overnight (settlement periods 47-14) and during the day (settlement periods 15-46). The difference is due to the lower load overnight, which means that any system event will have more of an impact (as a loss will represent a higher percentage of the overall level of load).

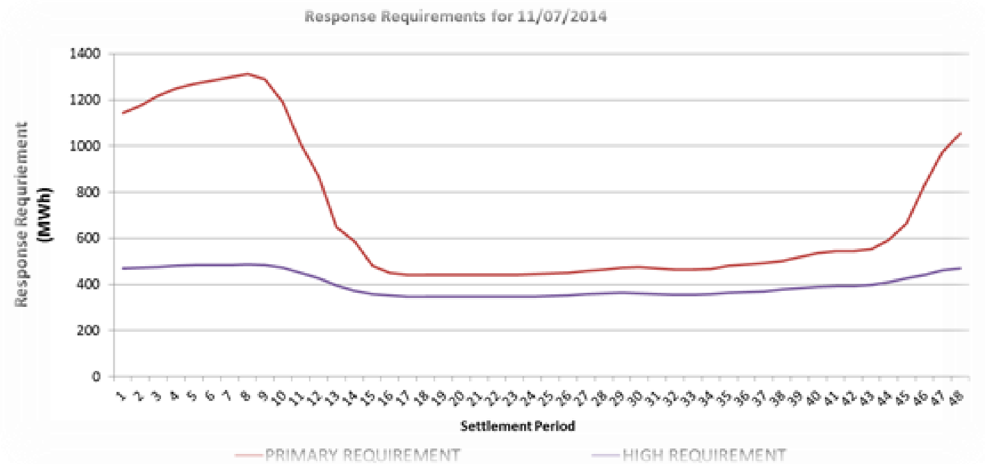
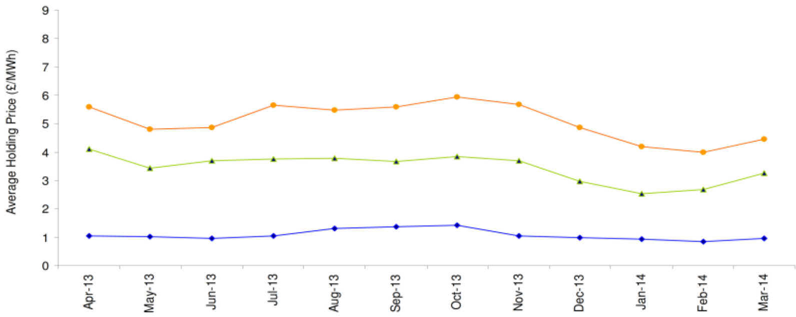


Figure A6.1 - Holding Response Requirement for a Typical Day (11th July 2014)

Figure A6.2 below illustrates the average holding price for different types of response.



	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14
Primary	4.11	3.44	3.70	3.77	3.80	3.68	3.85	3.69	2.98	2.52	2.67	3.25
Secondary	1.05	1.03	0.95	1.06	1.31	1.37	1.44	1.04	0.98	0.92	0.84	0.96
High	5.58	4.82	4.86	5.64	5.47	5.60	5.95	5.68	4.85	4.20	3.98	4.46

Figure A6.2 - Frequency Response Average Holding Price - April 2013-March 204

We have explained in Section 2, Project Description, and Appendix 5, Detailed Project Description, that system inertia is reducing and managing system frequency is therefore becoming more difficult. Under these conditions National Grid has three options:

1. Curtail the largest infeed/outfeed so the volume of holding response stays the same.
2. Constrain ON Synchronous Generator to increase the level of inertia
3. Increase the volume of holding response, so the largest infeed/outfeed is not constrained.

This section describes the methodology for calculating the costs indicated in Section 3, Business Case.

A6.2 Future Response Requirement

The future volume of response requirement is calculated based on future generation dispatch using the information available in National Grid's Future Energy Scenarios (FES). To calculate the volume of response required in a particular year (or % of time that the volume of response greater than xMW/s is required – "x" being the speed of response for each case) a future generation dispatch model enabling half-hourly inertia and response calculations has been developed. To validate this model, it has been compared against the 2013/14 actual generation dispatch and volume of response carried.

Figure A6.3 shows the process of calculating the future frequency response requirement.

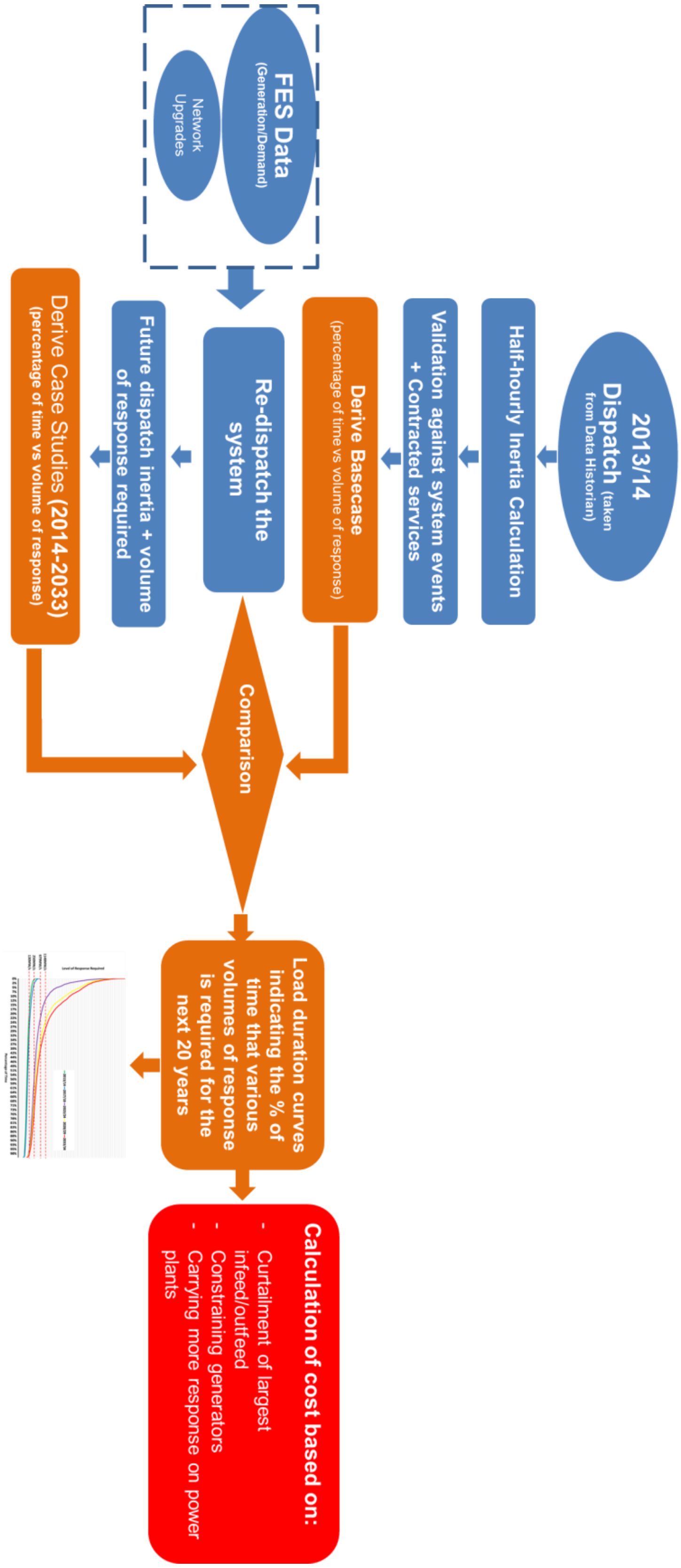


Figure A6.3 – Future Response Cost Calculation Methodology

The key information required to calculate the future cost of controlling system frequency can be derived from the process explained above.

Figure A6.4 shows the percentage of time various response levels will be required over the next 20 years. For example, a response level of 1148MW/s is not required at all until 2023/24, but by 2033/34 it is required over 27% of the time.

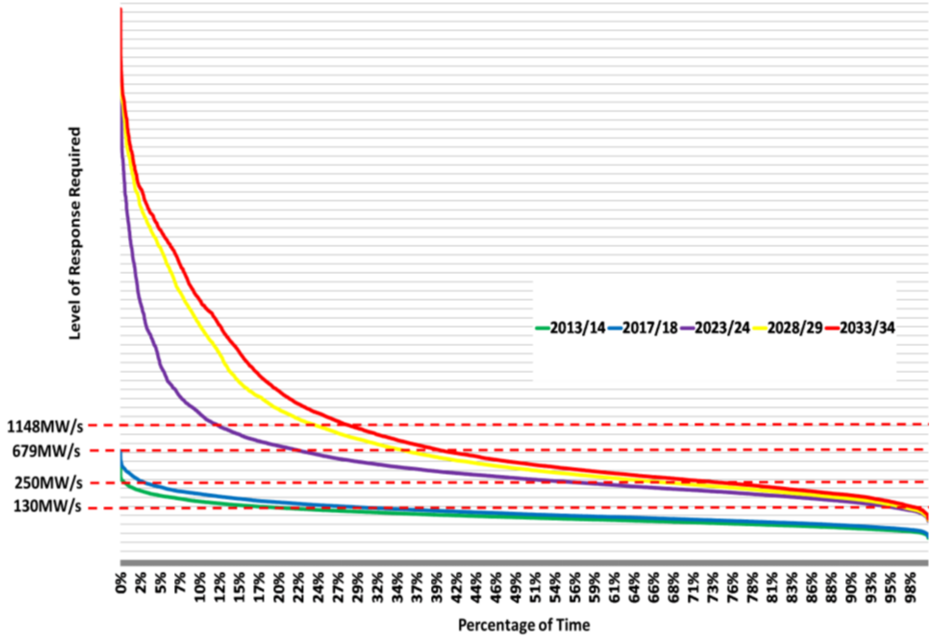


Figure A6.4 - Load Duration Curves showing the volume of response required for the next 20 years

There are three potential **business as usual approaches** to dealing with low system inertia and the resultant requirement for high volumes of response:

- Option (a) Curtailment of largest in-feed/out-feed;
- Option (b) Constraining generators (i.e. synchronise more generators to increase the level of inertia); or
- Option (c) Increase in volume of holding response.

The optimum cost has been calculated based on using the following cost figures, and ability to perform such actions (i.e. percentage of time that limiting flow across the interconnectors may be possible).

To calculate the overall cost, the following £/MWh costs were assumed:

1. For interconnector curtailment, the curtailment cost was assumed at £20/MWh (in either direction)
2. To curtail a large in-feed loss (other than interconnector) which was a CCGT a flat rate figure of £150/MWh
3. To curtail a large nuclear unit, was £2,000/MWh (based on confidential contractual discussions with a generator company) -> This was never exercised
4. To constrain ON additional synchronous unit, the cost was assumed at £150/MWh (to increase system inertia)

EFCC will establish a market mechanism for non-traditional response. After the capabilities of these technologies have been proved, other players will be able to enter the market. There will be no requirement for National Grid to roll out the project further.

A6.2.1 Option (a) – Curtailment of largest in-feed/out-feed cost

Purpose: lowering the size of loss, and therefore slowing down the rate of change of frequency. The costs associated with this are calculated based on the ability to trade across the interconnectors, and availability of constraining the synchronous power plants (if they were in the merit and shown as the largest in-feed).

All Costs £m (2013/14 prices)								
Year		2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Total Cost (additional cost incurred)					115	117	131	268
Implementation Cost								
EFCC (Total)	Cost	0.116	4.84	2.71	1.92			
Cumulative Implementation Cost		0.116	4.95	7.66	9.6	9.6	9.6	9.6
Savings								
When implementation in 2018					105.2	107.2	121.2	258.2

Table A6.1 - Additional Cost of Frequency Control for option (a) and savings which EFCC can bring

A6.2.2 Option (b) – Constraining ON Synchronous Generator to increase the level of inertia

Purpose: By increasing the level of system inertia, the rate of change of frequency will be slower. The costs associated with this option are calculated based on the extra payments to synchronous generator to stay synchronised for the number of hours the service is required. The associated costs for option (b) are shown in Table A6.5.

All Costs £m (2013/14 prices)								
Year		2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Constraining ON Synchronous Machines								
Percentage of Time Service Required					30%	38%	46%	54%
Number of Hours (per year)					2597	3300	4002	4705
Estimated Cost					390	495	600	706
Implementation Cost								
EFCC (Total)	Cost	0.116	4.84	2.71	1.92			
	Cumulative Implementation Cost	0.116	4.95	7.66	9.6	9.6	9.6	9.6

Savings				
When implementation in 2018	380	485	590	696

Table A6.2 - Additional Cost of Frequency Control for option (b) and savings which EFCC can bring

A6.2.3 Option (c) – Increasing the volume of holding response

Purpose: By increasing the volume of holding response, the system will have the capability of containing the frequency, following an in-feed/out-feed loss when the inertia of the system is low. This will have two major impacts:

a. Increase cost of primary and high frequency response
b. Potential reduction of volume of secondary response requirement

As shown below, the increase in costs of primary and high response is much greater than the reduction of secondary response requirement.

All Costs £m (2013/14 prices)								
Year		2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Increasing the Volume of Response								
Percentage of Time Service Required					30%	38%	46%	54%
Number of Hours					2597	3300	4002	4705
Estimated Cost					154	184	210	224
Implementation Cost								
EFCC (Total)	Cost	0.116	4.84	2.71	1.92			
	Cumulative Implementation Cost	0.116	4.95	7.66	9.6	9.6	9.6	9.6
Savings								
When implementation in 2018					144.4	174.4	200.4	214.4

Table A6.3 - Additional Cost of Frequency Control for option (c) and savings which EFCC can bring

A6.3 Summary of Costs of EFCC

Table A6.4 below presents the costs of EFCC broken down by work package and year.

	WP1	WP2.1	WP2.2	WP2.3	WP2.4	WP2.5	WP3	WP4	WP5	WP6	Total (£k)
Y1	117										**117**
Y2	1,170	1,011	259	277	777	577	60	449	207	58	**4,845**
Y3	516	914	75	193	270	75	94	268	233	80	**2,717**
Y4	587	104	75	75	283	75	90	268	256	112	**1,926**
	2,390	**2,029**	**410**	**544**	**1,329**	**727**	**244**	**984**	**696**	**249**	**9,603**

Table A6.4 – Summary of EFCC costs by work package and year

Project Code/Version No:
NGETEN03/V1

Electricity Network Innovation Competition Full Submission Pro-forma

Appendix 7: Organogram of the Project and Description of Partners

This Appendix provides more information of the partners of the project and their relation to the project.

A7.1 Organogram

Figure A7-1 below shows a high level organogram of the EFCC project.

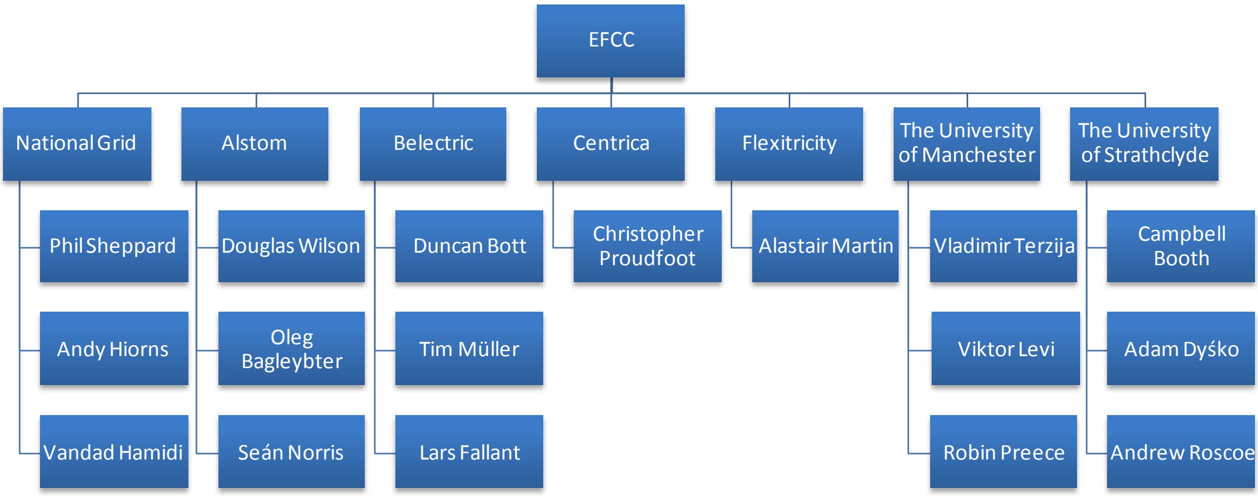


Figure A7-1 EFCC High Level Organogram

A7.2 Members of the team

The following section provides a short description of all the people involved in the EFCC project.

Phil Sheppard is Head of Network Strategy, accountable for ensuring the long operability of the Gas and Electricity Transmission Networks. This includes identifying the need for future transmission reinforcements to meet capacity requirements under a range of scenarios, the changing characteristics of supply and demand, potential regulatory and commercial options and that the delivered solutions are co-ordinated, economic and efficient. He has extensive knowledge of the industry, including various roles in the Electricity National Control Centre, as Head of Business Development in a National Grid smart metering subsidiary and in project development and delivery. He was project manager for the first re-locatable SVCs, a GTO SVC as well as wider business development projects, such as building a national telecoms network in Poland. Phil is currently chairing the Energy Research Partnership Smart Grids working group.

Andy Hiorns is Electricity Network Development Manager responsible for developing vision and direction for future electricity networks in National Grid. He has over 40 years of experience in the electricity industry and brings an in depth knowledge of power system. In his most recent role, he was the project director of Western HVDC project resulting in the most pioneering solution developed for design of a new 2.2GW link between Scotland to England. Andy has led the development of Network Development Policy (NDP) ensuring the most economic and efficient solutions for network investment.

Dr. Vandad Hamidi is the SMARTer System Performance Manager responsible for developing the advanced, tools and techniques enabling the most economic and efficient design and operation of the electricity transmission system. He received a Ph.D in power systems and was awarded the Royal Academy of Engineering (RAEng) prize for his project on Demand Side Response in 2008. He has extensive experience of control system design, and power system modelling and has managed number of front-end onshore and offshore electrical system design projects in Europe and North America. In his current role, he has developed National Grid’s System Operability Framework (SOF); ensuring future operability of the GB transmission system, and represents National Grid in Smart Grid Forum.

Ben Marshall is a Technical Specialist in Power System Analysis, specialising in areas of dynamic system and controller stability, code and standard application in design and specification, areas which he has some 17 years of experience of working on within National Grid since joining National Grid in 1996. Ben supported the design, inception and implementation of the first reactive power markets, and the review of Security Standards integrating operational approach following the establishment of the GBSO, and has further supported the contracting and analysis of Frequency response services contracted on the GB transmission system. He has, since 2001 supported Technical compliance liaison and incident investigations associated with both thermal and wind connections including those aspects associated with both frequency response and Fault-ride-through pertinent to the EFCC project.

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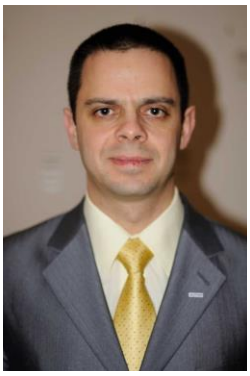
Dr Douglas Wilson is Chief Technology Officer for Psymetrix Ltd, an Alstom company. He has worked with Psymetrix since 1998, and was involved in developing and deploying the world's first continuous oscillation monitoring system, which has been operational in the GB system for 15 years. He has been involved in synchrophasor measurement systems and applications since 2005, with emphasis on the application of the technology in real-time operational systems, dynamics analysis and control, control system tuning, and renewable generation connections.

Douglas is involved in R&D, consulting and in commercial application of synchrophasor technology.



Dr Oleg Bagleybter is R&D and Engineering Manager at Alstom-Psymetrix based in Edinburgh, UK. Oleg has 8 years of utility experience (Power System Protection), 2 years in design and commissioning of protection systems (Senior Application Expert), 2 years in marketing (Product Manager for Protection and Control devices). Oleg's areas of expertise include protection and control of power systems, digital signal processing, development of protection and control algorithms, system stability calculations and wide-area protection schemes, power quality analysis, electromagnetic and electromechanical transients.

Dr Seán Norris is a Power System Engineer for Alstom-Psymetrix based in Edinburgh, UK. He graduated from University College Cork, Ireland with a B.Eng (first class honours) in 2009 and has completed a PhD from Durham University, UK. His research work was based on wide-area protection systems, power system stability and operation under emergency conditions. Seán has experience as a post-doctoral researcher in the areas of electromechanical oscillations and parameter estimation of dynamic models as well renewable generation capacity studies. He is also author on about 10 technical papers to date.

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Duncan Bott has been working in the Renewable Energy sector for over 10 years, and has extensive knowledge and experience across a wide spectrum of low carbon technologies, from hydrogen & fuel cells to solar photovoltaic and smart grid technologies. Duncan co-founded Belectric UK in 2010 which has now become a UK solar market leader, developing and constructing solar power plants to produce the equivalent electricity used by approximately 20,000 UK homes per year.

Tim Müller is the CEO of Adensis GmbH, the strategic R&D-company of BELECTRIC. At the same time he heads the R&D division inside of BELECTRIC. He holds a degree in physics and graduated in 2005 from Humboldt University in Berlin. Tim Müller started his career as a scientist studying high voltage impulse technology in a Daimler financed research project, which focused on engine technology. He came to BELECTRIC in 2006 and was responsible for the buildup of the entire R&D division. He established a power engineering group and a high voltage research laboratory as well as group for embedded design and for physical/electron-optical analysis. Starting in 2010 he introduced hybridized systems to BELECTRIC, focusing on future solar power plants which combine fossil generation and batteries. He is currently heading a staff of 70 people.

Dipl. Ing Lars Fallant is the Project leader of Hybrid Systems in the BELECTRIC R&D Division. He is heading a workgroup of 14 people. The main areas of work are: Prototyping MW-scale battery systems and developing new regulation systems for grid stability. During studies at the "Technische Universität Dresden" he specialized in electrochemistry and mechanical engineering. His specialties are battery systems and power grids.

Before he worked at BELETRIC, he worked for several research institutions, like Fraunhofer IKTS, Fraunhofer IWS or Leibniz-Institut IPF. The areas of work were: fuel cell systems and laser technology.

Electricity Network Innovation Competition Full Submission Pro-forma

Christopher Proudfoot graduated from Strathclyde University in 1989 and has worked in the UK Electricity Supply Industry ever since! He worked for National Grid for 18 years in a number of operational roles, including ten years in their regional and national control rooms. He has worked for Centrica for the last 7 years and is presently responsible for the day to day despatch of a portfolio consisting of over 4 GW of CCGT and nearly 1 GW of wind, as well as a 20% stake in all nuclear output in the UK. He is an active member of a number of industry forums and was appointed to the ACER Expert Balancing Group in 2011. He is a chartered electrical engineer, as well as graduating from Henley Management College with a MBA in 2006. His area of expertise is in the technical and commercial interaction between generators and the power system.

Dr Alastair Martin is the Founder and Chief Strategy Officer of Flexitricity. Dr Alastair Martin is a professional energy engineer with 22 years of experience in the energy industries, ranging from gigawatt-scale coal and nuclear power stations, through industrial energy efficiency, to small wind, solar, biomass and hydro generators.

In 2004, Alastair founded Martin Energy Ltd, now Flexitricity Limited, after formulating the core Flexitricity concepts of aggregated load management and flexible generation. He previously worked at Scottish Water, Doosan Babcock, Heriot-Watt University and the University of Edinburgh.

Alastair graduated from the University of Edinburgh in 1992 in electrical and mechanical engineering. He completed his PhD in offshore engineering in 1997, also at the University of Edinburgh. He has been a chartered engineer and a member of the Institution of Mechanical Engineers since 2000.

The University of Manchester

Prof Vladimir Terzija holds an EPSRC Chair in Power System Engineering at The University of Manchester and is a Humboldt Research Fellow. Over six years, he was with ABB, Germany, working as an expert in switchgear, protection and distribution automation. Terzija leads many research projects. Terzija is also PI of several industry funded projects addressing the issues of power system protection, fault detection and location, System Integrity Protection Schemes and prevention of system blackouts. He is the key academic involved in the NIC VISOR project (total value £7.4million), which started in April 2014. He is the convener of Cigré WG B5.14 on "Wide area protection and control technologies" and a member of several other Cigré and IEEE Working Groups and Task Forces. Terzija has published over 300 technical papers.

Dr Victor Levi has both long-term industrial experience working for the UK distribution companies and long-term university experience. Dr Levi has spent many years developing methodologies for planning of distribution and transmission networks, and then practically applying various planning concept in day-to-day business within distribution companies. He has wide experience in strategic and development planning of distribution networks, such as, network modelling including LCTs, load forecasting, loadflow, security analyses and assessment of compliance with planning standards, voltage-VAR, fault level, harmonics and transient stability studies, frequency response studies, risk/reliability analysis, use-of-system pricing and cost analysis. Dr Levi is the PI on the recently awarded project 'Distribution System 2030' by ENA and he is one of the invited academics delivering the IET 'Power Network Joint Vision' project. He has published a book on power system planning and 80+ relevant papers in the leading international journals.

Dr Robin Preece is a Lecturer in Future Power Systems at the University of Manchester with expertise in modelling complex mixed AC/DC networks, risk analysis in uncertain systems, and dynamic power system analysis. His research focuses on the understanding of system uncertainties and their impact on the stability and control of mixed AC/DC transmission systems and quantifying the risks associated with system instability. Robin has experience working at, and consulting with, DNOs and TSOs on individual projects and collaborative work coordinated by Ofgem and the Energy Networks Association. He is a member of Cigre Working Group B4.64 which is actively investigating the effects of AC network stability and dynamic performance on connected HVDC systems. In 2013, his PhD Thesis was recognised as outstanding and published by Springer as part of the Springer Thesis Prize. Robin has more than 20 international publications and has spoken at the leading power system conferences around the world

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University of Strathclyde Glasgow

Dr Campbell Booth is presently a Reader in the Electronic and Electrical Engineering department at the University of Strathclyde in Scotland. He leads the development, teaching and assessment of power engineering classes and has built a portfolio of research in the areas of power system protection, control and monitoring, working with government and industrial funding partners. He leads the technical team of the Power Network Demonstration Centre (PNDC), a £12.5M smart grid demonstration facility that opened early in 2014, and is responsible for the supervision of a team of 12 post-doctoral and PhD candidates.

Many of his projects involve prototyping, real time simulation and laboratory demonstration, which is increasingly including activities at the PNDC.

Dr Adam Dyśko has been with the Strathclyde since 1994, first as a PhD student, then as a research fellow, and finally as a member of academic staff. Since 2007 he has been a lecturer in the Department of Electronic and Electrical Engineering. His research activities focus on unconventional power system protection methods for transmission and distribution networks of the future.

His research activities often inform the on-going revision of the engineering recommendations and grid codes in order ensure safe operation of the power system under the envisaged high renewable energy scenarios. He also provides technical expertise and research support to industrial working groups and organisations such as Grid Code Review Panel (GCRP), Distribution Code Review Panel (DCRP) and Energy Networks Association (ENA). He actively participates in the activities of international engineering organisations such as CIGRE, IET and IEEE. He has published widely in peer reviewed journals and presented regularly at the leading international conferences.

Dr Andrew Roscoe is the lecturer in Smart Grid Integration at the Department of Electronic and Electrical Engineering, Strathclyde University. His active research interests include:

- Inverter control algorithms within microgrids, marine/aero power systems, and future power systems for 2020-2050 with increasing amounts of inverter-connected equipment.
- The provision of inertia and first-swing stability from renewables, converter-connected devices and HVDC links.
- Interactions of converter-connected devices and HVDC links with AC power quality, faults, DC bus ripple, energy storage, prime movers and inertia, and dynamic power-sharing with other power sources.

Andrew is a member of the IET (Chartered CEng since 1996), IEEE, IEEE PES, and IEEE Standards Association. He has published widely in peer reviewed journals and presented at the leading international conferences.

Appendix 8

National Grid House
Warwick Technology Park
Gallows Hill, Warwick
CV34 6DA

Ms Rhianne Ogilvie
Ofgem
Distribution Policy
5th Floor
9 Millbank
London
SW1P 3GE

Mike Calviou
Director, Transmission Network Service
UK Transmission

mike.calviou@nationalgrid.com

24 July 2014

www.nationalgrid.com

Dear Rhianne

Network Innovation Competition – Enhanced Frequency Control Capability (EFCC)

National Grid Electricity Transmission (NGET) as the system operator the GB power system, welcomes the opportunity for the 2nd year to engage in the RIIO Network Innovation Competition.

Many low carbon generation technologies connect to the distribution or transmission system using power electronics. This type of connection does not contribute to system inertia in the same way that large synchronous generators directly connected to the system do. As the level of renewable generation increases, reducing the inertia of the system, the frequency of the system is becoming much more sensitive to events such as a loss of demand or generation. The current approach to frequency management will become increasingly ineffective and expensive. This project will consider alternative technical solutions that may offer more effective strategies in managing a more dynamic frequency. These range from new generation types, transmission and distribution connected as well as demand side and storage solutions. These trials will allow the identification of effective strategies to manage the reduction in inertia and allow new commercial products to be developed.

NGET has worked with a number of key partners in developing this project to ensure the range of activities and solutions are appropriately supported by those best placed to do so. Further partners may join the project as each stage is entered in to depending on the outcome of the previous stage assessment. NGET is committed to leading this project with the appropriate resource and expertise to assess the opportunities to provide secure, economic and efficient measures to manage the reduction in system inertia and the resulting greater dynamic frequency.

Yours sincerely

Mike Calviou
Director, Transmission Network Service
UK Transmission

GRID
Network Management Solutions

ALSTOM

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Edinburgh, EH3 5DA, United Kingdom
Phone: + 44 (0) 131 510 0700
www.alstom.com/grid www.psymetrix.com

Date: 19 June, 2014
Your Ref:
Our Ref: Psy-L140619-NGRID-NICpartners-v01A
Direct Dial: 0131 510 0703
Email: douglas.wilson@alstom.com

Dr Vandad Hamidi
SMARTer System Performance Manager – Transmission Network Services
National Grid
National Grid House, C3
Warwick, CV34 6DA, UK

Dear Vandad,

Alstom Partnership in Enhanced Frequency Control Capability (EFCC) NIC Project

We are very pleased to accept your invitation to participate in the EFCC project as partners. We see this as a strategic project with value in the UK and internationally, and we look forward to participating with you in the design, development and demonstration of the wide-area control scheme that facilitates the EFCC services.

We look forward to the collaboration with National Grid to prepare the NIC submission to Ofgem, and beyond this, to the delivery of the project.

Best regards,

Dr Douglas Wilson
Chief Scientist, Psymetrix/Alstom

PSYMETRIX
AN ALSTOM COMPANY

Appendix 8

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Intelligent Solar Solutions

BELECTRIC Solar Limited
Thorney Weir House,
Thorney Mill Lane,
Iver,
SL0 9AQ
20/06/2014

Ref. Electric Network Innovation Competition- Full Submission Pro Forma

Dear Dr. Vandad Hamidi,

I hereby confirm that BELECTRIC Solar Limited will be acting as partner on the project titled 'Enhanced Frequency Control Capability' as part of the Electric Network Innovation Competition led by the National Grid.

I welcome any questions or queries you may have.

Yours sincerely,

Duncan Bott,
Managing Director
BELECTRIC Solar Limited

Duncan.bott@belectric.co.uk
01895 452 640
07812 817 177

University of Strathclyde Engineering

Dr Vandad Hamidi
SMARTer System Performance Manager – Transmission Network Services
National Grid
National Grid House, C3, Warwick, CV34 6DA, UK

22 July 2014

Dear Dr Hamidi,

I have been informed by Dr Campbell Booth that the University of Strathclyde is acting with the University of Manchester in the preparation of the NIC EFCC £10.3M project proposal.

After learning the specific project details, which I consider as an impressive attempt to contribute to a more efficient system operation in the future, I am delighted to inform you that the University of Strathclyde will provide use of our RTDS facilities, our fully programmable inverter, preparation time at PNDC, plus access to CDT PhD students that will work on related activities, all of which provides an in-kind level of support of £150k.

I am particularly pleased to see a intensive involvement of the academic partners in extensive and novel system studies, validation and testing of the new monitoring and control scheme, strong involvement in the risk assessment of the proposed scheme, as well as assistance in dissemination and with the commercialisation of the scheme.

I wish you success in your attempts to get the EFCC project proposal approved from Ofgem and look forward to collaborating with your Consortium.

Yours sincerely,

Professor Stephen McArthur,
Head of Department

Department of Electronic and Electrical Engineering

University of Strathclyde

Appendix 8

MANCHESTER
1824

The University
of Manchester

Prof A Brown
Head of School
School of Electrical and
Electronic Engineering
The University of Manchester
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www.manchester.ac.uk

Vandad Hamidi (MEng, PhD, CEng, MIET, MIEEE)
SMARTer System Performance Manager – Transmission Network Services
nationalgrid
National Grid House, C3, Warwick, CV34 6DA, UK
(M) +44 (0)7962 827267
Vandad.Hamidi@nationalgrid.com

23 July 2014

Dear Dr Hamidi,

I was informed from Prof Vladimir Terzija that The University of Manchester is acting as the leading academic partner, jointly with Strathclyde, in the preparation of the NIC EFCC £10.3M project proposal.

After learning the specific project details and the list of Work Packages, which I consider as an impressive attempt to contribute to a more efficient system operation, I am delighted to inform you that The University of Manchester is happy to provide an in-kind EFCC project support in the scale of **£100k**. This means, that our brand new hardware in the loop facilities (The Manchester RTDS), laboratory space and technicians will be offered for free.

I was particularly pleased to see a very intensive involvement of the academic partners in extensive and novel system studies, validation and testing of the new monitoring and control scheme, strong involvement in the risk assessment of the proposed scheme, as well as dissemination and commercialization of the new scheme.

I wish you a success in your attempts to get the EFCC project proposal approved from Ofgem and look forward to collaborating with your Consortium.

Yours sincerely

Prof Tony Brown,
Head of School

Prof A Brown, Head of School
School of Electrical and Electronic
Engineering
0161 306 4703
0161 306 4820

flexitricity
Unlocking smart grid revenue

Exchange Tower
19 Canning Street
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t: 0131 221 8100
f: 0131 629 9375
w: www.flexitricity.com

17th July 2014

Dear Vandad

Subject: Network Innovation Competition (NIC): Enhanced Frequency Control Capability (EFCC)

Thank you for the opportunity to be involved in your EFCC project under the NIC.

In the years over which Flexitricity has been providing Demand Side Response (DSR) services to National Grid, it has become ever clearer that the problems of inertia and frequency control are real, present and growing. In your project, you have identified a range of potential technical approaches which you intend to explore. This is a very pragmatic approach at this stage, as all innovations carry risks, and in the energy industry it is rare that any one technology is sufficient to address a complex challenge such as falling system inertia. I also believe that the innovations identified are well chosen, and I am very pleased that DSR is one of these.

Flexitricity has wide experience of dealing with the industrial and commercial electricity users who will be at the heart of delivering EFCC through DSR. Notwithstanding the technical challenges and risks which we must address, I believe that DSR is capable of providing highly economic EFCC at volumes comparable to the large power stations whose inertia we must look to replace.

I am particularly pleased that the project will include investigation of the commercial approach to EFCC. This is vital to the successful recruitment of electricity customers to a long-term roll-out of EFCC through DSR.

Flexitricity is fully supportive of your project and is proud to be a project partner.

Yours sincerely

Ron Ramage
Chief Executive Officer

Appendix 8

SP ENERGY NETWORKS

Vandad Hamidi
SMARTer System Performance Manager
Transmission Network Services
National Grid
Warwick, England

20th July 2014

Dear Vandad,

Re: National Grid Electricity Transmission plc:
Enhanced Frequency Control Capability (EFCC)

ScottishPower Transmission are pleased to provide this letter of support for your Enhanced Frequency Control Capability (EFCC) project.

ScottishPower, and other transmission licensees alike, have witnessed the unprecedented development of renewable generations in recent years. There are concerns over the stability of future power systems incorporating a reduced amount of conventional synchronous machines, which in turn reduces the system inertia. It is important to address those concerns and ensure that the transmission network development and operation remain efficient and reliable for a low carbon economy.

It is thus important for both network licensees and generation developers that system inertia issues can be resolved with minimal need to restrict operation of generation. However we do recognise the significant challenge of design and implementing an enhanced frequency control capability.

This enhanced frequency control capability (EFCC) project is concerned with identifying the possible corrective control and commercial measures to minimise the system operational costs. An EFCC will enable new types of services, such as rapid frequency response, to be acquired from new service providers. This will bring greater savings for the consumers.

SPT look forward to the successful delivery of this project and the associated knowledge dissemination.

Yours sincerely

David Campbell,

Manager of Future Networks, SP Energy Networks

Ochil House, 10 Technology Avenue, Hamilton International Technology Park, Blantyre G72 0HT
Telephone 0141 614 0008
www.spenergynetworks.com

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Vandad Hamidi
SMARTer System Performance Manager
National Grid
National Grid House, C3,
Warwick,
CV34 6DA,
UK

Thursday, 17th July 2014

Dear Vandad

I appreciate the ongoing engagement with WPD through the development of your NIC projects, South East Smart Grid (SESG) and Enhanced Frequency Control Capability (EFCC). The areas both projects are investigating are forecast to become problematic in the future. Further they are likely to be difficult and costly to solve using conventional methods.

The solutions being investigated will have impacts on both the Distribution Network and Transmission Network and consequently warrant further investigation. Both solutions require careful design and operational coordination between the DNO and TSO to ensure that both networks operate safely and effectively at all times.

If successful in the NIC competition, both Project Solutions could deliver benefits to all GB consumers. I am therefore happy to provide this letter of support and look forward to hearing the outcome in the Autumn.

Yours faithfully

Philip Bale
Innovation and Low Carbon Networks Engineer

Appendix 8

École Polytechnique Fédérale de Lausanne
Distributed Electrical Systems Laboratory
EPFL-STI-DESL-ELL_136, Station 11 CH- 1015 LAUSANNE

Prof. M. Paolone, *Ph.D.*
Tél: +4121 - 693 26 62 Fax: +4121 - 693 46 62
E-mail: Mario.Paolone@epfl.ch , Web: http://desl-pwrs.epfl.ch

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

To:
Vandad Hamidi (MEng, PhD, CEng, MIET, MIEEE)
SMARTer System Performance Manager Transmission
Network Services National grid
National Grid House, C3, Warwick, CV34 6DA, UK
Vandad.Hamidi@nationalgrid.com

Date/place: Lausanne, July 18th, 2014.

Subject: Support letter for the project EFCC – Enhanced Frequency Control Capability.

Dear Dr. Hamidi,
I was pleased to be informed about the project Enhanced Frequency Control Capability and delighted to express my strong support to it.

Before providing an assessment of the EFCC project, I am summarising my competences in the area of the project proposal.
Since 2011, I am Associate Professor at the *Swiss Federal Institute of Technology of Lausanne* (EPFL) and I have the honour to chair the *Distributed Electrical Systems Laboratory* (DESL). The DESL does research on the following topics:

- synthesis of distributed controls protocols for the explicit control of active distribution networks;
- protocols for exploiting demand side management contribution to (primary) ancillary services;
- energy storage modelling planning and control;
- synchrophasors estimation algorithms deployed in Phasor Measurement Units (PMUs) prototypes;
- metrological characterisation of PMUs;
- PMU-based Real-Time State Estimation processes and their deployment;
- real-time voltage/congestion processes in Active Distribution Networks (ADNs) based on PMU-based Real-Time State Estimation;
- experimental deployment of PMU-based monitoring and control systems in ADNs.

In the context of the above research topics, I have provided early research contributions on the definition of a control philosophy called *Composable Method for the Real-Time Control of Active Distribution Networks with Explicit Power Setpoints – COMMELEC*. It has conceived to allow distribution networks, as well as and their resources, to directly communicate with each other in order to define explicit real-time setpoints for active/reactive power absorptions or injections. The proposed protocol aims at performing the explicit control of power flows and voltage, combined with a recursive abstraction framework.
Concerning the subject of demand side management, I have recently contributed on the definition of a low-overhead decentralized demand response control mechanism called *Grid Explicit Congestion Notification – GECN* intended for deployment by distribution network operators to provide ancillary services to the grid by a seamless control of a large population of elastic appliances.

On the subject of energy storage, I have recently published contributions on the improvement of circuit-based models of electrochemical storage systems composed by supercapacitors or Lithium-based batteries. Further, my laboratory has recently proposed optimal planning approaches of distributed storage systems in order to provide short-term alternatives to distribution network reinforcement in presence of massive penetration of stochastic generation resources. In particular, the proposed approach accounts for: network voltage deviations; feeders/lines congestions; network losses; cost of supplying loads (from external grid or local producers) together with the cost of storage systems investment/maintenance; load curtailment; and stochasticity of loads and renewables productions. A convex formulation of an AC optimal power flow problem is used to define a Mixed Integer Second-Order Cone Programming problem to optimally site and size the distributed energy systems in the network.
About the subject related to the synchrophasors estimation, I developed the one the first PMU specifically designed for ADNs. The innovation came from a dedicated synchrophasor estimation process that, for the first time, was able to perform measurements of synchrophasors with parts-per-millions accuracy levels irrespective of the signal dynamics and distortion. This process, and its deployment into a dedicated device, opened a new way to operate these ADNs by integrating monitoring, protection and control functionalities, which is an essential step for the massive deployment of distributed energy sources in ADNs.
These devices have been further used for a number of ADN Real-Time applications ranging from optimal voltage control to line congestion management. The technologies developed by my laboratory are currently deployed into a number of industrial-related projects associated to PMU-based monitoring systems.

Concerning the *project assessment*, I carefully went through the proposal finding it extremely timely and scientifically sound. The technological developments are well focused and described in detail. Additionally, the theoretical and validation activities appear well cross-linked and making use of up-to-date real time simulation infrastructures.
In this respect, I would like to mention that the proposed project would definitely make available modern tools to the network operators that would potentially enable the development of new tools to ensure secure system operation in future grids with increased number of renewable energy resources and in general reduced system inertia. At the same time the project, will make available advanced metering assets for the acquisition of critical data and to design novel monitoring and control scheme for providing enhanced frequency control capabilities. Particularly interesting is also the validation of the project outcomes that will make use of an up-to-date real-time simulation facility that will enable the possibility to study scenarios with a significant level of complexity and time-related constraints.

In view of the above, I fully endorse the EFCC project.

Sincerely yours,

Mario Paolone

Prof. Mario Paolone, PhD
Chair of the EPFL Distributed Electrical Systems Laboratory

Appendix 8

technische universität dortmund

Fakultät für Elektrotechnik
und Informationstechnik

Institut für Energiesysteme,
Energieeffizienz und
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EFCC Consortium

Diktatzeichen	Aktenzeichen	Ort	Datum	Dienstgebäude/Raum
		Dortmund	21.07.2014	BCI-G2-409

Dear Dr. Hamidi

I am very pleased to strongly support your EFCC Consortium in attempts to get the NIC funding from Ofgem. I hope that the funding will be approved and that your Consortium will deliver the proposed deliverables. This would be a massive success and a precious example for other Transmission Network Owners in Europe and worldwide. Furthermore, the EFCC project is in line of the Horizon 2020 agenda, what is a proof that you are working on a timely and important topic.

Based on the project description, from which I could learn that you plan to design a new control strategy to monitor the system frequency control needs and to use the available service providers to respond quickly enough in systems in which the system inertia is significantly reduced and variable, I am pleased to confirm that I believe that the Consortium consisting of recognized industrial and academic partners will be capable to achieve all proposed targets listed in the project proposal. Your proposal has all key elements to be successful. It starts with system studies, moves forward with hardware in the loop testing type validation and finishes with a trialling stage. Last but not least, it converts the results into the commercial aspects relevant to the business processes in National Grid. From my own experience as Professor and former R&D manager in ABB Switzerland and China, I believe that the topic and approach of the project is very timely and promising. My research activities in the field of electrical power systems and power economics include technologies for network enhancement and congestion relief like stability assessment, wide-area monitoring, protection, and coordinated network-control. Concluding this letter of support, I look forward learning that the EFCC project proposal has been approved and hope that I will be privileged to be updated about the project progress and its final results.

Yours sincerely

C. Rehtanz

Prof. Dr.-Ing. Christian Rehtanz

IDAHO POWER
An IDACORP Company

July 23, 2014

System Planning Engineer
Milorad Papic
Idaho Power Company

To: Vandad Hamidi (MEng, PhD, CEng, MIET, MIEEE)
SMARTer System Performance Manager – Transmission Network Services National Grid
National Grid House, C3, Warwick, CV34 6DA, UK

Subject: Support for the Enhanced Frequency Control Capability (EFCC) project proposal

Dear Dr Hamidi,

I was pleased to be informed that you intend to submit the Enhanced Frequency Control Capability (EFCC) project proposal to Ofgem. Furthermore, I was privileged to be informed about the project details. Thank you for this.

Idaho Power is following the newest developments in modern technology and Smart Grid trends. Our recent projects include a full scale implementation of Phasor Measurement Units for advanced monitoring of power system and hybrid state estimation. We are also increasingly active in the penetration of renewable energy resources and consequently concerned about the issues related to the expected drop of the system inertia. In near future we are planning to investigate the options for implementation of advanced Wide Area Control System based on Synchronized Measurement Technology. Thus, I see a number of reasons to be extremely supportive regarding the EFCC project, which will provide Idaho Power with the critical technical experience which as such will be useful for the operation of Idaho Power.

The EFCC proposal is extremely novel and it targets the technical problems which must be solved in future. If not, as seriously addressed in the project proposal, the customers will overtake the responsibility for high electricity bills. The frequency regulation in power systems with low inertia will be very challenging and expensive, so that I am delighted to learn that National Grid and partners are planning to investigate the options to solve this problem.

In conclusion, I am privileged to express my strong support to National Grid and partners in their attempt to get the EFCC project proposal approved from Ofgem.

Looking forward to receiving a positive response from Ofgem,

Best regards,

Sincerely, M. Papic

Dr. Milorad Papic

1221 W. Idaho St. (83702)
P.O. Box 70
Boise, ID 83707

Appendix 8

July 23, 2014

To:

SMARTer System Performance Manager –
Transmission Network Services
National Grid
National Grid House, C3,
Warwick,
CV34 6DA,
UK

From:

Bryan Gwyn, PhD, CEng
Senior Director Protection Team
USA Main Office
4020 Westchase Boulevard, Suite 300
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Office: +1 508-787-5013
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Re: Letter of Support for the Enhanced Frequency Control Capability (EFCC) Project

Dear Mr. Vandad Hamidi

It is our pleasure to express our interest and support of your Enhanced Frequency Control Capability Project.

Quanta Technology is an expertise-based, independent consulting company providing business and technical expertise to the energy and utility industries. Quanta Technology's client base is well established in North American and in numerous international markets. Our clients include energy delivery utility companies, large industrial companies, energy suppliers, Regional Transmission Operators and Independent System Operators (RTOs/ISOs), and energy industry research and support organizations. We strive to provide an environment that attracts and develops the best energy industry professionals, and attribute our success to our exceptional staff, many of whom are industry leading experts in Smart Grid, Asset Management, System Reliability, Storm Investigation and System Hardening, Sustainable Energy and Workforce Development.

Quanta Technology, LLC is headquartered in Raleigh, NC with offices in Boston, MA; Chicago, IL; Oakland, CA; Toronto, Ontario in Canada and in Guayaquil, Ecuador. It is the independent consulting arm of Quanta Services, headquartered in Houston, TX, (NYSE: PWR), member of the S&P 500, with 2014 revenue of $6.5 billion, the largest specialty engineering constructor in North America, serving energy companies and communication utilities.

In reviewing your Enhanced Frequency Control Capability (EFCC) Project proposal, we believe our extensive experience and expertise in practical large-scale wide-area monitoring, protection and control (WAMPAC) system deployment projects based on synchrophasor technology, and in renewable energy resources integration, energy storage, and demand side management would enable us to provide the much needed support for this project.

To date, Quanta Technology has supported and is still supporting the majority of the large-scale WAMPAC system deployment projects based-on the synchrophasor technology and the implementation of their applications in US, and a number of international WAMPAC system deployment projects (e.g. in Brazil, Ecuador and Colombia). The US projects that we supported, were co-funded through Smart Grid Investment Grants (SGIG) of US Department of Energy accounted for about 70% of the total funding from the US Government. These projects' focus was to achieve increased reliability, wide-area situational awareness and control capability of the electricity grids with growing in complexity from the increased integration of renewable energy sources. A list of our recent projects is listed in the appendix.

We see your EFCC project as an important step in addressing the future power system frequency control needs for a grid integrated with a large amount of renewable energy resources. Reduced power system inertia due to

the integration of the renewable energy resources such as solar and wind will require a much faster detection and control of the frequency changes than that in a power system 10-20 years ago. Synchrophasor technology, with synchronized measurement across entire system and high data rates, has been used in several wide-area protection and control systems (e.g. SCE Centralized Remedial Action Schemes (C-RAS), CENACE's Special Protection System (SPS)), which should be the technological enabler for an enhanced frequency control capability.

In addition, Quanta Technology has a great deal of experience and expertise in using Real-Time Digital Simulator (RTDS) to perform hardware-in-the-loop closed-loop testing and validation of such control system. Our experience has indicated that RTDS testing can help to resolve the majority of issues that would require considerable more time and effort to resolve them in the field, thereby minimizing the risks to the project.

Quanta Technology would welcome the opportunity to be part of the project team, and would provide our full support to the project with our experience and expertise in the relevant areas of the project.

Sincerely yours,

Bryan Gwyn
Senior Director Protection Team
Quanta Technology

CC. David Elizondo, Director - International Business

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Project Code/Version No:

Electricity Network Innovation Competition Full Submission Pro-forma

Appendix 9: Previous Projects

Below we list the various projects National Grid has undertaken that have contributed to developing EFCC project.

1. Assessment of Distributed Generation Behaviour during Frequency Disturbances

Introduction:

The work will provide a comprehensive view of distributed generation types and susceptibility to RoCoF for the entire GB synchronous network. The feasibility and implications of using revised protection settings to avoid coincident distributed generation losses during loss of infeed events will be established.

Objectives:

The key objectives are to reduce operational costs and to enable increased system access for asynchronous generation types including renewable generation (wind, solar).

If measures are not taken to ensure distributed generation is less susceptible to RoCoF events, then increased operating costs are likely to result through the curtailment of large infeed risks or the operation of synchronous generation in favour of asynchronous generation to manage RoCoF risks. Potential increases in system operating costs by 2018/19 are forecast to be £250m per annum, rising to in excess of £1000m per annum by 2025.

2. Demonstration of Distributed Demand Side Management as a Service to the UK Grid Operator

Introduction:

Improve demand side management technology to allow the commercial building demand in particular air conditioning load to be effectively controlled to minimise CO2 emissions from power stations and also help to reduce the impact of intermittency of wind generation on system performance.

Objectives:

This project will demonstrate the operation of distributed demand side management as a service to the UK grid operator, providing fast response in order to reduce reliance on conventional generation for grid balancing and security and thus permit much greater penetration of renewables and aid in maximising the use of existing assets. The demonstration will focus on the control of commercial air conditioning to provide an aggregated service of some tens of MW. The value and scope for wide scale application of the technology across the UK, and with regard to transmission constraints will be demonstrated through software modelling based on the results of the practical trial.

3. Development of Dynamic Demand Models in DIgSILENT PowerFactory

Introduction:

Dynamic demand models will be developed in PowerFactory and be used to represent the sizeable industrial dynamic demand service (hundreds of MW and beyond for primary and secondary frequency response) provided to the GB system. These dynamic demand models consists of a set of various dynamic demand technologies (from small-scale to large-scale with various operational characteristics), and will be integrated with the GB dynamic power system model in National Grid. The feasibility, reliability and predictability of the dynamic demand service to the GB power system will then be investigated, based on the integrated dynamic demand model and the GB dynamic power system model.

Objectives:

The key objective of this project is to develop validated dynamic demand models in PowerFactory and integrate it with the Master GB dynamic power system model in National Grid, which will provide a means for National Grid to quantify the impact of various dynamic demand technologies and gain confidence in the service provision from dynamic demand.

4. Frequency Sensitive Electric Vehicle and Heat Pump Power Consumption

Introduction:

National Grid has a licence obligation to control system frequency within the limits specified in the 'Electricity Supply Regulations'; +/-1% of the nominal frequency of 50.00Hz. System frequency is determined and controlled by the real time balance between system demand and total generation.

Historically, electricity generation has flexed to meet demand, in order to maintain frequency within the operational limits. However, this dynamic is likely to change in the future, as a result of both changing supply and demand, bringing with it new challenges for system operability.

Over coming decades, intermittent renewable generation will account for a greater proportion of the UK's electricity supply. For both commercial and technical factors, this type of generation is less flexible than traditional coal and gas generation and therefore less able to respond to frequency imbalances. In addition, new demand loads from electric vehicles and heat pumps are expected to change the demand profile. As uptake increases, these new loads not only have the potential to increase total annual electricity demand but also to increase demand over peak if no action is taken. Without appropriate measures in place, these loads could be inflexible; therefore the way in which the electricity system is balanced will need to change in order to remain economic, efficient and coordinated.

Objectives:

To complete a desktop study to investigate the potential to use system frequency to control the power consumption of electric vehicles and heat pumps, and explore the value of making these technologies frequency sensitive, through testing the associated commercial, technical and logistical challenges.

5. Granular Voltage Control (GVC)

Introduction:

Phase 1 – develop a working prototype of the GVC with the following deliverables;

- GVC concept proved and tested.

- Working prototype available.
- Report delivered on this phase (Report).

Phase 2 – small scale trial of the GVC to determine whether dynamic voltage control is a viable primary frequency response solution, dependent upon the successful completion of Phase 1 and with the following deliverables;

- Communications and frequency algorithms proved and tested in the field (Report).
- Testing and field trials completed (Report).
- Analysis report delivered (Report).
- Project completed (Full Report).

Objectives:

Phase 1 (develop a working prototype of the GVC with the following deliverables) objectives;

Enhance the automatic voltage control functionality to provide fast response (within 500ms) to frequency trigger with appropriate communications and aggregation solutions to provide real-time data on the aggregate capacity.

6. Improve Reliability of Future System by Enabling Integration of New Generation

Introduction:

The project will concentrate on, frequency response capability, load rejection and operation under power system split situation, black start capability, reactive capability and control system stability.

Objectives:

Collaboration projects with developers and manufacturers of power plant to ensure that design of new low carbon plant (CCGT,Clean Coal, Nuclear) meets minimum technical system requirements.

7. Co-ordinated Intelligent System Protection Against Frequency Collapse in Future Low Inertia Networks

Introduction:

The high penetration of renewable intermittent energy sources will undoubtedly cause the system inertia (stiffness) to vary significantly. Moreover, the trend of connecting generation resources that are interfaced via inverters will cause an unaffordable reduction in system inertia. Any significant fall in the inertia of a system may compromise the operational system security, in the form of angular- and frequency-instability related problems. This project, if successful will lead to a new co-ordinated system protection against frequency collapse in energy networks in the future.

Objectives:

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The goal of the proposal is to research and create a new adaptive protection concept that is capable of guarding against frequency collapse in future energy networks incorporating significant amount of inverter- interfaced energy sources and loads. This concept will be based on synchronized measurement technology and wide area measurements and will be capable of maintaining system frequency stability in future power systems with low and/or variable inertia levels.

The objectives for this project which consist of four main Work Packages (WPs) are;

1. WP1 Modelling of key system components relevant for the future system frequency response

2. WP2 Dynamic performance and interaction between different network components

3. WP3 Creation of a co-ordinated protection against frequency collapse in future energy networks.

4. WP4 Validation and Integration.

Electricity Network Innovation Competition Full Submission Pro-forma

Appendix 10: Accelerated Wide-area Frequency Control

A10.1 Introduction

Section 2, Project Description, and Appendix 5, Detailed Project Description, explain the reduction in system inertia and subsequent increase in the rate of change of frequency (RoCoF).

There is a need to accelerate the frequency response in line with these faster rates of change in frequency. This requires reducing the delay in starting a frequency response, and faster ramp rate of the corrective action. While the conventional frequency response services depend on governor control, other generators, interconnectors and demand are technically capable of delivering frequency response, but there is not an infrastructure or market mechanism to make use of the capability. The purpose of the control approach is to provide the control framework to demonstrate that non-conventional frequency reserve can be deployed quickly and effectively. Work Package 6 – Commercial of the EFCC project address the market mechanisms for the service.

Typically, local frequency measurements have been used for frequency response which was sufficient when inertia levels were high and there was time to respond. It was based on the assumption that system frequency is global. There was no regional bias when frequency response was initiated. However, in practice the frequency excursion starts at the source of the disturbance and propagates through the system. As inertia is not evenly distributed around a system, the extent of local deviation from the system frequency varies according to the location of the disturbance and the inertia in the surrounding area, as well as the overall system inertia.

A10.1 shows the frequency drop from a measured generator trip. While all generators decelerate, the earlier movements indicate measurements closer to the source of disturbance, and show a much faster initial decline. Therefore, it is these locations that would benefit from the fastest allocation of frequency control resource. Applying frequency control near the source of the problem reduces the change in the load-flow and relieves stability issues. A10.1 also shows the influence of electromechanical oscillations that distort the frequency and RoCoF, requiring mechanisms to identify at an early stage that the event is actually a frequency disturbance, and also to avoid degrading the stability of oscillations.

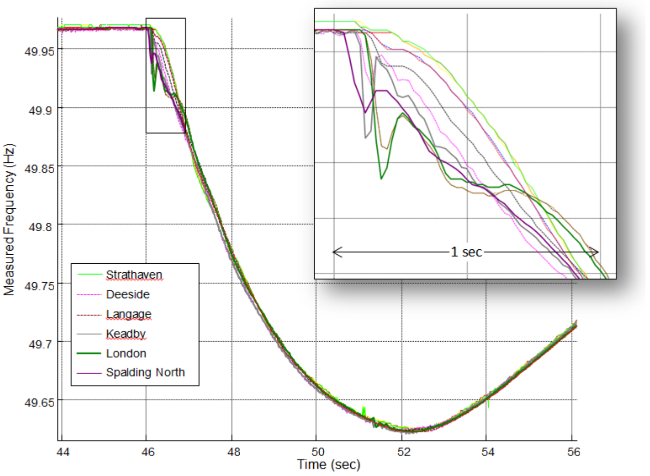


Figure A10.1 Synchronised system-wide measurement of frequency disturbance

With the increase of embedded generation, there is greater opportunity for control on a zonal level, therefore areas with a faster decline in frequency can be targeted. Individual frequency measurements may be quite variable over time and location (due to system dynamics), so wide-area measurements are used to create aggregate measurements for the different zones. This method will allow the effects from noisy signals to be minimised.

Logically, the scheme will be arranged using a central controller which obtains signals from a number of zones, so that frequency reserve can be prioritised by zone. This project will be demonstrated with minimal communication infrastructure enhancements, but will provide learning outcomes for the optimal architecture for the future system rollout.

The scheme is intended to supplement local control, rather than replacing it. Existing load shedding and governor-frequency control processes will continue, but new forms of frequency control will reduce the extent to which the conventional response would be called on. Also, non-conventional frequency response can include both local and central response components, and the project will examine how local and wide-area control can be used to best effect.

It is envisaged in future that response services would be purchased through a commercial mechanism that reflects the value of the response provided. Faster responses that are close to the disturbance trigger are of most value to the system. A response provider could therefore choose to use only local measurements, or to subscribe to the central control system service that would accelerate the response. The service provider would therefore balance the cost of installing communications links with the additional income from the service income.

A10.2 Control Scheme Concept

The power system is considered as a number of zones, each of which include some phasor measurements and frequency response capability including fast-acting response, and separated by constraining boundaries. Eventually, these zones may coincide with the conventional study zones, but the EFCC zones can span multiple study zones as in A10.2(a). The aim is to treat each zone as a block in which frequency disturbances are measured and response is deployed (A10.2(b)).

The frequency response is controlled from a central system, which comprises Zonal Aggregators and a Central Application Processor (A10.3). PMUs within each zone will measure frequency, RoCoF[1] and phase angles. The Zonal Aggregators each receive individual measurements from the PMUs, and aggregate the signals to form zonal frequency and RoCoF signals that are less influenced by the local variations seen in individual PMUs. These aggregate signals are passed to the Central Application Processor to derive a control response. The Zonal Aggregators also communicate with the frequency response providers to update the record of available resources. The logical organisation into zones helps to reduce complexity and improves resilience to loss of data sources.

The Central Application Processor will receive data from each zone and coordinate the required actions. Each of the PMUs will communicate the data to the Central Controller, ideally without routing through data concentrators, but the demonstration will be adapted to use existing infrastructure. Additionally, an inventory of the time/volume capability information and availability will be maintained in the controller. This allows the

[1] Different PMU models have ways of calculating df/dt, and there may be a need to trial different window lengths. Therefore, one function of the Zonal Aggregator is to recreate a RoCoF signal from frequency.

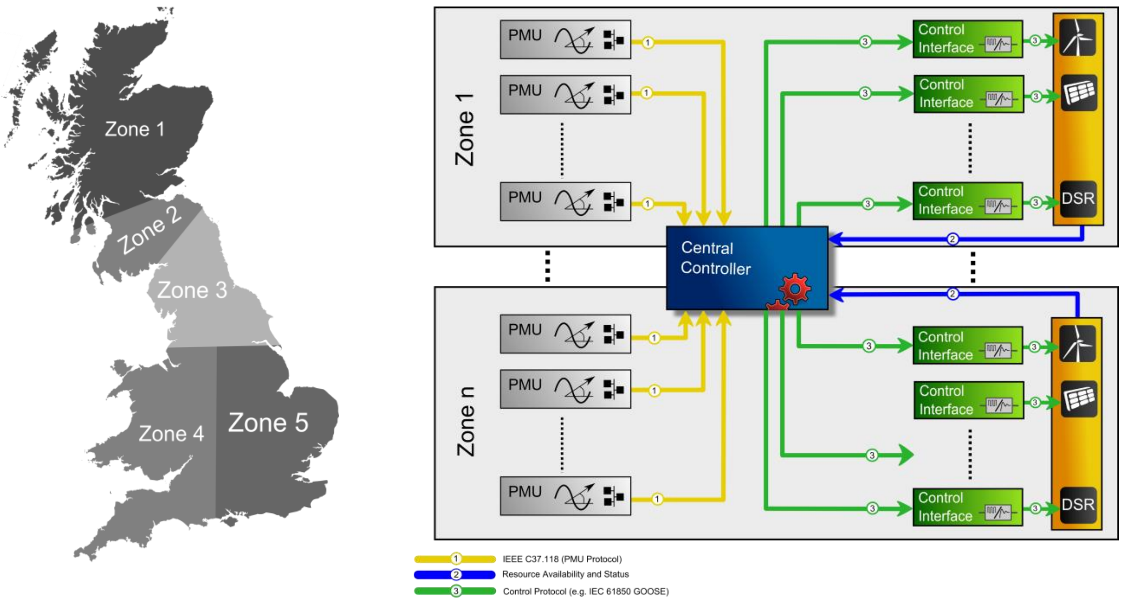
controller to choose from the available resources and create the optimal level of response and make-up of the response, which may include several zones and response speed characteristics. The Action Selection is then directed to the appropriate unit(s) through the Control Initiation block.

The central controller will provide a number of functions including:

- Detection of an event which merits a response
- Calculation of the level of response required
- Optimal selection from available resources to create the required response
- Deployment of frequency response resources

The Central Controller should communicate directly with the resources by means of a suitable interface which will convert the controller control signal into an actuating signal on the resource. After the initial action from the central controller, control will be handed over to local controllers employed at an individual resource level which will respond to local measurements. This transfer enables the scheme to be self-limiting. However, some care is required in the local and wide area control co-ordination to ensure that the non-conventional response is not withdrawn when RoCoF reduces to zero when frequency reaches a minimum. Also, the CCGT units require a smooth transition from fast-acting response to conventional primary and secondary response.

The required action of the control scheme during system separation will be considered, to ensure there is no degradation in the chance of successful islanding. However, islanding is not a goal of the scheme. Using a centralised controller would allow detection of separation which can take this into account when selecting appropriate response. The approach should provide positive support in other large, multiple disturbance scenarios. Even if these events are beyond the system security criteria, it is important that the EFCC system improves the system state, rather than degrading it. Also, provisions to avoid incorrect operation in oscillatory instability are to be incorporated.



(a) **(b)**

Figure A10.2 - Central Control Scheme

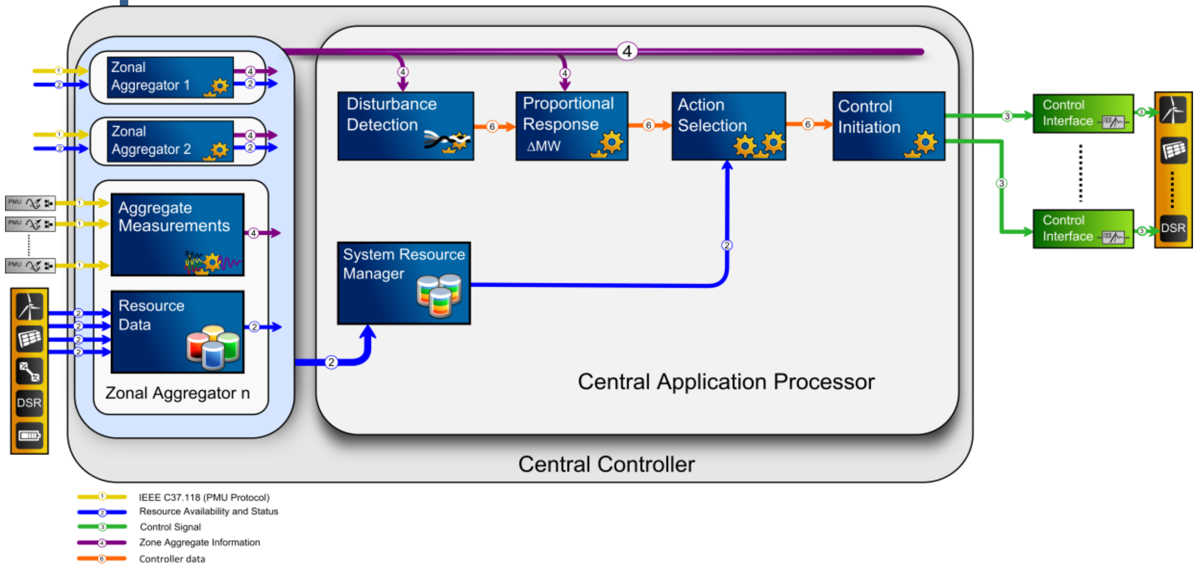


Figure A10.3 - Central Controller

A10.3 Control Scheme Processes

A10.3.1 Central Control Process

The proposed control process flow chart to be implemented on the controller is shown in A10.4. Some tuning of the approach may be required based on observation of complex real power system behaviour, and in particular, possible methods for determining a proportionate response will be considered during the project. The tuning will use real disturbances captured during the project before any network implementation or trialling, as well as simulations.

The controller must first detect an event which merits a response, and filter out lesser events to prevent spurious actions. In order to detect significant frequency events quickly, a wide-area approach is required. Using the aggregated frequency, phase angle and RoCoF information from the zones, threshold crossing and signal coherency will be used to identify a system frequency event and grade the impact.

On detection of an event, the controller will initiate the fast-response reserve in the zone of the disturbance. The role of the central control is to initiate response, broadly in proportion to the scale of the event, as quickly as possible. The faster and more localised the response is, the more useful it is for stabilising the grid. Thus, the controller will select and dispatch response based on the observed wide-area response. The controller response is intended to be taken within 1s of the triggering disturbance, and within 0.5s if possible. As the event progresses, local control can be used to adapt to the grid condition, thus the overall scheme response is self-limiting.

The Resource Manager function will provide information on the responses available in the respective zones. The frequency reserve requirement will be initiated by the controller, for example using a simple pre-defined $\frac{\Delta P}{df/dt}$ factor. The action will be compiled by a combination of fast-acting and longer-term responses ideally leading to a substantial reserve deployment equal to the required MW response. The available resources may include wind, storage, HVDC, Demand Side Response (DSR), Solar and the enhanced response from conventional plants. Within the controller, the system resource manager will compile the data from all resources. Each of these resources has different time-dependent characteristics, such as duration of service and speed-of-response, and are geographically distant.

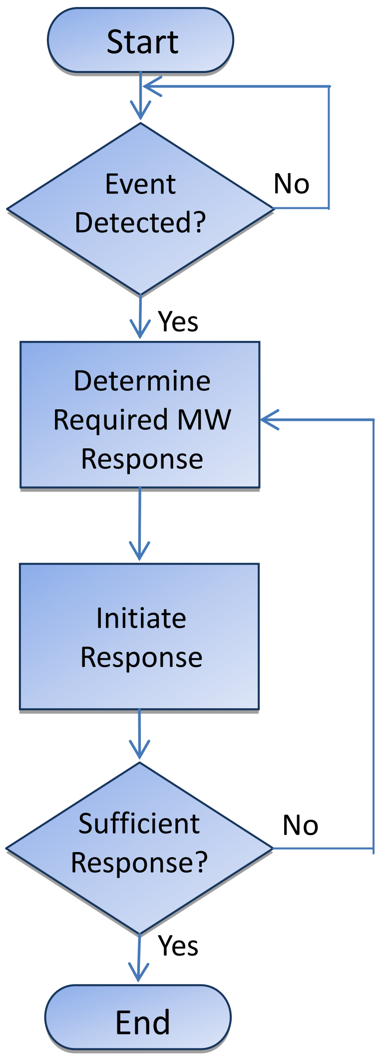
While response within the zone of the disturbance is prioritised, in most cases there will be a need to call on reserve from multiple zones. The sustained response comprises several elements, as illustrated in A10.6. This will include short-term capability that is replaced over time with longer-term capability. Having initiated the response, the controller will continue to observe the frequency trajectory, and if the downward (or upward) trend continues, then further response can be called, either by a central command or local control.

It may be noted that RoCoF by itself does not define the required MW response precisely. Both the initial MW loss ($\Delta P_{\downarrow} loss$) of the event and the inertia factor $2H_s$ are unknown in (1)

$$\Delta P_{loss} = -2H_s \frac{df}{dt} \quad (1)$$

Research work to date suggests that system inertia can vary by a factor of two already in the GB system, and the variability is likely to increase. However, the approach is relatively insensitive to errors in the approximation of the response required, as the local control will adapt the response such that the scheme does not over-respond.

Validation of the response taken is required to ensure that the resources being called upon are deployed successfully. An unsuccessful response will leave a MW deficit which will result in a continued decline in frequency. Further response can be taken either by a second round of control initiated by the central control, or through local control. This stage also handles the uncertainty in the estimate of the volume of response called. The response will be validated using measurements from the system along with information from the resources to verify the correct operation.



Action is only required when a real frequency event is detected. The scheme must not be subject to spurious triggers. Event detection will also include location.

A volume of response will be deployed corresponding to a pre-defined $\frac{\Delta P}{df/dt}$

From the set of controllable resources available, a subset is chosen for deployment. This subset uses the time-dependent characteristics of the different resources, and longer-term will replace fast-response.

If the response is sufficient, the frequency deviation should be slowed or halted, otherwise a second stage action may be initiated. Sufficient action will bring df/dt within an acceptable margin, allowing the conventional response to return frequency to nominal.

The central controller's role is to generate the fast initial response, triggering a response in about 0.5-1s. Subsequent local control will adapt the response, typically from around 3-5 seconds onwards.

Figure A10.4 - Flow Chart of scheme Process

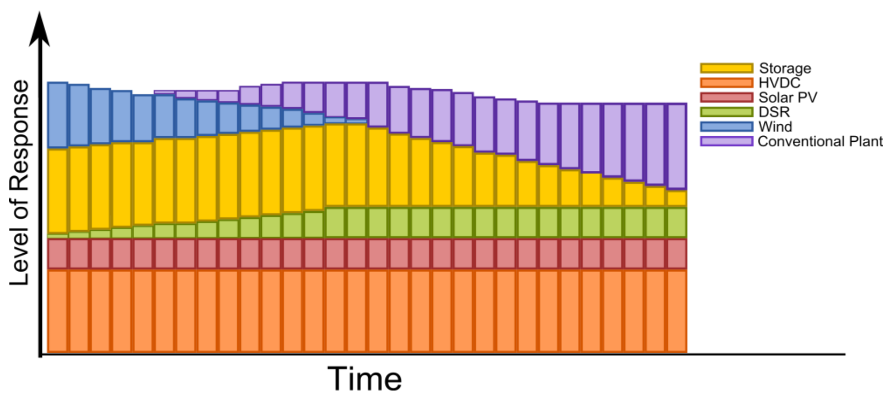


Figure A10.5 - Example Technology Response rates

A10.3.2 Local and Wide-Area Control

The control process described above initiates discrete response at the controlled devices. However, there is the potential for the frequency response provision to use local measurements to deliver a proportionate response to the disturbance. One of the learning outcomes of the project is to compare the relative benefits of local response, wide-area response and hybrid control using both local and wide-area information.

The local control mode involves the use of frequency and RoCoF measurements to achieve a form of virtual inertia, or in the case of the CCGT response, to use a rotor speed measurement to control governor output. However, a local control mechanism involves some delay to filter local variations and electromechanical oscillations, and avoid spurious response triggering that would be costly for some providers (e.g. CCGT fast response). The project will evaluate the benefits of local and wide area control, and a combination of the two, and the timescales when each would respond. A potential combined control approach would be that the central scheme triggers an initial fast-ramp response (setpoint change) and un-blocks the local control mechanism, which self-limits the response and increases the response if the initial ramp is not sufficient.

A10.4 Demonstration

To demonstrate the applications for the GB system, an archive of reference events from both GB measurements and simulations will be created. Off-line testing will be carried out using this archive on the developed applications to validate performance, and allow for any tuning of the applications for best performance on the GB system. Data from existing phasor-based monitoring would provide useful test cases to evaluate the scheme. Hardware testing with the implemented control applications would be carried out using suitable simulated input streams to replicate the signals received in the field, and outputs validated.

Demonstration	Description
Standalone Controller	Testing the controller in isolation with pre-recorded and simulated data to confirm performance, including algorithms and latency.
Hardware-in-the-Loop (HiL)	HiL demonstration is collaboration between Manchester University and Alstom. Using the Manchester RTDS system, the entire system is tested, including PMUs, controller and communications. The grid and the response provision are represented in models, and the effect of the entire scheme tested. Practical issues such as robustness against loss of signal, communications delays,
Strathclyde Power Network Development Centre (PNDC)	The advantage of testing on a physical system over HiL is that the behaviour will show some of the complexity of the real power system, while still being a controlled environment. The scheme can be deployed in the PNDC and the system response confirmed.
National Grid in-situ	The scheme will be demonstrated in the National Grid system to prove the responses initiated in real conditions, and record what the controller would do in the disturbances experienced. There are limitations on the existing PMU and communications latency, and the availability of communications links to sites, but the important aspects of the demonstration are a) the provision of correct signals (acting and restraining) from real grid signals, and b) to

evaluate the contribution of the response providers.

Some new PMUs should be deployed on the system, in particular to capture the sub-second synchronised detail of the fast response capability of the response providers. Continuous communications should be used wherever possible to centralise the data, but there may be locations where data needs to be logged locally using disturbance recording functionality. Additionally, it would be of value to install a controller unit locally where there is no communications to demonstrate the response provider's use of the external signals.

The characteristics of the frequency response services must also be reviewed in order to design the System Resource Manager function and co-ordinate with the response providers to create appropriate signals. In principle, relatively simple control signals will be communicated from the controller, such as:

- Discrete response trigger (e.g. breaker opening, wind farm rapid short-term response)
- Block/unblock local response (e.g. input to CCGT control system to enable RoCoF response)
- Setpoint change (e.g. power order to storage or HVDC, CCGT governor setpoint)

The method of transferring signals will be agreed between partners.

The applications will allow for additional tuning of the control algorithms when they become operational. This stage will allow the control scheme to be fine-tuned for use with the real measurements to allow for any discrepancies between the archival data and measurements obtained from the deployed system.

The goal of the project is to provide experience and knowledge to implement this system as Business-as-Usual (BaU). It will inform the specifications in all aspects of the technical requirements. The experience from the demonstration will be valuable in creating a BaU approach, while the knowledge will be disseminated through the appropriate sources to allow this system to be rolled-out for future BaU operation.