Issue 07

Enhanced Frequency Control Capability (EFCC)

Progress report: January to June 2018

Contents

Executive summary

Great Britain's (GB) electricity sector is becoming increasingly decarbonised; many traditional thermal power stations have closed and will continue to close. There is also more renewable generation on the electricity network, including solar photovoltaics (PV) and wind.

This changing energy landscape leads to system challenges that are explained in National Grid's System Operability Framework (SOF)*. One of these challenges is that while traditional thermal power stations provide inertia (an object's resistance to any change in motion), renewable generation technologies typically do not. Inertia acts as a natural aid in maintaining system frequency. Reducing system inertia increases the risk of rapid changes in system frequency and the threat of severe faults on the electricity network.

National Grid is working with industry and academia on the Enhanced Frequency Control Capability (EFCC) project. This aims to identify innovative ways to control frequency in low inertia transmission systems. It will explore how technologies such as demand-side response (DSR), solar PV, wind and different ways of operating combined cycle gas turbines (CCGTs) can help to keep the transmission system stable in the most cost-effective and efficient way.

* http://www.nationalgrid.com/SOF

Summary of progress: January to June 2018

At the beginning of 2018, the EFCC project made a formal request to the regulator, Ofgem, to extend the project timeline by four months from its original March 2018 end date. The new project end date is now 31 July 2018 and the Project Closure Report will be available three months after that. The extension allows extra time for the commercial project partners to gather and assess the test data from their field trials and for the academic partners to complete their assessment of the monitoring and control scheme (MCS).

All academic and commercial project partners continue to make good progress in testing and validating the GE Grid Solutions MCS and, where appropriate, demonstrating its ability to provide fast, initiated frequency response. The installation, configuration and site acceptance testing of Phasor Measurement Units (PMUs) and the monitoring and control applications for demonstration on the National Grid network also continues to be progressed. However, this work was not included in the original scope of EFCC so National Grid is now evaluating a Network Innovation Allowance (NIA) funding proposal for these demonstration activities. This also includes the potential to link up with third party project partner sites. This would be the next step in progressing how the MCS could be used in an operational environment and transitioned into business as usual activities.

The project has also continued to establish how faster frequency response could be incorporated into the existing suite of commercial ancillary services. This includes quantifying the value of rapid frequency response to the National Electricity Transmission System Operator (NETSO), and what commercial opportunities such a service could provide to industry participants. A cost benefit analysis underpins this assessment. Early indications suggest there are potentially significant benefits associated with the ability to co-ordinate the dispatch of rapid frequency response from a diverse range of service providers. The indicative results are consistent with the original analysis submitted at the bid stage of the project, with both sets of analysis highlighting the potential cost savings associated with the EFCC concept.

A highlight of this reporting period was the hugely successful third knowledge dissemination and stakeholder engagement event at Cheltenham Racecourse on 27 and 28 March. A large number of stakeholders from across the industry attended and the entire project team delivered two days of interactive sessions designed to share their knowledge, insights and project learning to date.

The project team is now focused on the final stages of the project and drawing together its conclusions and recommendations. This will include suggestions for future work to progress the EFCC concept.

Project background and business case

We need to increase our use of renewable generation in order to meet future carbon reduction targets. However, this presents a challenge because most renewable generation does not provide inertia. A reduction in system inertia is known to increase the risk of rapid changes in system frequency and consequently the threat of severe faults on the electricity network. This means that we will need to deliver more frequency response more quickly to keep the electricity network stable.

By developing an innovative wide-area monitoring and control frequency response system (MCS), the EFCC project aims to allow newer, more sustainable energy solutions to provide more frequency response, thus creating a more diverse market. The project will also seek to influence the development of commercial incentives and products to encourage the widest participation in a new market for fast frequency response.

The challenge of managing low system inertia is not unique to National Grid so we'll share important knowledge from the project with relevant network licensees and service providers. We'll also share the results of trials, and the solutions offered, with global Transmission System Operators (TSOs). To discover more, please visit our project website at www2.nationalgrid.com/efcc or email us at box.EFCC@nationalgrid.com.

Project manager's report

The project received formal approval and the Project Direction in December 2014. This is the seventh progress report and covers the period of January to June 2018.

Major project deliverables during the reporting period include:

Project extension – at the beginning of 2018, the EFCC project made a formal request to the regulator, Ofgem, to extend the project timeline by four months from its original March 2018 end date. The regulator acknowledged the extension, noting that it was not a material change to the project as defined by the Electricity Network Innovation Competition (NIC) Governance Document. The new project end date is now 31 July 2018 and the Project Closure Report will be available three months after that date.

Knowledge dissemination and stakeholder engagement event – in March the project team hosted the third annual knowledge dissemination and stakeholder engagement event. The two-day event consisted of interactive sessions designed to share knowledge, updates and next steps. Once again this proved to be hugely successful and attracted many stakeholders from across the industry. In addition, and building on the success of this event, in June our academic partners and GE Grid Solutions joined National Grid in Glasgow to provide further insights into the testing and validation of the wide-area MCS.

GE Grid Solutions' Data Review and Performance Report – this analysed the commercial partner field trials and overall performance of the EFCC MCS up until the end of March 2018. This included an evaluation of the individual PMU and PhasorController performances. Changes made to the Application Function Blocks (AFBs) during the reporting period were also described and a summary of recommendations was presented.

Further detail on each of these project highlights can be found later in this report.

Project steering committee

The project steering committee is responsible for:

- developing and agreeing project activities
- approving project results
- raising, testing and reducing identified risks to the project
- authorising changes to the project plan.

The project steering committee continues to hold frequent teleconference and face-to-face meetings to discuss project progress, identify and manage risks and agree actions. There have been no changes to the steering committee in this reporting period.

Project progress against SDRC milestones

Progress against our SDRC milestones during this reporting period is shown in Table 1 below. Further details are also provided in the SDRC chapter later in this report.

Table 1
SDRC summary: January to June 2018

Description	Due Date	Status
Report with recommendations regarding implementation of the new service	31 January 2018	Ongoing*1

*1 These activities remain ongoing and have passed their original due date. These activities will continue during the project extension period and will be reported in detail when the project ends.

Project risks

The robust project structure and governance process make sure that any issues or changes that could affect project delivery are identified quickly and that actions are put into place to resolve them. Appendix C provides an update of the project risk register. Major risks for this reporting period can also be found later in this report.

Project knowledge sharing and dissemination

The project team will continue to:

- record and share all lessons learned throughout the lifetime of the project
- discuss and assess all learning points through reviews and project meetings
- share outcomes and breakthroughs at conferences, workshops, university demonstration events, webinars, industry events, social media and our project website as appropriate
- upload and share reports on the project website wherever possible – however, some project reports are part of the intellectual property that is being developed.

Events that were attended and publications that were submitted by all project partners during this reporting period are listed in Table 2 below.

Table 2
Knowledge sharing and dissemination events: January to June 2018

Event/Publication	Date	Organisation	Contribution
Electricity System Change, Glasgow, UK	January 2018	Flexitricity	Promoted the participation of DSR in EFCC
University of Edinburgh Lecture, Edinburgh, UK	January 2018	GE Grid Solutions	The changing role of control in future power systems and the ever-increasing need for clever optimisation to co-ordinate distributed resources for electricity services provision
IET Scotland Event, Glasgow, UK	February 2018	National Grid GE Grid Solutions University of Manchester University of Strathclyde (UoS)	An event with talks from the EFCC team on the "Application of a Wide-Area Monitoring and Control Technique for Fast Frequency Response in the GB Transmission Network"
Smart Energy, London, UK	March 2018	Flexitricity	Promoted the participation of DSR in EFCC
Future of Utilities, London, UK	March 2018	Flexitricity	Promoted the participation of DSR in EFCC
IET International Conference on Developments in Power System Protection (DPSP), Belfast, UK	March 2018	UoS	An invited talk in a tutorial session on "Potential Solutions to Mitigate Risks Associated with Low-Inertia Systems"
EFCC Knowledge Dissemination and Stakeholder Engagement Event, Cheltenham, UK	March 2018	All project partners	Project knowledge dissemination and stakeholder engagement event (for further information see below)
IEEE Transactions on Smart Grid (special issue)	April 2018 (extended abstract accepted)	UoS	Paper on "Design and Validation of a Wide-Area Monitoring and Control System for Fast Frequency Response"
All Energy, Glasgow, UK	May 2018	Flexitricity	Promoted the participation of DSR in EFCC
IEEE Transactions on Industrial Electronics	May 2018 (paper submitted)	UoS	Paper on "Augmenting the Control of a MW-Scale Motor-Generator Set to establish Power-Hardware-in-the-Loop (P-HiL) capability"
Energy and Power Forum for World Young Scholars, China	May 2018	UoS	An invited talk on "Fast Frequency Response in Power Systems with Low Inertia"
EFCC Academia Dissemination Event, Glasgow, UK	June 2018	National Grid GE Grid Solutions University of Manchester UoS	Academia knowledge dissemination and stakeholder engagement event (for further information see below)
IET International Conference on AC and DC Power Transmission 2018, Chengdu, China	June 2018	National Grid GE Grid Solutions University of Manchester UoS	Paper on "Fast Frequency Response for Effective Frequency Control in Power Systems with Low Inertia"
Energy Networks Association Electricity Innovation Forum, London, UK	June 2018	National Grid	An overview of the EFCC project, the learning achieved and how the concept could be implemented into business as usual activities
IEEE TPWRS	2018 (submitted journal paper)	University of Manchester	A new approach to the online estimation of the loss of generation size in power systems
EPSR	2018 (submitted journal paper)	University of Manchester	Synchronous machine modelling based on transient time constants and reactance
IEEE TPWRS	2018 (submitted journal paper)	University of Manchester	36-Zone GB test network based on National Grid data: Development and frequency response application
IEEE TSG	2018 (submitted journal paper)	University of Manchester	Online power system inertia calculation using wide-area measurements
IEEE TPWRS	2018 (revised journal paper)	University of Manchester	Disturbance size, location and time estimation using limited PMU measurements

Knowledge dissemination and stakeholder engagement events

The EFCC project team continues to share the most up to date results, insights and best practice with stakeholders. On 27 and 28 March, the team hosted their third knowledge dissemination and stakeholder engagement event at Cheltenham Racecourse. Various industry representatives attended to hear the latest updates from the technical and commercial work streams. There was lots of discussion and feedback forms were extremely positive.

Building on the success of this event, our academic partners and GE Grid Solutions joined National Grid in Glasgow to provide further insights into the testing and validation of the wide-area MCS. Delegates could witness real-time examples of testing and simulation of the effects of the EFCC control approach, and further understand the considerations needed for EFCC to be implemented in practice with individual providers. Across the day, the team was on hand to discuss the project's work.

To raise the profile of the project further internally, the EFCC project team exhibited at innovation week at the National Grid office in Warwick. Throughout the week, the team were on hand to discuss the project with employees from across the business. Some good discussions were had and employees were invited to join a webinar scheduled for later in the summer.

Through the webinar, the EFCC team will share the results and findings from the commercial work stream. Delegates from across the industry will be invited to hear the findings from the cost benefit analysis.

To share this message further, an interview with *New Power* has been scheduled. *New Power* is a specialist report, both online and in print, for anyone with an interest in the UK energy industry. The publication takes an in-depth look at all the issues that need to be addressed as the energy industry changes.

On 26 June, the EFCC project exhibited at the Power Responsive event in London. This was a great opportunity to meet with industry and energy users. We could share updates from the project and invite delegates to our webinar scheduled for later in the summer as described above.

Award nominations

The EFCC project was shortlisted for the Project Award in the 13th British Renewable Energy Awards. This recognises a company that has developed an outstanding building-integrated, on-site or stand-alone project. The annual awards celebrate the achievements of companies and individuals who have done amazing work in renewables and clean technology over the past year. We were delighted to be highly commended in our category.

The project was also nominated at the Real IT Awards and the Utility Week Star Awards.

Within National Grid, the project has been nominated for the Chairman's Awards in the 'Fit for the Future' category. This category recognises something that has not yet been done and explores how things could be done differently and better. At the time of writing, the results of this have not yet been revealed.

Project website

As ever, the project website is updated to share the latest updates and news. To make the site more user friendly, sub folders have been created and the documents are now easier to locate. Please visit our project website at www2.nationalgrid.com/efcc.

Forecast for the remaining project period

The project activities for the remaining project period are shown in Table 3 below.

Table 3
Work package activities: January to July 2018

Work Package	Description	Partner	Comments	Status	Timescale
1	MCS	GE Grid Solutions National Grid	Demonstration 4: installation, configuration and site acceptance testing (SAT) of PMUs and monitoring and control applications for National Grid demonstration	Amber*2	Jan 2018 to Jul 2018
1	MCS	GE Grid Solutions	Deliver updated control scheme data review report	Green	Jan 2018 to Jul 2018
2.1	DSR	Flexitricity	Complete and analyse DSR field trials	Green	Jan 2018 to Jul 2018
2.2	Large-scale generation	Centrica	Complete and analyse large scale generation field trials	Green	Jan 2018 to Jul 2018
2.3	Solar PV power plant	Belectric	Complete and analyse solar PV power plant field trials	Amber*3	Jan 2018 to Jul 2018
2.5	Wind	Ørsted, Siemens	Complete and analyse wind field trials	Amber*4	Jan 2018 to Jul 2018
3	Optimisation	University of Manchester	System studies on representative GB transmission network to assess proportionate responses from service providers and develop an optimal supervisory control strategy	Amber*5	Jan 2018 to Jul 2018
4	Validation	University of Manchester UoS	Implement MCS for Hardware-in-the-Loop (HiL) and Power Network Demonstration Centre (PNDC) testing and validate the MCS	Green	Jan 2018 to Jul 2018
6	Commercial	National Grid	Assess the economic value of a new rapid frequency service	Green	Jan 2018 to Jul 2018
7	Communications	National Grid	Evaluate the communication infrastructure requirements, assess the current technical capabilities of the scheme and co-ordinate the installation of additional PMUs at National Grid substations to increase wide-area monitoring capability	Green	Jan 2018 to Jul 2018

Status	Description
Red	Unlikely to complete by due date
Amber	Minor issues but expected to complete by due date
Green	On track to complete by due date

*2 This activity is amber because of the delay in establishing an appropriate demonstration scheme and the new requirement for GE Grid Solutions to further develop the PhasorControllers. This includes the IEC 61850 MMS client interface and cyber-security considerations. However, a large element of this work was not included in the original scope of EFCC. National Grid is therefore now evaluating a NIA funding proposal for these demonstration activities. This would be the next step towards progressing how the MCS could be used in an operational environment and transitioning it into business as usual activities.

*3 This activity is amber because of minor contractual issues limiting access to the solar PV plant. These issues are in the process of being resolved and the solar PV trials are expected to resume and conclude imminently.

*4 This activity is amber because of difficulties in agreeing liabilities during trials on a commercially operational windfarm. This continues to be discussed and alternative options explored.

*5 This activity is amber because of resource issues at the University of Manchester. The affected work package continues to be reviewed to make sure the necessary study analysis is effectively reported and communicated.

Business case update

Project extension
At the beginning of 2018, the EFCC project made a formal request to the regulator, Ofgem, to extend the project timeline by four months from its original March 2018 end date. The extension would allow extra time for the commercial project partners to gather and assess the test data from their field trials and for the academic partners to complete their assessment of the MCS. During the extended timeline, the project will continue its assessment of the system benefits and associated cost savings of the EFCC concept and how the knowledge obtained during the project can be shared and integrated within the industry.

The new project end date is 31 July 2018 with the Project Closure Report available three months after. The regulator acknowledged the project timeline extension requested, noting that the extension was not a material change to the project as defined by the Electricity NIC Governance Document. The allocated project funding will remain the same during the extension period.

Progress against plan

The project continues to make steady progress against our revised plan, which takes into account the project extension granted by Ofgem. All notable achievements and events from this reporting period, including a full list of our forecast activities between now and the end of the project, have been provided in the project manager's report section of this document. Appendix A also provides a high-level view of our project plan on a single page.

Progress against budget

Table 4 shows the project expenditure to date as of 30 April 2018 and highlights any variances against the budget. This excludes the funding for Work package 2.4: Storage, in accordance with the Project Direction.

Table 4
Proposed and actual spend: January 2015 to April 2018 (£000s)

Cost Category	Actual	Budget	Variance
Labour	1225.6	2150.0	(924.4)
Equipment	461.9	574.0	(112.1)
Contractors	1898.6	2349.7	(451.1)
IT	60.3	86.0	(25.7)
IPR costs	0.0	0.0	0.0
Travel and expenses	74.8	139.0	(64.2)
Payments to users	261.1	653.0	(391.9)
Contingency	183.9	708.3	(524.4)
Decommissioning	0.0	24.0	(24.0)
Other	79.7	340.0	(260.3)
Totals	**4245.9**	**7024.0**	**(2778.1)**

The project was due to finish in March 2018; however the timeline has been formally extended for the trials to be completed in July 2018. There is no change to the overall project budget. The variance in the table above between actual and budget is due to the timeline extension and subsequent phasing of project spend.

Project bank account

Bank statements have been provided to Ofgem. Due to the confidential nature of the project bank statements, these have been included within a redacted appendix of this report.

SDRC

One SDRC was due during this reporting period. This was to provide a report with recommendations regarding the implementation of the new EFCC service. However, these SDRC activities remain ongoing and have passed their original due date. These activities will continue during the project extension period and will report in detail when the project ends. For further information please see Table 1 in the project manager's report section earlier in this document.

In addition, there is the annual requirement to host a project knowledge dissemination and stakeholder engagement event. This was achieved on 27 and 28 March 2018. For further information please see the relevant earlier chapter.

SDRC for the remaining project period
There are no further SDRCs in the remaining project period.

Data access details

Network licensees must make clear how interested parties can request any network or consumption data gathered in the course of a project. From 30 September 2017, network licensees must have a publicly available data sharing policy in place, setting out the terms on which such data will be provided. National Grid's data sharing policy relating to NIA and NIC projects can be found at:
https://www.nationalgrid.com/sites/default/files/documents/National%20Grid%20NIC%20and%20NIC%20Data%20Sharing%20Policy%20September%202017.pdf

Ofgem expects network licensees to share network and consumption data if the party requesting it can demonstrate it is in consumer's interests to do so, subject to anonymisation and/or redaction for reasons of commercial confidentiality or other sensitivity.

Learning outcomes

This section describes what has been learned in the project during this reporting period.

This shall be reported in work package order and include descriptions, among others, of: activities undertaken, challenges overcome and learning achieved.

Work package 1: Monitoring and control system

Activities undertaken

GE produced a report on the control scheme's performance to date in the EFCC field trials where the focus was on the schemes installed on partner sites using live PMU data compared to the academic laboratory testing.

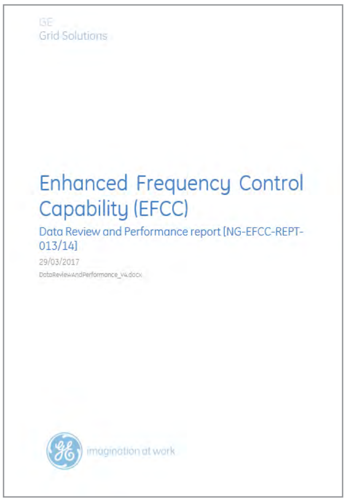


Figure 1. EFCC - Data and Performance Report - Delivered March 2018

1. Data and performance report summary

This report presented the results from the field trials and overall performance of the EFCC scheme up to the end of March 2018, along with an evaluation of the PMU and EFCC PhasorController performance. Changes made to the algorithms during the reporting period were also described and a summary of recommendations based on the findings was presented.

The focus of the report was on the industrial field trials, while the academic testing results are being reported by the individual academic partners in line with the original scope of works.

Three partners have finished initial testing and key baselining of their field trials: Flexitricity, Belectric and Centrica/EPH. The wider end-to-end National Grid field trials are being pursued under a separate project due to the additional scope. The EFCC scheme settings used by the partners during the field trials were agreed in a joint exercise between GE and National Grid in August 2017. During the trial period, some of these settings were tuned for particular site characteristics, such as noisy data. Industrial field trials are using local measurements only, as the wide-area testing will be performed in the extended National Grid trials.

(i) Belectric field trials

The Belectric SAT was the first industrial test to be completed in March 2017, however computer failure led to extensive delays in Belectric beginning field trials. Field trials began in January 2018 when the hardware issue was resolved. By that date, a new PhasorController firmware version had been released and was deployed on the Belectric PhasorController in late 2017. Additionally, as a number of trials had already begun by this date, it was possible to see that the rate of change of frequency (RoCoF) threshold agreed between GE and National Grid was not resulting in the detection of any frequency events. Belectric therefore trialled a lower threshold for RoCoF during the baseline testing to evaluate the sensitivity of this setting. It was found that a RoCoF threshold of 0.04Hz/s was more suitable for trials since it was triggered by a number of genuine large frequency disturbances. There has already been one occurrence where the control equipment detected and deployed a physical response. This marks the beginning of the Closed-Loop field trials where PhasorControllers have the ability to instruct response from their resources.

The equipment's behaviour under short-circuit fault conditions was also evaluated during a real short-circuit event in March 2018, which resulted in an incorrect EFCC triggering. It was found that there was an incorrect setting configured on the Belectric PhasorController. An investigation revealed that the false triggering would not have occurred with the recommended setting. The recommended settings are now being used.

(ii) Flexitricity field trials

Field trials at Flexitricity's static RoCoF site ran in a mixture of Open-Loop and Closed-Loop modes. Production issues at the site reduced the amount of time that the site was able to participate in Closed-Loop mode. The Flexitricity field trials have been the longest running in terms of operating period. An issue with noise on the frequency measurements was identified that could lead to spurious detections, highlighting the importance of data-quality. As this is one of the first uses of synchrophasors for wide-area control, new requirements are being identified when using such devices for control applications.

Two solutions were proposed for this issue. The first was to redefine the requirements of the measurement devices used. New software based on these new requirements is being developed. The second solution was adding robustness downstream in the event detection logic to identify noise and prevent false detection. This activity has been completed, tested and deployed and there were no reports of false detections due to frequency spikes since the update in mid-December 2017. The update was also rolled out to Belectric.

The Flexitricity PhasorControllers used the initially-recommended RoCoF setting of 0.1Hz/s until 13 March, but as there were no 0.1Hz/s events in that period, no genuine frequency events were detected by the scheme. The thresholds were reduced from 13 March 2018 to allow the PhasorControllers to detect and respond to events which are occasionally seen in the system. A small number of such events have now been observed, however, the availability issues noted above have prevented the site from responding to them.

The trials also identified a problem in the data transfer between the PMU and PhasorController, and more generally between the site and the Flexitricity server in Edinburgh, with frequent loss of data being observed. The missing data between the PMU and PhasorController led to jumps in the RoCoF calculation. From the offsite investigation, the findings show that data was not getting to the PhasorController, but without a suitable device onsite to monitor the traffic, further analysis is not possible. It should be noted that the same behaviour was not observed in any other installations. The jumps in RoCoF can be mitigated by filtering mechanism updates in the event detector. This behaviour has not been noticed onsite from data observed from May 2018 onwards. The likely cause for this issue is in the hardware between the PMU and PhasorController somehow not forwarding all data, but it highlights the importance of all equipment in the critical data paths. Investigation is ongoing.

(iii) Centrica field trials
The final set of field trials is with Centrica/EPH, however, as it uses the same 0.1Hz/s threshold as Flexitricity was using up to 13 March 2018, no events have been detected. For Closed-Loop trials, this threshold should be reduced. However, deployment of response will still depend on the alignment of a frequency event with the gas turbine being operational, as well as the owner, EPH, allowing EFCC control. Additionally, the updated event detection AFB deployed to Flexitricity and Belectric should also be rolled out on the Centrica PhasorController.

(iv) GB event analysis on EFCC scheme
Disturbances on the GB grid between January and March 2018 were gathered from partner sites, EFCC PMUs and a transmission-connected PMU at a site in Scotland. The data was used to replay the events through the EFCC control scheme acting in local mode. This allowed GE to test the current scheme settings to determine if they should be adjusted to trigger the EFCC scheme more frequently and obtain results from real frequency events.

This analysis demonstrated that the RoCoF threshold could be reduced to 0.04Hz/s and would still only detect the larger events, typically where frequency drops below, or close to, 49.7Hz. This is applicable in all cases except for Flexitricity's static RoCoF site where a higher RoCoF of 0.08Hz/s is recommended because of noise issues observed at the site.

(v) PMU and PhasorController performance
The PMU performance was reviewed, including an investigation into the frequency spike identified during the Flexitricity trial. Additionally, the performance of P-class (Protection) and M-class (Measurement) PMUs was reviewed. Since the GE PMU tested was M-class, they have a relatively long filtering window which translates to a long delay in the data coming from the PMU. It was shown to have a latency of around 140ms, which is correct according to the IEEE C37.118 standard, meaning that when a data packet is sent from the PMU, it is already 140ms old. Therefore, this must be considered in the total time budget available for communications latency and EFCC response. A test was performed on a P-class PMU and it was found to have a latency of 40ms, which is significantly lower than the M-class device. It is therefore recommended that for a wide-area control scheme where network delays are likely to be an issue, P-class PMUs must be considered.

The Centrica field trial was used to evaluate overall PhasorController performance, as this was the longest operating PhasorController with no manual interruptions. The availability was found to be 99.957% over a period of >3 months (1 December 2017 to 7 March 2018). One issue identified related to the PhasorController logging functions, where logs would not store and update correctly. A fix has been created for this and is due to be rolled out during the extension period.

(vi) EFCC scheme performance
Two AFBs – event detector and central supervisor – were updated during the trial. The event detection AFB was updated due to the PMU frequency noise issue, while the central supervisor was updated to fix an issue identified by the PNDC, at one of the academic partners. This has not been rolled out to partners yet, as none of the field trials currently use the central supervisor.

(vii) Conclusions
Overall, the field trials have provided crucial, real-life data and the experience needed to make improvements to the scheme. Additionally, unexpected behaviours are being seen, which is resulting in new requirements for the AFBs. The GE PhasorController platform was specifically designed to reduce development and testing times, which was successfully demonstrated through the quick turnaround for rolling out solutions and fixes. The resulting platform and applications have been very stable. The number of false detections has been reduced and the report demonstrated that the remaining false trips are either due to incorrect settings or poor PMU measurements, which will be resolved in due course.

The project extension will allow for further evaluation of the scheme until July 2018. The report will be revised after the extended trials have finished.

2. Support activities
In addition to the report delivered by GE, GE has been providing continued support to the EFCC field trial partners. This includes debugging, configuration and event analysis. A number of interesting frequency events have been detected by the hardware since the schemes were installed. Industrial partners and National Grid have requested analysis of these events to understand in more detail the behaviour of the frequency in these short timescales. It is currently being seen that the frequency observed in the control room is not fully reflective of what is being seen at a regional level and this will have a direct impact on the control schemes.

(i) Event analysis
Additionally, there have been some events with high RoCoF but within frequency operation limits. This raises questions as to whether or not such events need a response, as they would conventionally not have been considered as significant. Therefore, the trials are currently providing useful information that will shape the future of the frequency services market, even from a technical understanding of frequency behaviour.

(ii) MMS development
The recent undertaking by GE has been on the IEC 61850 MMS development for the control scheme. In the original design, IEC 61850 GOOSE was envisaged due to its small data size and speed, however in wide-area networks it can be difficult to configure, particularly when multiple networks, or subnetworks, are involved. GOOSE was typically used for intra-substation design as opposed to wide-area communications. Therefore, IEC 61850 MMS was developed to replace part of the GOOSE implementation of the scheme and facilitate easier wide-area configuration. MMS is a routable protocol and better lends itself to wide-area communication networks. Development is now complete and testing is taking place in a replica National Grid system in the GE offices. This will then be moved to the National Grid test lab for further testing in the coming months.

(iii) National Grid scheme

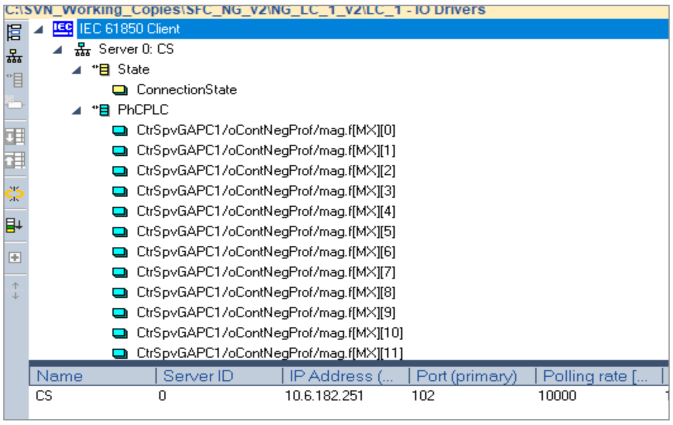


Figure 2. MMS reporting configuration in Straton

With the inclusion of the MMS into the PhasorController, and the upcoming cyber-security testing, it was decided to migrate the complete National Grid control scheme to the latest version of the firmware. This has meant a few scheme changes in the programmable logic controller (PLC) which have now been completed and it's now in the testing phase.

The latest PhasorController firmware is similar to the earlier EFCC beta version but there are a number of differences between the builds, including some of the input and output blocks. This meant changes had to be made to the original PLC logic but not to the fundamental EFCC logic.

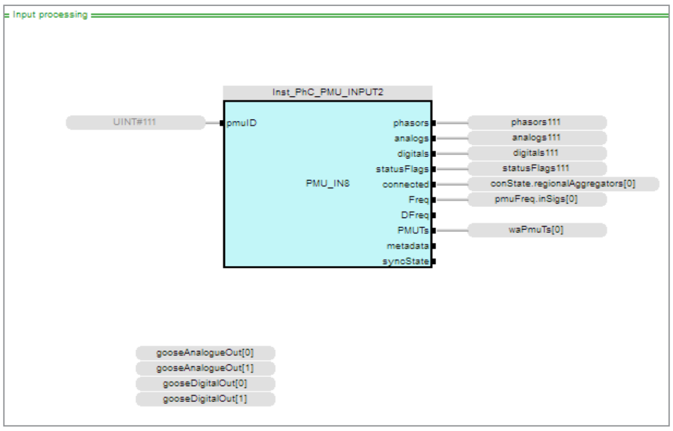


Figure 3. Example of the changes with the new firmware version – input PMU block in PLC

Challenges overcome

There have been challenges in this reporting period. The first was the development of the new communication protocol: IEC 61850 MMS. As the team did not previously have in-depth knowledge of the protocol, it was a challenge to learn the new protocol for development and for the implementation and configuration phases. The GE team worked closely with the 61850 stack development team to fully integrate the protocol into the PhasorController. This knowledge then had to be passed on to the PhasorController users responsible for commissioning the devices on-site.

There were also some challenges with how the PMUs reported time-synchronisation errors. As out-of-sync data can directly impact the scheme's performance, it was important to fully understand and classify any errors caused by time-synchronisation issues. GE is working closely with the manufacturer to define the desired operation of the PMU when time-synchronisation errors occur. This is one of the first uses of PMUs in fast wide-area control, and hence is forming new requirements for PMU devices. This is the first of these requirements where devices conventionally used for monitoring can also be used in more time-critical control applications.

Learning achieved

The GE team has now developed and implemented the new IEC 61850 protocol which is a new addition to the device. This included learning how to integrate the protocol into the software and, at end-user level how to configure and use the MMS protocol in the end PLC schemes. Where once data was sent between PhasorControllers via GOOSE, it will now be sent using MMS. Therefore, the teams learned how MMS differs from GOOSE, how the MMS protocol works, how to set up and configure an MMS report, and how to bring MMS data into a PLC scheme for use in the control AFBs.

There have been significant learnings on how external components influence the scheme's performance. Data issues have been seen on sites which were not observed in any of the lab testing or Factory Acceptance Tests (FATs). In these schemes, the GE equipment is often connected with non-GE equipment, such as routers, which have not been tested before. The field trials showed how the effect of missing data can disrupt the schemes and have an impact on the calculations performed. What may have been considered very low risk activities, such as sending PMU data from a local PMU to the PhasorController installed in the same cabinet, may not always be low-risk as there may be additional devices connected between them, such as a router, which can impact data availability.

It is important to note that the scheme has been designed with graceful degradation in mind and can hence ride-through bad quality data issues. As the wide-area data is not being tested in these specific trials, the graceful degradation in wide-area mode has not been demonstrated. The local mode of operation, which was tested in these trials, is meant as the backup or failover mode; hence no data or missing data in this mode can result in the device not operating. However, it would not impact on the performance of the overall wide-area scheme.

Involvement in project knowledge sharing and dissemination activities

There were several dissemination events in this reporting period. The first event was at the University of Edinburgh presenting the EFCC project to leading academics in the field of industrial mathematics. The intention was to present the changing role of control in future power systems and how, as the services become more distributed, there will be an ever-increasing role for clever optimisation algorithms to co-ordinate the many distributed resources for electricity services provision.

The second event was at the Institution of Engineering and Technology (IET) in Glasgow, which was shared by National Grid, the UoS and the University of Manchester. This was a very popular event which was said to have the largest turnout of any of the IET events held in Glasgow. After the project was presented there was a very involved question and answer session.

The final event was the project knowledge dissemination and stakeholder engagement event in Cheltenham. GE was involved in two presentations: the GE work package update and the GE and Landsnet experiences of control to date, which greatly overlaps the work being done in EFCC.

Forecast of activities between now and project completion

Activities for the coming months, until the end of the project include:

- continued support for the field trial partners. This is expected to continue until mid-July and will be provided on an as-needed basis. Wide-area testing of the National Grid scheme will begin in late June/early July, with an installation of the control scheme in Enderby. This will also include refresher training for the National Grid team, including the new developments such as the MMS protocols developed for the National Grid wide-area scheme

- the field trials are due to be fully completed by end June/early July. This will allow GE to update the performance report delivered in March. The update will include the finished partner field trial results that were not available in March.

Work package 2.1: DSR

Activities undertaken

1. Live sites – operations and monitoring

During this period, six sites in live operations were participating in the three different EFCC services, with a mixture of operational patterns and availability profiles. Flexitricity's operational team managed arming and disarming at the start and end of service participation periods, working around site operational patterns and other parameters. New processes make sure that arming and disarming is carried out at the correct time, sites are monitored and that performance data gathered during operational hours are recorded.

2. Site commissioning
Dynamic RoCoF equipment was installed on site at the cold store partner site during December 2017. On-site commissioning was carried out during January 2018. The site went live for service on 16 January 2018. This is the sixth and final of our partner sites taking part in the trial.

3. Adjustments to settings – Dynamic RoCoF
Our dynamic RoCoF sites began their EFCC operational duty with equipment settings that represented a best estimate of the parameters suitable for those sites. It became clear that different settings would be required for different locations. Over time and through observation we were able to adjust and improve the RoCoF setting calculation and power deviation output algorithm.

The following changes were made at the pumping station site:

- increase deadband size to reduce number of power deviations
- update power deviation to include cubic root to make power deviation proportional to RoCoF value (following pump affinity laws)
- change regularity of RoCoF calculation.

The following changes were made at the wastewater treatment site:

- increase deadband size
- increase max and min RoCoF value
- update power deviation to include cubic root to make power deviation proportional to RoCoF value
- change regularity of RoCoF calculations
- change average sampling.

The following changes were made to the cold store site:

- increase deadband size
- update power deviation to include cubic root to make power deviation proportional to RoCoF value.

4. Trip setting adjustments – Static RoCoF
Our objective for our static RoCoF site was to have a RoCoF setting that would trip approximately 10 times per year. The initial setting was adjusted in March 2018 when it was decided that it was not sensitive enough (no trips due to RoCoF events were observed in the period). The under frequency RoCoF threshold was changed from 0.1Hz/s to 0.08Hz/s and the detection window was increased from 0.04s to 0.06s. Testing is ongoing but the current setting would appear to be close to the level of activity we are looking for.

5. Frequency spikes – Static RoCoF
Frequency readings have been subject to periodic frequency spikes. These spikes were typically in the region of 58Hz; we conclude that these were due to frequency reading errors in the PMU. Flexitricity has been working with GE to both understand the source of these errors and to prevent them leading to erroneous RoCoF readings and trip outputs. In December 2017, adjustments were made to the PhasorController event detection algorithm to reduce the likelihood of an erroneous frequency spike leading to a RoCoF trip. A firmware upgrade to the GPS clock was applied in February 2018 to reduce the number of frequency spikes.

6. Adjusting operational hours – Spinning inertia
Through negotiation with partners, we extended the operational hours for spinning inertia sites in order to gather data during a wider period of the day.

Challenges overcome

1. Communications and data transfer issues
There were difficulties with uploading data from certain sites. At our static RoCoF site (a chemical plant) we observed large gaps in the PMU data captured by PhasorPoint. We installed a higher bandwidth fibre connection to deal with this.

At our district heating site, the volume of data produced by the data logger exceeded the broadband connection's capability to support the extended operational hours we considered necessary to gather adequate data. This issue was resolved by an upgrade to our communications channel. After upgrading the connection and running for longer hours, we put an automated process in place to transfer log files from the data logger to the outstation PC and then from the outstation back to the Flexitricity office. This was necessary to manage data buffer load.

2. PhasorPoint communications
PhasorPoint collects data from the two PMU sites. The PhasorPoint server is located in Flexitricity's office. We replaced the server in January 2018 in order to deal with the large volume of PMU data.

3. Data logger data format
Our data logger collects current and voltage measurements. Working with our data logger firmware provider Metis, we developed a way to use these measured values to calculate the values we require: specifically, frequency, RoCoF and real power.

Learning achieved

The output setting for both static RoCoF and dynamic RoCoF have evolved during the trial. The static RoCoF trip output is now expected to provide approximately the level of activity that we set out to achieve at the start of the trial. In the case of dynamic RoCoF sites, individual settings have been developed for each site depending on the frequency behaviour at their location. We are much more aware of the extent to which local RoCoF measurement can vary from location to location.

Involvement in project knowledge sharing and dissemination activities

Flexitricity took part in the EFCC knowledge dissemination and stakeholder engagement event at Cheltenham Racecourse in March 2018, and has promoted EFCC through presentations at a number of conferences and events, including Electricity System Change (Glasgow, January 2018), Smart Energy (London, March 2018), Future of Utilities (London, March 2018) and All Energy (Glasgow, May 2018).

Forecast of activities between now and project completion

1. Completion of trials
On-site trials on all partner sites are currently in progress and will be completed during the current three-month period. Details of expected completion dates for individual sites are as follows:

Dynamic RoCoF:

- pumping station: budget for running hours due to be exhausted in June 2018
- wastewater treatment works: budget for running hours due to be exhausted in June 2018
- cold store facility: trial due to run until July 2018.

Spinning Inertia:

- industrial horticulturalist: budget for running hours due to be exhausted in June 2018
- district heating: site unavailable as of 7 May 2018 due to maintenance for an estimated six to eight weeks. Further running in June/July is a possibility.

Static RoCoF:

- chemical plant: the site has a limit of 500 hours/five shutdowns before trial is over
  - at least one simulated RoCoF trip will be arranged if this does not occur naturally during the measurement period.

2. Decommissioning equipment on partner sites
Equipment installed for the EFCC project will be removed from partner sites after onsite trials have finished and before project completion at the end of July 2018.

3. Analysis of data collected onsite
Analysis of data collected is ongoing: more data is being collected as the onsite trials continue.

4. Writing report
The technical report and the project closure report will be written after the above steps.

Work package 2.2: Large-scale thermal generation

As required by Electricity NIC Governance, Centrica fully collaborated with the entire project team and presented their findings at the final EFCC knowledge dissemination and stakeholder engagement event in Cheltenham in March 2018. Centrica's previous six months' project work is outlined below.

1. Limited Operational Notification (LON)
Following lengthy discussions, it was agreed with National Grid that a Limited Operational Notification (LON) would be drawn up to enable the revised (RoCoF based) logic to be used on GT-21 only. The LON was in place from 1 January 2018 until 30 April 2018. Unfortunately, during the periods in which South Humber Bank was instructed to carry frequency response by the normal market mechanism, no significant frequency deviations occurred, so the effectiveness of the revised frequency response logic could not be observed. This is not so surprising, as the module did not run all the time during this period and, like most CCGTs, is only used for frequency response on a portion of the period during which it is running. This portion is reducing over time as National Grid increasingly uses demand side sources of frequency response rather than response from conventional generation.

As the sale of South Humber Bank Power Station to Energetický a Průmyslový Holding (EPH) took place on 1 September 2017, this part of the project reached a natural conclusion at the end of April 2018, coinciding with expiry of the LON. Centrica's involvement in the project ended with the expiry of the LON, other than writing closing reports and attending final project meetings.

2. Passive monitoring
As previously reported, the revised frequency control logic, using RoCoF as an input rather than deviation in frequency from 50.0 Hz, was installed in one of the two gas turbines at South Humber Bank (GT-21). Between February 2017 and January 2018, the revised frequency control logic was not driving the plant's response and was working in a passive mode only. Throughout this period we could review any significant frequency deviations on the National Grid and look at how the conventional frequency control logic, as well as the revised frequency control logic, would have driven the plant. Review of these events was encouraging and consistently showed that the revised frequency control logic would give more response in the early stages (sub 10 seconds) of a significant frequency event.

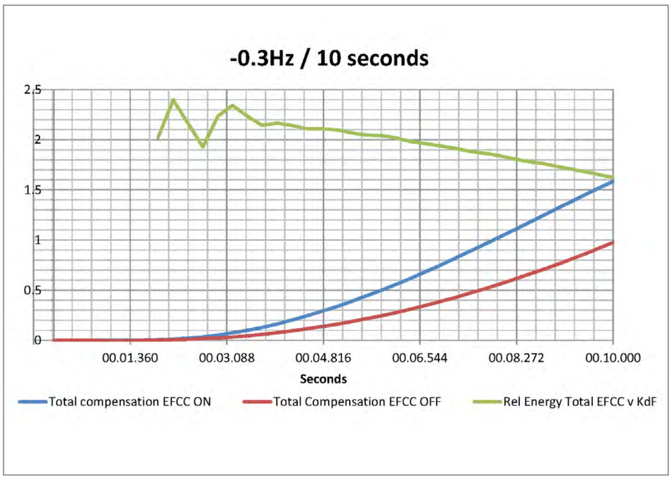


Figure 4. Improvement in response delivery in the first 10 seconds of an event during testing

This review was also shared with the wider EFCC project team, promoting good discussion and furthering the team's understanding of plant and system characteristics in frequency incidents.

3. GE equipment
The GE Grid Solutions system installation was completed at the end of the previous reporting period and the successful SAT was carried out on 22 November 2017. Since this period, events captured by the system PMU have been shared with project partners both as trends and comma-separated values (CSV) files. The CSV files were used in testing for work package 2.2 as described below.

RPV 311 PMU log files from the system have also been provided to GE, as requested, to help with their software/firmware development during the period.

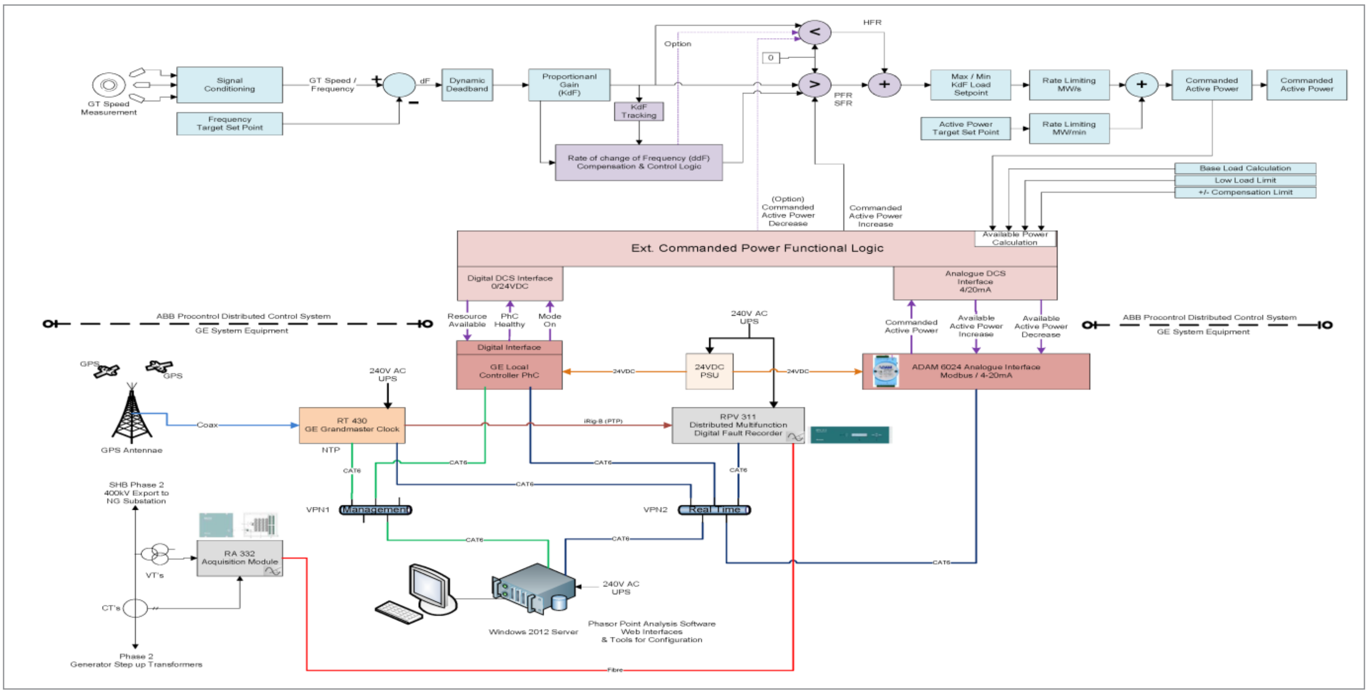


Figure 5. South Humber Bank Power Station – schematic showing GE monitoring installation

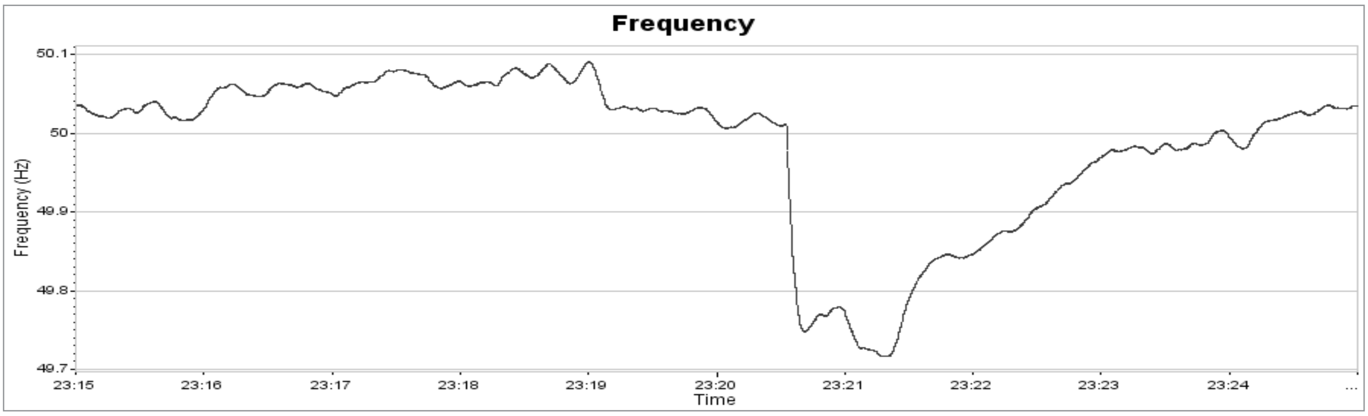


Figure 6. PMU trace of frequency event trend recorded at South Humber Bank Power Station

4. Improved modelling capability
The capture of real-time events using fast data from either the GE supplied PMU or the DEPP fast data recorder (an Alstom system that was already installed at the power station) had been used before in the dynamic mathematical software simulation. However, the control elements in this model form a simplified representation of the real control system.

While an offline simulation using real gas turbine control system hardware had been developed, it was not previously possible to input real events beyond Grid Code compliance standard ramps and steps. This capability has been developed through the use of visual basic applications (VBA) coding and protocol translation tools to allow real events to be played back directly into the hardware simulation test rack environment where the actual control system code response can be observed and analysed. This allows the real control system code to be optimised against real world events.

5. Response optimisation – offset tracking
With reference to the trend in Figure 8 and the test logic, during a frequency event the fall in frequency (red line – gas turbine speed) generates a demanded power compensation greater than the kDF (conventional response – black line) and the dDF (RoCoF based response – blue line) control response.

The real event captured in passive mode clearly shows the requirement for tracking to take into account the effects of any offset from 50 Hz that may already exist in the form of kDF (at the start of an event) in order for the dDF to be effective in delivering improved response times.

The tracking was optimised and is fully incorporated into the design. Offline testing in Figure 9 shows the same event played back through the offline software simulation. The black line shows the compensation with tracking while the orange line shows the conventional response.

Offline testing in Figure 10 shows the same event but this time played back through the offline test rack simulation using real control system hardware. The violet line shows the compensation with tracking while the orange line shows the conventional response.

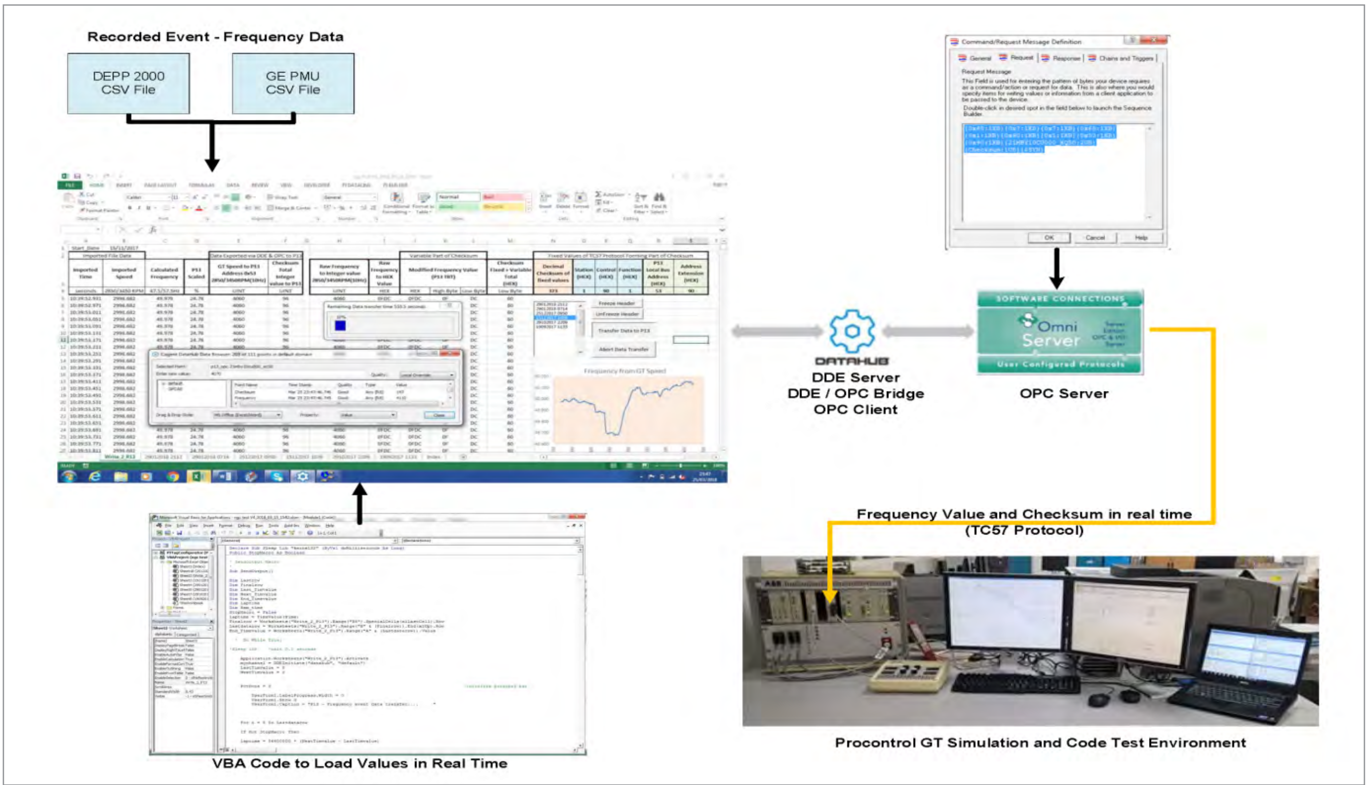


Figure 7. Pro-control offline test environment – Event playback capability development

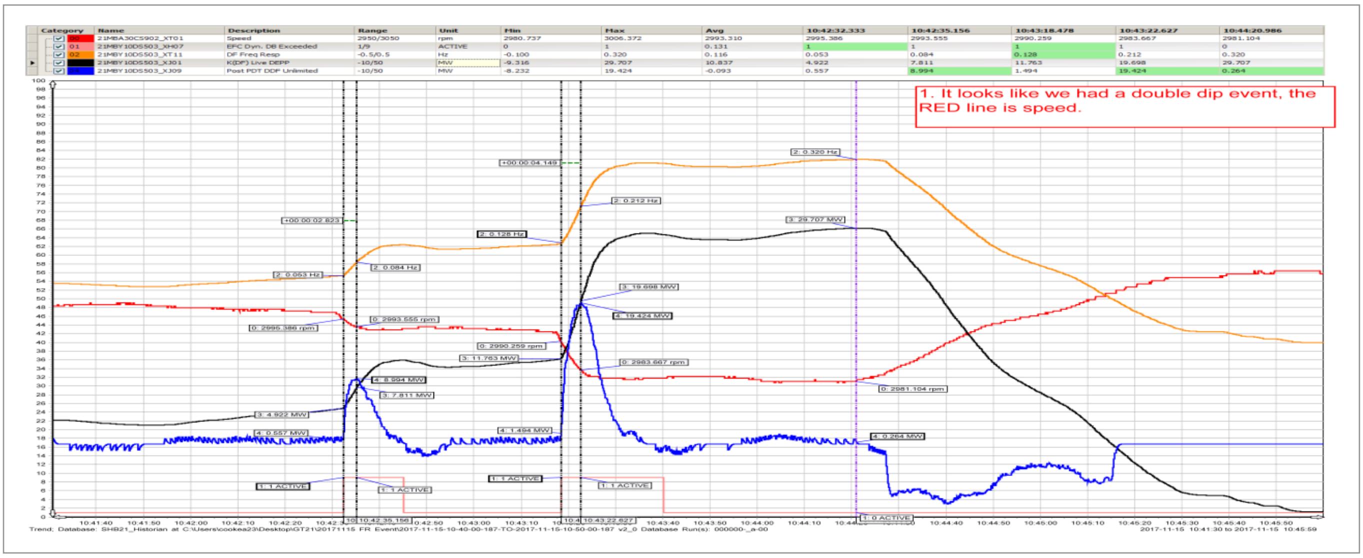


Figure 8. Passive monitoring of an event with 800 MW loss of generation

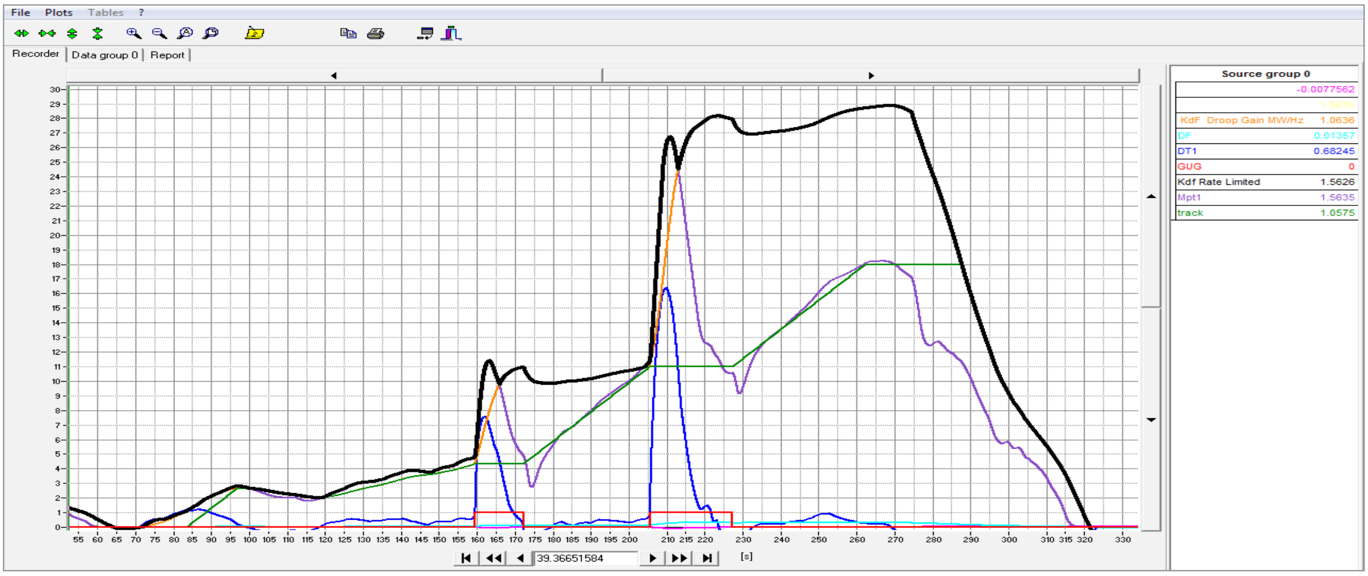


Figure 9. SimApp simulation showing playback with offset tracking enabled

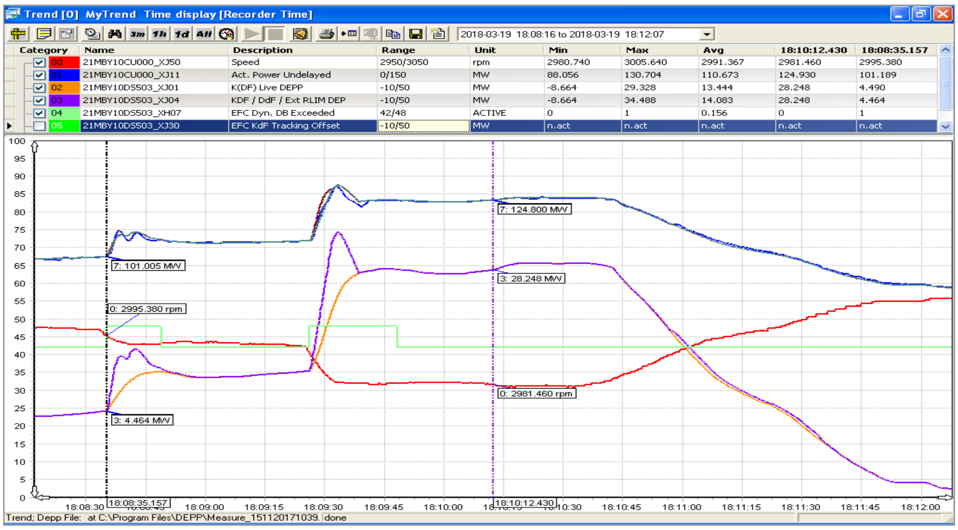


Figure 10. Pro-control test rack simulation showing playback with offset tracking enabled

Work package 2.3: Solar PV

Belectric carried out the following activities at the Rainbows solar PV power plant during this reporting period:

- started and completed most parts of the solar PV test and trial schedule including:
  - inverter control tests
  - ramp rate and reaction time tests
  - Open-Loop tests with simulated and real events
  - HiL tests with simulated and real events
- continued to develop the software for the Belectric hybrid controller and advanced the control algorithms based on the first test results
- identified issues with the solar PV power forecasting system and developed and implemented a new forecasting algorithm with less response delay
- improved the inverter control and behaviour after evaluation of test results
- investigated and resolved Modbus TCP/IP communication issues and improved the communication commands between the inverters and the hybrid controller
- redefined and improved the curtailment algorithm after the first evaluation of test results and in consultation with National Grid
- resolved outstanding hardware and software issues on the solar PV communication and measurement chain
- measured and shared data and results of EFCC relevant frequency events
- implemented a frequency event simulation tool from GE Grid Solutions and successfully used it for Open-Loop tests and HiL tests
- took part in the evaluation of solar PV and battery storage for the commercial EFCC application
- took part in the knowledge dissemination and stakeholder engagement event in Cheltenham and presented first results and learning outcomes.

We've learned the following during this reporting period:

- positive and negative frequency response is possible from solar PV by putting a forecast and curtailing algorithm into the Belectric hybrid controller. This can be done by shifting down the operating point of the solar PV plant. However, it is a costly solution suitable only for short forecasted periods of high volatility
- real and simulated frequency events showed that it is possible to provide positive and negative frequency response within the EFCC scheme using solar PV power plants equipped with central inverters
- measurement and detection of frequency events is working successfully and as intended
- ramp rates of solar PV inverters are a limitation in the current set-up but may be optimised in future applications
- Modbus TCP/IP connection to the inverters is a potential limitation to the reaction time in the current set-up but may be optimised in future applications
- interestingly, ramp rates and reaction times of the available solar PV inverters are not symmetrical for positive and negative response. This is because the inverters' internal control algorithm is optimised to the expected shape of the I-U-curve of the PV modules
- the implementation and use of the new communication protocol IEC 61850 GOOSE between the Belectric hybrid controller and GE Grid Solutions' PhasorController has proved successful
- the integration of GE Grid Solutions' PhasorController, PMU equipment and PhasorPoint measurement software has been demonstrated and is working with the Belectric controller components within the solar PV power plant
- the concept of a Belectric hybrid solar PV and battery storage resource is still being pursued and will be tested in the project extension timelines.

Belectric continues to work towards the hybrid solar PV and battery storage resource and achieved the following during this reporting period:

- the combination of solar PV and battery storage can provide a positive and negative frequency response with more regulating power and at a lower cost than using solar PV alone
- the Belectric Energy Buffer Unit (1 MW/1 MWh) has been deployed and is installed close to the solar PV plant
- installation of the communications infrastructure is in progress
- the grid connection point in Western Power Distribution substation is installed and energised
- the contract between National Grid and Belectric has been concluded
- Combined solar PV and battery storage tests are being prepared.

Work package 2.5: Wind

During this reporting period, National Grid has continued to work with DONG Energy (now Ørsted) and Siemens Gamesa Renewable Energy (SGRE) to test a windfarm's ability to provide fast, initiated frequency response. Following the stage one contract signing, Inertial Response (IR) has been tested during multiple detailed field trials on a SWT-7.0-154 wind turbine. Further data has been submitted by SGRE to Ørsted and National Grid based on simulation models to demonstrate that the function can deliver the specified additional generation.

Ørsted has used the field trial data provided by SGRE to write a report that considers the commercial implications of IR and how the frequency response market must change to include this type of service. The report details their view on:

1. Portfolio-wide usage including probabilities for activation and overall volume
Based on the single turbine performance, the response was extrapolated to the entire fleet of wind power plants using historical data from Ørsted sites.

2. Optimisation and suggestions for further development of IR
To maximise grid support value, the IR function must be optimised for wind conditions that statistically result in the most frequent and critical frequency events, e.g. when conventional power plants are offline. IR has the least recovery time at high wind speeds, which is also when conventional power plants are out of service. Ørsted sees this as an opportunity and suggests optimising the function for high wind conditions.

3. Commercialisation and implementation of IR
Ørsted suggests that the System Operator (SO) should integrate the energy output and recovery time of this new product into existing models of primary response requirements. Ørsted believes that fast response is worth more to the system than

slower response, because it leads to a lower overall deviation of frequency from the target as response kicks in before frequency hits its low point. Therefore, the benefits of this response should be higher than the costs in terms of primary response required to make up for the recovery period.

4. Shaping the frequency response market to accommodate variable resources
The three major changes recommended are rewarding fast response, procuring services closer to real time, and creating a fast-acting, pre-primary, upward response product.

Key takeaways from this report were presented at the EFCC knowledge dissemination and stakeholder engagement event in Cheltenham.

Ørsted is now awaiting data for the next step in the project which is currently being negotiated. Ørsted and Siemens have also met with the University of Manchester to discuss their results and modelling approaches.

Work packages 3 and 4: Optimisation and validation – the University of Manchester

Work package 3: Optimisation

The work undertaken and the learning achieved at the University of Manchester within this reporting period can be categorised under: interim wide-area EFCC, wide-area EFCC and Linear Quadratic Gaussian Control (LQGC). All are modelled in DIgSILENT PowerFactory software and used to test and validate the performance of frequency response service providers and compared to the GE Grid Solutions' MCS.

1. Assessing the value of interim wide-area EFCC and wide-area EFCC in the GB power system
Both EFCC schemes developed in DIgSILENT PowerFactory use available data from PMUs to monitor the electricity network at regional and national levels and instruct frequency response from a range of frequency response service providers.

In traditional frequency controllers, most responses are based on the absolute value of frequency. Corrective responses are initiated automatically when this value violates predefined thresholds. However, traditional techniques have inherent delays to prevent spurious triggering and over-response.

The interim wide-area EFCC and wide-area EFCC schemes monitor and respond to the regional and national RoCoF respectively. Both allow frequency response to be triggered as soon as an event occurs. This is achieved by a number of settings related to the calculation of RoCoF in both schemes and emulates the concepts being deployed in the GE Grid Solutions' MCS.

Two sensitivities of the wide-area EFCC scheme have also been considered: proximity and equality. In proximity mode, the wide-area EFCC scheme, as per the GE Grid Solutions' MCS, can target the frequency response near to the area of the event so that the extent of the disturbance is minimised. Whereas in equality mode, the frequency response is evenly distributed across all zones and is informed by national demand. In both sensitivities, the frequency response is proportional to the size of the event. Both sensitivities are also self-limiting and do not over-respond.

The main advantages of the developed EFCC schemes in DIgSILENT PowerFactory are as follows:
- allows the pathway of EFCC optimisation to be mapped and the effect of the GE MCS to be simulated

- models the effect of traditional frequency response and compares it with faster and coordinated response options allowing the benefits of EFCC to be further defined as the system inertia changes in the future
- drives the right level of response to the right area of the system to support stable system recovery
- contains maximum active power loss within 500ms-700ms of the event to avoid restricting the maximum loss possible at that time
- simulations have demonstrated the potential to accommodate a maximum system loss between 400MW and 850MW larger than is possible without EFCC. However, this is still subject to further analysis.

To summarise, the schemes considered (interim wide-area and wide-area) and the associated sensitivities with the wide-area scheme (proximity and equality) are:
- **interim wide-area EFCC:**
  - response is regionally provided based on regional information
  - has a reduced infrastructure requirement
  - approach is only effective provided that local measurement is calculated accurately and the data captured ahead of an event informs the control sufficiently. These requirements are not possible for RoCoFs exceeding 0.6Hz/s, which are expected to be more probable from the mid-2020s onwards.
- **wide-area EFCC (proximity):**
  - resources closest to the event are deployed
  - mirrors GE's MCS in function
  - is most efficient in damping inter-area behaviour.
- **wide-area EFCC (equality):**
  - resources are evenly distributed across all zones but informed by national demand.

The configuration of interim wide-area EFCC and wide-area EFCC is shown in Figure 11.

As a disturbance occurs, the scheme will determine to run under either interim wide-area or wide-area. If interim wide-area is selected then the regional aggregation function in the Local Controllers (LC) will calculate the regional: centre-of-inertia (COI), frequency, RoCoF and loss of generation, in addition to recording the frequency nadirs and maximum RoCoF. Whereas if wide-area is selected, the system aggregation function in the Central Supervisor (CS) will calculate the national equivalents of all the parameters listed above.

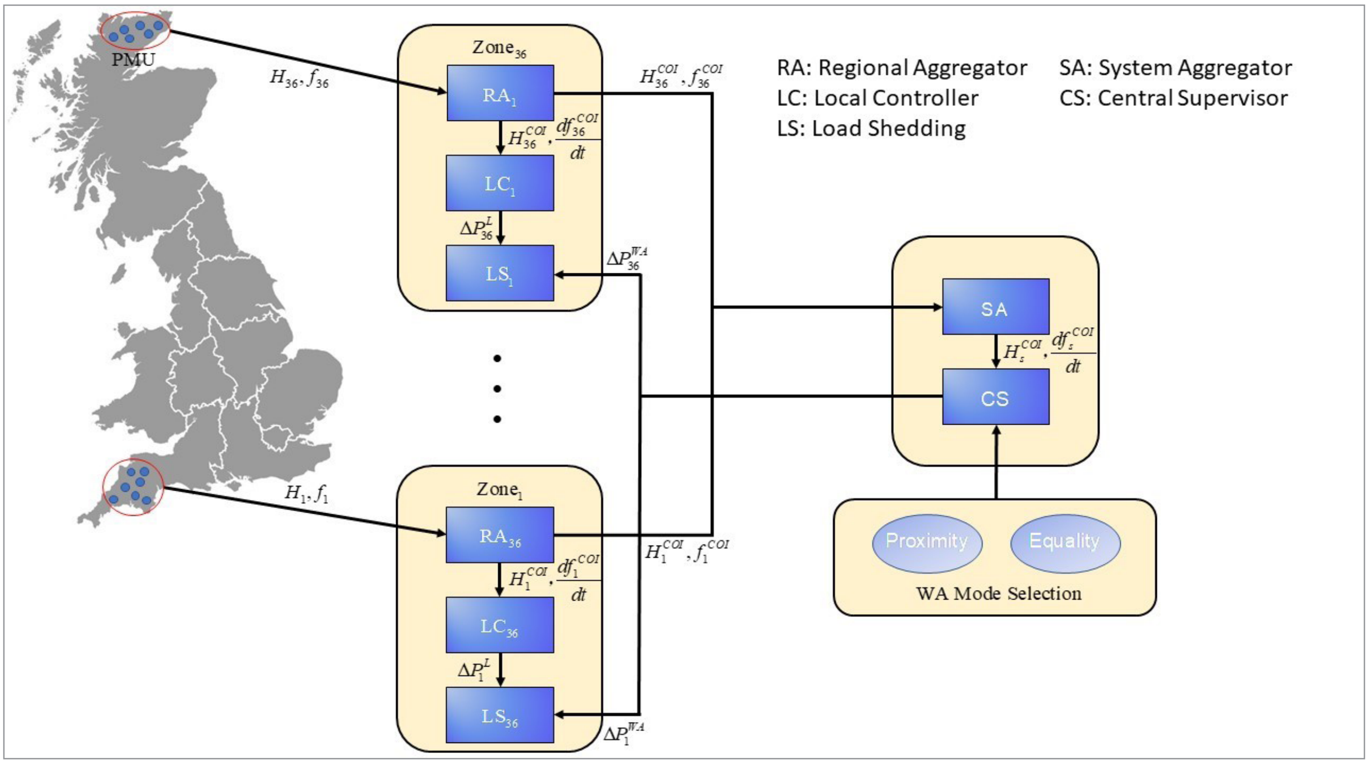


Figure 11. Interim wide-area and wide-area EFCC scheme configuration for the 36-zone GB system

The roles of the different functions are as follows:

- interim wide-area EFCC:
  - calculating regional MS(2HS), MSF(2HSF), where M is the mechanical starting time, which is equal to 2H, where H is the inertia constant of the generator, and S and F are the generator's apparent power and frequency respectively
  - calculating regional COI frequency
  - calculating regional COI frequency nadir
  - calculating regional COI RoCoF
  - calculating maximum regional COI RoCoF
  - estimating regional loss of generation
  - calculating regional electrical/mechanical power change.

- wide-area EFCC:
  - calculating national MS(2HS), MSF(2HSF)
  - calculating national COI frequency
  - calculating national COI RoCoF
  - calculating maximum national COI RoCoF
  - considering the EFCC RoCoF threshold
  - estimating national disturbance size i.e. loss of generation
  - Equality: calculating the level of response to be triggered for each zone by equal allocation
  - Proximity: calculating the level of response to be triggered by the zones closest to the disturbance
  - considering national electrical/mechanical power change.

- load response:
  - selecting interim wide-area or wide-area EFCC
  - arranging ramp rate limiter of load shedding or response
  - inserting a low limiter.

The system and zonal frequency response of the 36-zone GB system for different frequency controllers including i) without EFCC, ii) with interim wide-area EFCC, iii) with wide-area EFCC (equality) and iv) with wide-area EFCC (proximity) are shown in Figure 12.

- The key to EFCC optimisation is the deployment of enough resources to respond to the event. The proposed modelling approach can achieve this.

- While deploying resources close to an event, as per the MCS approach, is beneficial, it has been identified that this is not essential until 2025 and interim wide-area EFCC is sufficient in the short term.

- It is noted that the ability to deliver an interim level of wide-area EFCC that is not dependent on real time frequency and RoCoF, other than locally received measurements, does still require a wide-area "picture" of the system's state prior to an event.

- Simulations have demonstrated the potential to accommodate a maximum system loss between 400MW and 850MW larger than is possible without EFCC. However, this is still subject to further analysis.

- The regional and national frequency identify how and to what extent regional resource is important and how best to combine EFCC with other forms of frequency response.

- EFCC needs enough time to deliver. Should frequency containment faster than 500ms become necessary, the future options beyond EFCC are explored under LQGC.

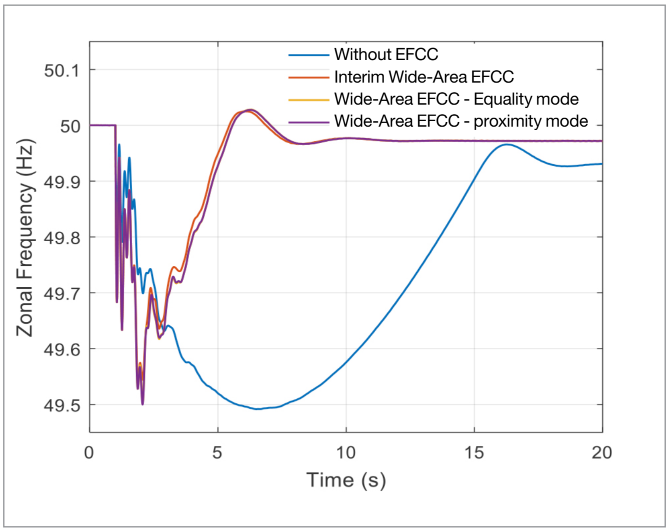


Figure 12. (a) Zonal frequency response at disturbed zone (SW zone)

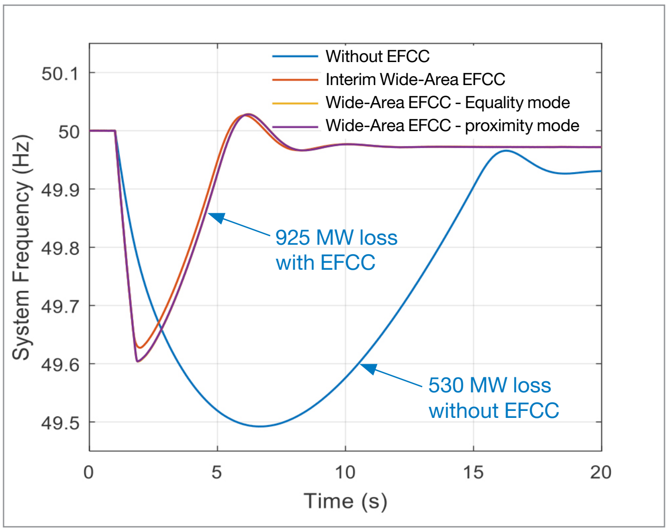


Figure 12. (b) National frequency for 36-zone GB system (2025 case study)

2. Supervisory-based LQGC

Activities undertaken

The University of Manchester have designed and developed a multi-variable, Linear Quadratic Gaussian (LQG) based supervisory control scheme for optimal regulation of system frequency and integrated a Battery Energy Storage System (BESS) into the network models. This process involved system linearisation and the development of a state-space linear model that reliably and accurately represents the dynamics of the power system. See Figure 13. Based on the linear model, the design of the LQG controller could be developed. Thereafter, the LQG supervisory controller is integrated, in Closed-Loop form, into the non-linear power system network. The test power systems used for our simulation studies include the Kundur two-area power system and the IEEE 10-machine, 39-bus New England test system.

Challenges overcome

One of the initial challenges faced during the design of the supervisory control scheme was extracting a reliable, accurate and precise state-space power system model that accurately represents the wide power system dynamic profile of the highly complex and meshed test power systems used during our simulation work. Once this had been successfully tackled, a further challenge faced was the optimal tuning of the multi-variable LQG controller to get the best coordination of system frequency once incorporated in the power network. In addition to the above, a significant amount of time was also spent accurately and realistically modelling the BESS.

It was also initially intended to undertake GB system equivalent modelling. However, due to factors beyond the university's control, outputs have been limited at this stage to the industry standard reference models named above. End reporting will however draw together the work to date with insights into how the MCS could be used to practically deploy the approach, together with discussion of the real world conditions, such as network access and generation dispatch, that could impact such optimisation and the steps that could be explored to mitigate these.

Learning achieved

During the above process, a lot of lessons were learned. These included the need to follow an optimal and reliable way of developing an accurate linear power system model that can be used for a number of future activities, such as developing a linear controller, as well as a forecasting system and dynamic responses for a number of different operating conditions.

Throughout this research and innovation period, we have identified an optimal tuning process for an LQG controller that assists the dynamic performance of a power system, such as enhancing power system transient stability and system frequency performance and robustness.

Improvement in knowledge

An LQG-based supervisory control scheme has been developed for enhanced system wide-area frequency regulation with the parallel coordination of a number of system active elements, such as BESS, solar PV and wind generators. This has been confirmed and validated through a wide variety of case studies as well as the use of different test power system models.

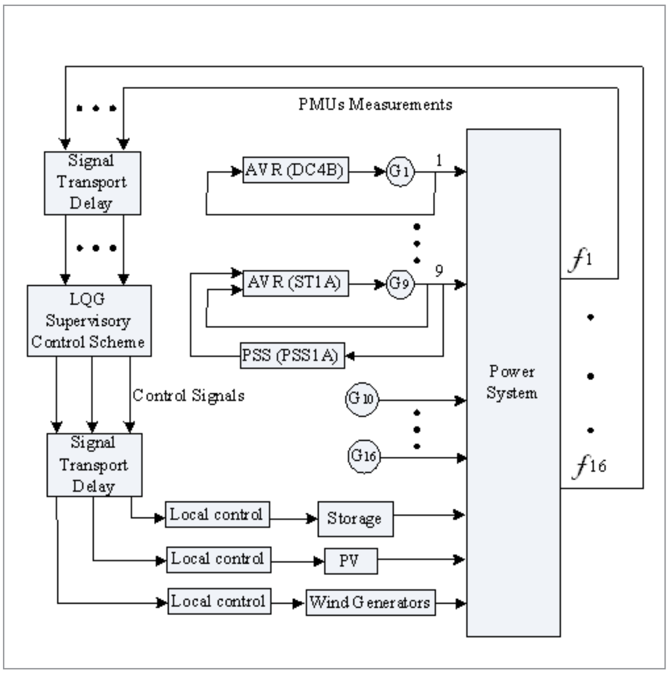


Figure 13. Illustration of the wide-area supervisory control scheme

Work package 4: Validation

RTDS HiL testing

A Real Time Digital Simulator (RTDS) is used for HiL testing and validating the MCS developed by GE Grid Solutions. To fulfil the validation activities, a dedicated HiL test environment was developed as shown in Figure 14. High quality network models were also developed in the RTDS to make the most of its capability.

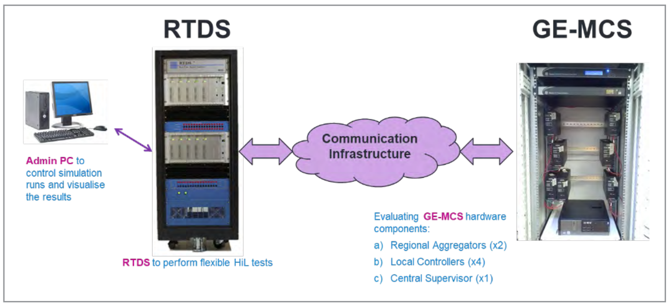


Figure 14. GB test system in RTDS

(i) GB network test system model in RTDS

The GB network model received from National Grid in PowerFactory is used to create the RTDS model. A reduced substation model of the 36-zone GB network model is simulated in RTDS with 26 buses. In this work, the GB network model consists of 20 synchronous generators and 25 asynchronously connected generators (inverter-based generation) and 26 lumped loads and is selected for EFCC validation and HiL testing, as presented in Figure 15. In this model, four different types of service providers are also modelled and integrated: solar PV, doubly fed induction generator (DFIG), CCGT and DSR, and are connected at buses 4, 20, 25 and 9, respectively. The nominal voltage of transmission lines is 400 kV.

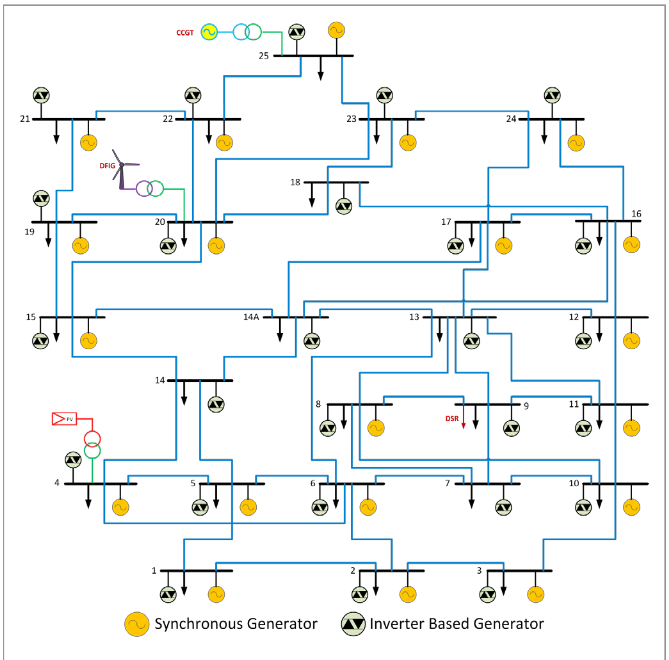


Figure 15. GB test system in RTDS

The simulated GB network model in RTDS is used to validate the entire MCS.

(ii) Testing entire MCS

In the GB network model, four types of test have been designed and conducted:

- various sizes of load increment at different locations
- various sizes of load disconnection at different locations
- the effect of fault (single line and three-phase fault to ground) with different fault durations at different buses
- event after a fault e.g. generator tripping after a fault, etc.

Results such as system frequency, system RoCoF, event detection, fault detection, service providers' responses and other variables are obtained from the GE PhasorControllers and the RTDS, and are summarised and reported. An example is shown in Figure 16.

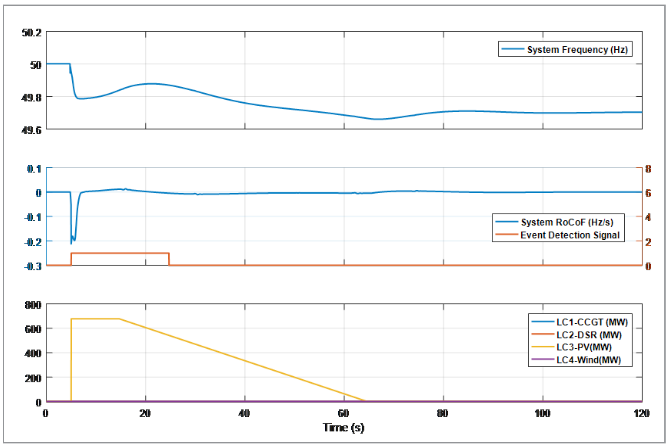


Figure 16. Simulation results of a 1000 MW load increase in zone 1

Sensitivity analysis is also conducted against the previous test cases. Various parameters are selected in the PhasorController e.g. PMU weights, ramping rate of service provider, response time of service provider and fault detection blocking time etc. Through all these test cases, the impact of key parameters is analysed and the robustness of the MCS is validated.

Lessons learned from the HiL testing are significant and will be reported through EFCC project reports, at EFCC dissemination and stakeholder engagement events, at international conferences, and in peer-reviewed journal publications.

Work package 4: Validation – the University of Strathclyde

The UoS main role in this project is to conduct comprehensive validation of the EFCC scheme using a realistic testbed established at the Power Networks Demonstration Centre (PNDC). The test activities at the PNDC include the validation of the EFCC scheme when operating in its wide-area mode (when all the communication links are available) and local operational mode (when the wide-area communication signals are lost and/or are of poor quality) and to test the impact of communications performance on the scheme's operation.

By the end of 2017, validation of the EFCC scheme's performance in local operational mode was completed and the details were discussed in the previously-issued six-monthly project progress report. During this reporting period, the UoS team has been focusing on testing the EFCC scheme in its wide-area operational mode and evaluating the impact of communications performance on its operation.

1. Validation of the EFCC scheme operation in wide-area mode
During the reporting period, extensive tests of the EFCC's wide-area operation mode were conducted using a flexible P-HiL test arrangement as shown in Figure 17. This provides a realistic testbed by coupling the physical 11kV network with the simulated transmission network (represented using a reduced GB grid model) in a RTDS.

Two Local Controllers (LCs) are used – one controlling the load banks at the PNDC's physical network and the other controlling a simulated resource represented in the RTDS simulation. These LCs receive measurement data from three Regional Aggregators (RAs) through an emulated wide-area communication network. An emulated Central Supervisor (CS) is used for supplying resource availability information.

During the tests, it was found that the locations of the disturbances and the resources providing frequency response both impact frequency behaviour during disturbances, particularly when the power system exhibits low inertia with high penetrations of renewables.

In the tests, the EFCC scheme has demonstrated that it is capable of taking such locational impacts into account when deploying the resources needed to effectively restore the frequency, while minimising the risk of power system splitting/ system separation.

The team will continue working on this phase of tests to conclude the remaining test items and analyse the data collected to fully evaluate and report on the performance of the EFCC scheme for the entire test programme.

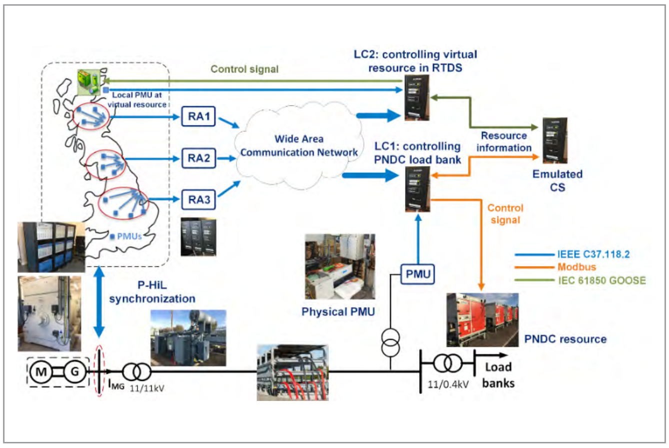


Figure 17. Schematic of the wide-area mode test configuration

2. Testing the impact of communication system performance
Another focus of the UoS team during the reporting period was evaluating the impact of communication system performance on the status of the EFCC scheme. The test set-up, as shown in Figure 18, has been established where the regional communication network connecting the PMUs and RAs and the wide-area communication network connecting the RAs and LCs are both emulated with different levels of latencies, jitters and data loss rates.

It has been established that the performance of the EFCC scheme under the various emulated communication conditions largely depends on the size of the data buffering window used in the EFCC PhasorControllers. For certain levels of latency and jitter, it has been found that the PhasorControllers are less likely to lose data packets if the buffering window is relatively large. However, increasing the buffering window could potentially increase the scheme's response time during disturbances. Therefore, we must find a balance between the desired speed of response to events and the ability to tolerate communication delay.

The team is currently working on establishing ways to quantify the best buffering window size to achieve both satisfactory tolerance to communication degradation and suitably low response times/speed of operation during disturbances and this will be reported upon in due course.

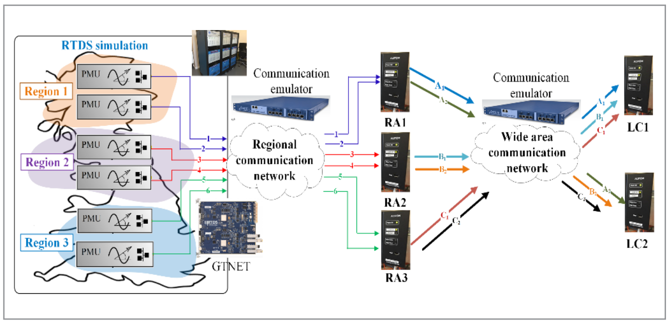


Figure 18. Test configuration for evaluating communication impact on the EFCC scheme

3. Knowledge dissemination
The team has also been working on sharing knowledge generated and lessons learned from this project through a variety of publications and events. There's more information about dissemination activities in the knowledge dissemination section in this report.

Work package 6: Commercial

This work package focused on establishing how faster / rapid frequency response could be developed and incorporated into the existing suite of commercial ancillary services. The work package has been aligned with other industry initiatives, in particular the product simplification strategy outlined in the Systems Needs and Product Strategy document and associated Product Road Map*.

* https://www.nationalgrid.com/sites/default/files/documents/Summary_SNAPS_Consultation_vFinal.pdf

By aligning in this way, the project team has been able to support the System Needs and Product Strategy work to demonstrate the viability of obtaining rapid frequency response from new technologies such as solar PV, batteries and wind farms. The aim was to ensure that these new technologies are being adequately considered alongside existing technologies in the ancillary service market to encourage competition, leading to lower overall prices and cost savings for the GB consumer.

The work package is being supported by commercial field trials which will confirm what frequency response services different technologies could provide to help operate the electricity transmission system, both now and in the future. Initial results range between successful, practical trials confirming performance, to limited evidence due to a lack of frequency events. In the latter cases, simulated events have been used to demonstrate capability. During the extension period, we hope to see further practical evidence of performance. Full details of the results will be provided in the Project Closure Report.

The project has continued to focus on quantifying the value of rapid frequency response to the NETSO and what commercial opportunities such a service could provide to industry participants. This assessment is being underpinned by a cost benefit analysis. The work, which is still underway, also considers what additional value implementing the MCS, with the ability to co-ordinate the dispatch of rapid frequency response providers, could provide to the NETSO including any associated cost savings.

Early indications suggest there are potentially significant cost benefits associated with the ability to co-ordinate the dispatch of rapid frequency response from a diverse range of service providers. This is consistent with the original analysis submitted at the project's bid stage, highlighting the potential cost savings associated with the EFCC concept.

The cost benefit analysis, being completed by Baringa Partners, aligns with National Grid's Future Energy Scenarios (FES) and SOF. The final results will be disseminated to the industry via webinar and made available in the Project Closure Report along with any proposed next steps.

Work package 7: Communications

The project has created a Systems Investigation and Business Impacts Report which has been through several internal review and comment cycles. In addition, the first part of the year was spent working on presentations for the dissemination event at Cheltenham, and then contributing to the dissemination event itself.

An internal design document has been created for the National Grid test centre so the PhasorControllers can be set up in a National Grid test lab environment with a more complex networking configuration than has been previously tested by the rest of the project.

While it will still be contained within one lab, the network will introduce data from remote PMUs and PhasorControllers will be separated into their own virtual networks. This will allow the National Grid network engineers to familiarise themselves with the set-up and configuration of the PhasorControllers. It will also allow National Grid to evaluate any complexities or difficulties that could be introduced by adding routing and firewalls into the system.

During the test lab evaluation phase, Digital Risk and Security will carry out vulnerability assessments on the PhasorController solution. An output from the lab testing will be a network design that will allow National Grid and any selected partners to carry out live integrated field trials. In this respect, network service providers have been engaged to try and price up an option to use mobile broadband with encryption for remote providers that do not have fixed wire communications.

1. National Grid demonstration of the MCS
It was previously reported that before project completion, National Grid would demonstrate GE Grid Solutions' MCS using the central supervisor, regional aggregator and local controller units. This was to understand how the existing communications infrastructure can support reliable operation of the control scheme, the results of which would form a basis for progressing EFCC towards business as usual.

During this reporting period, communications interface details with Centrica and Belectric were discussed and the scope of the demonstration outlined. Site surveys took place to evaluate regional aggregator installations at Grain, South Humber Bank and Walham 400kV substations. A local controller is also to be installed at Grain and encoded to represent an interconnector i.e. pre-set with similar power ramping characteristics to show its response to a frequency event.

Work has continued on the installation of new PMUs at National Grid substations with the capability to interface with the MCS. This will also serve to increase real-time monitoring across the electricity network. A PMU was commissioned at St John's Wood in May, with additional units at Swansea, Sellindge and Drax planned for installation during the summer.

It was anticipated that this demonstration, though not included within the original scope of EFCC, could be catered for within the EFCC project budget. However, during this reporting period it was established that to guarantee that the prototype PhasorControllers are cyber-secure, additional firmware development would be needed, as well as additional testing scenarios with commercial partners. This meant additional funding was needed to be sought.

National Grid is therefore now evaluating a NIA funding proposal for this demonstration work. Although the EFCC project has developed the MCS concept and validated its functionality, it was never intended to deploy the control system in an operational environment. An NIA project is therefore the next step to demonstrate the MCS in an operational environment. This will allow us to transition the MCS into our business as usual activities.

The main aims of the demonstration are to establish:

- how the control scheme can be installed on the existing National Grid communications infrastructure making sure cyber-security practices are met, and assessing the impact in terms of latency and lost data and/or signals
- the practical aspects of setting up communication links to resource providers to show how third parties could connect to the MCS and provide a frequency response service. The central supervisor, sited at a National Grid office, will update the MCS with regional inertia data to simulate how these values change during the day, as well as receive available power information from the local controllers
- how the MCS could respond to real frequency events using active measurements from PMUs and monitoring devices already installed at National Grid sites. In addition, simulated data from historical frequency events will be input to test the MCS and reinforce live system testing. This will be done using the PhasorPoint platform put in place as part of the NIC VISOR project to capture the output signals from each of the PhasorControllers used
- the performance of dynamic monitoring devices already installed on the transmission network in terms of how they connect with GE Grid Solutions' equipment and relay electrical measurements to the MCS. Speed of data handling, data resolution and reliability can be used to determine a minimum specification for reliable control operation
- how regional transmission system inertia estimates impact the MCS frequency response calculations with varying generation and demand patterns and define acceptable levels of error to evaluate operational consequences i.e. potential effect on control room frequency measures and National Grid processes.

During the next few months National Grid's IS team will interrogate the PhasorControllers, carry out a cyber-security assessment to understand whether they meet technical requirements, and facilitate any further software or firmware development needed to target problematic areas and ensure the PhasorControllers are ready to be installed on the electricity network. This exercise will contribute towards outlining a technical specification for implementing a wide-area control system. This will be invaluable in taking these developments into operational use.

Intellectual property rights

GE Grid Solutions and all other project partners will make their reports and documents available on the project website wherever possible to meet the requirement to publish intellectual property developed within this project. Full versions will be available to all project partners as part of the multi-party contract they signed. This approach to reviewing and publishing background and foreground intellectual property will be repeated on all documents produced throughout the project.

Risk management

Current risks

All project partners regularly monitor and review project risks. Crucial risks for this reporting period are detailed below and a full risk register can be found in Appendix C of this report.

Risk no.	Work streams/ area	Risk description	Cause	Consequence	Risk owner	Likelihood (1-5)	Financial impact (1 - 5)	Reputational impact (1 - 5)	RAG	Escalation route	Action plan	Control opinion
18	General	Communication between devices underperforms.	Communication infrastructure is not fit for purpose.	The existing communication infrastructure may inhibit the speed of response of a control, reducing scheme effectiveness.	National Grid	5	5	4	25	Project manager	Throughout the NG demonstration, show that the communications infrastructure is appropriate for the EFCC solution and document/report on required changes to either post-project for a full-scale rollout.	Partially effective
56	WP2.5 - wind	EFCC project needs to agree with Ørsted and Siemens and associated Joint Venture partners for the use of wind farm (test to be conducted on 6 MW turbines without deloading).	Delay in agreeing use of wind farm.	Delays to work package and overall project outcomes.	National Grid	5	3	4	20	Project manager	Agree a schedule of tests and activities with Ørsted and Siemens and begin contractual discussions in parallel for phase 2. Agree contractual arrangements for trials. Ørsted and Siemens to undertake tests and to submit test report to NG.	Partially effective
62	WP3 - optimisation	Revised timeline for University of Manchester affects the project's work deliverables.	University of Manchester deliverables slipping due to delays in project recruitment and acquiring the appropriate tools for the systems studies.	Timeline for work deliverables compromised.	Project manager	4	3	4	16	Steering Group	Revised project timeline agreed with University of Manchester, with associated project dependencies identified and managed.	Partially effective
78	WP2 - NG demonstration	The data input into the MCS for the NG demonstration is likely to be complicated, manual and time intensive.	The MCS developed to date is only a prototype and is therefore not as user friendly as it could be!	The NG demonstration could be difficult to implement and very time consuming, leading to potential delays.	Charlotte Grant and Nick Martin	5	3	3	15	Project manager	Execute the NG demonstration as per the agreed approach.	Partially effective
82	WP1 - control system	Reason RPV311 (PMU) has shown unexpected behaviour in terms of data jumps.	Reason RPV311 algorithm/time synchronisation issues.	Control scheme may act upon data jumps/spikes which are not related to an event. The RPV data becomes somewhat unreliable for control purposes.	GE (Reason)	4	1	4	16	Project manager	Temporary workaround: adapt PhasorController control scheme (event detection) to deal with certain predefined data jumps/ spikes. RPV firmware update: GE Reason team to provide latest firmware upgrade for installation. GE WAMS team to test in Edinburgh lab before making available to partners.	Partially effective
92	WP2.3 - PV power plant	Lack of access to solar farms to complete tests.	Inability to gain use of solar farm from owner (contractual issues).	Inability to complete the trials and reduce learning from workstream.	Belectric	4	2	4	16	Project manager	Negotiate contract with solar farm owners.	Partially effective

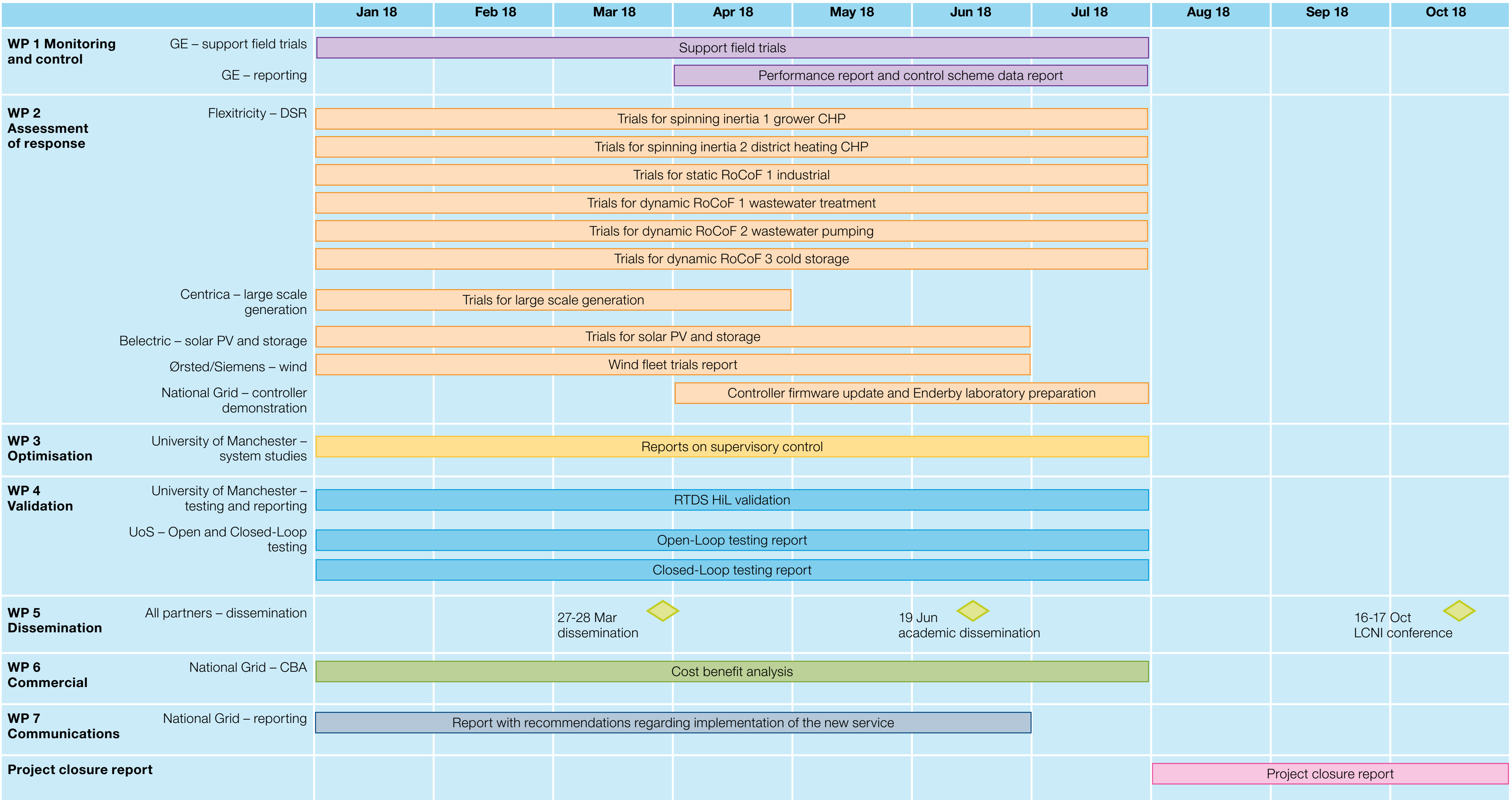
Accuracy assurance statement

This EFCC progress report has been produced in agreement with the entire project steering committee. All project partners have been involved in writing and reviewing it. The report has been approved by the EFCC project steering committee and by Graham Stein, Network Operability Manager, on behalf of Julian Leslie, Network Capability – Electricity Manager and the project sponsor. Every effort has been made to ensure that all information in the report is true and accurate.

Graham Stein
Network Operability Manager
National Grid

Appendices

Appendix A: EFCC project plan



Appendix C: Project risk register, risk management and contingency plans

Risk no.	Work streams/ area	Risk description	Cause	Consequence	Risk owner	Likelihood (1-5)	Financial impact (1 - 5)	Reputational impact (1 - 5)	RAG	Escalation route	Action plan	Control opinion
2	General	Partners leave project before completion.	Partner decides to leave the project. Reason could be commercial, operational, etc.	Work is lost or unable to start and the usefulness of the project results is reduced or project is delayed.	Project manager	3	2	4	12	Steering Group	Put thorough contracts in place. Procurement processes have considered ongoing size and reliability of partners. Project management is working with partners to resolve issues.	Partially 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.	Overspend requiring Ofgem change request approval.	Project manager	2	3	4	8	Steering Group	Work with partners to manage workstream budget to completion.	Partially effective
4	General	Material costs increase.	The cost of materials rises for unforeseen circumstances.	Potential project funding gap. Alternative funding is needed or the project scope is reduced.	Project manager	3	2	3	9	Steering Group	Each partner to assess cost of equipment for ongoing basis and provide change requests for additional spend.	Partially effective
5	General	Significant changes to the GB electricity system during 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	5	3	5	25	Steering Group	We will consider future developments and scenarios. We will make sure the solution's usefulness matches planning of system and consider future system/market changes in the Project Closure Report.	Partially effective
6	General	Critical staff leave National Grid or our project partners during project lifecycle.	Usual and unavoidable staff turnover means key staff leave National Grid or our project partners.	The project is delayed. The project team doesn't have the expertise to deliver the project.	Project manager	4	2	3	12	Steering Group	Knowledge of, and responsibility for, project will not be with one person. Make sure there is documentation and guidance to help anyone joining project team. Thorough handover processes to be in place.	Partially effective
7	General	The technology quality 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.	All partners	3	3	3	9	Project manager	Ensure close co-operation between all partners throughout the demonstration phase to clearly identify bugs/defects/issues and provide fixes/patches wherever possible. Clearly document identified bugs/ defects/issues and suggest areas of future work, post-project, to improve the EFCC solution offered.	Partially effective
9	General	Costs of solution over lifetime are high.	Full cost of solution is not considered and/or understood.	The solution's usefulness and commercial opportunities are restricted.	Project manager	4	4	4	16	Steering Group	Full long-term costs of solution have been considered as part of detailed cost benefit analysis calculations.	Partially effective
11	General	Component failure during project.	Equipment will be run in new ways that may cause problems or failures.	The equipment may need to be repaired or replaced. The tests may be delayed.	Belectric, Centrica, GE, Flexitricity	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. Flexitricity issue resolved. Belectric issue for PV stand-alone resolved. Equipment at partners' sites. Risk remaining open as 'low probability', as there could be component failure.	Effective
12	General	Strategic spares policy.	Spares policy for new technology may not be suitable when all risks are considered.	If suitable spares are not identified and available, the risks of losing the PMU/controller in the network may reduce effectiveness of project.	National Grid	4	3	3	12	Project manager	Contingency plans will be drawn up to include potential alternative monitoring locations that could be used if equipment and/or communications fail. Off-the shelf products that are readily replaceable are used. The proposed structure will contain PMUs in each zone that should allow continued supervisory actions with the loss of a device. Redundancy will be planned for to make sure the controller is suitably backed-up.	Partially effective
13	General	Maintenance requirements.	Manufacturer recommends intensive and regular maintenance activities that do not fit with project owner's expectations.	Regular intensive maintenance requires additional field staff. This could affect the network operation, reducing power transfer levels and constraint costs.	National Grid	3	3	3	9	Project manager	Work with the manufacturers to understand maintenance requirements and the impact on the design or selection of components. Arrange remote VPN access to controller for remote logging and maintenance, especially for beta release stages.	Partially effective
14	WP7 - comms	Loss of telecommunications.	Technical fault leads to loss of telecommunications between systems.	Reduced availability and performance.	National Grid	3	3	4	12	Project manager	Design a scheme for continued operation, or graceful degradation, if telecommunications are lost.	Partially effective
15	General	Inefficient operation of MCS.	MCS incorrectly configured, resulting in spurious tripping or too many control initiation commands.	Over-response from resources reducing stability; excessive set-point changes in generators reducing asset lifetime.	National Grid	3	3	5	15	Project manager	The scheme will be extensively tested in a laboratory environment before it's used on the network. 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.	Partially 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.	National Grid	4	3	3	12	Project manager	Ensure we manage our own OPEX costs in an economical and efficient manner in any potential future rollout.	Partially effective
18	General	Communication between devices underperforms.	Communication infrastructure is not fit for purpose.	The existing communication infrastructure may inhibit the speed of response of a control, reducing scheme effectiveness.	National Grid	5	5	4	25	Project manager	Throughout the NG demonstration, show that the communications infrastructure is appropriate for the EFCC solution and document/report on required changes to either post-project for a full-scale rollout.	Partially effective
19	General	Outage required for commissioning.	Inability to obtain the relevant outages for commissioning.	Possible delays to commissioning programme or cost of outage.	National Grid	4	1	3	12	Project manager	Acquire outages required to facilitate PMU installation.	Partially effective
20	General	Problems with commissioning procedures.	Commissioning procedures are unclear or untested, being difficult to complete in practice.	Delays in commissioning the project.	National Grid	4	3	3	12	Project manager	Identify and agree all the commissioning procedures with the supplier for the new technology, and any problems that arise.	Partially effective
22	Health, safety and environmental	Use of new equipment causes a safety incident.	Lack of experience and knowledge about new pieces of equipment.	Health and safety risks caused by 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	Arrange specialist tools and training for maintenance activity. Procedures to be developed and reviewed by all partners' SHES consultants. Controller to go through rigorous testing.	Partially effective

Appendix C: Project risk register, risk management and contingency plans cont.

Risk no.	Work streams/ area	Risk description	Cause	Consequence	Risk owner	Likelihood (1-5)	Financial impact (1 - 5)	Reputational impact (1 - 5)	RAG	Escalation route	Action plan	Control opinion
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. The controller and the individual resources must exchange information so that resources can be called upon when needed.	Lack of comms path or interoperability issues between the controller and the resources could delay initiation of response and make the central control scheme less able to halt frequency excursions.	GE	2	2	2	4	Project manager	Agree common standards and offer a simple IO for all controllable components through standard interface protocols, which will be agreed 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. Need for different interface protocols to communicate with distributed resources. The concepts of Local Control Units and Central Supervisor were highlighted during project partner meeting 30 April. Specifications Event Detection, Control Platform and Resource Allocation were issued for partner review and comments were addressed. GE will work with project partners to discuss requirements and concepts for different WP1 applications. Interface discussions with project partners completed and interfaces successfully developed and demonstrated. Change request approved for GE development of PhasorController IEC61850 MMS Client Stack interface.	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 measurements. The control platform's performance may be reduced because of more measurement and resource data with larger-scale roll-out. Another risk is 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, delaying its full effectiveness and putting the learning from the project into action. The risk for this stage of the project is minimal.	GE	3	4	2	12	Project manager	Laboratory testing will allow scalability testing of the control platform with more inputs than will be used in the trials. This will allow the limits of the control platform to be found and define new ways to overcome these limits. One of the learning outcomes of the project will be how to deploy the control system for larger roll-out, which will minimise the risk of delayed roll-out. Controller development path enables easy porting between hardware platforms – other hardware solutions will be considered if greater performance is needed. GE will continue performance testing/monitoring at different stages throughout the project life-cycle and look into areas for further improvement. Ongoing discussions between GE and NG IS team to discuss infrastructure. No issues expected.	Partially 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	1	4	4	4	Project manager	Have pursued three separate technical approaches to spread risk (spinning inertia, static RoCoF, dynamic RoCoF). We now have live sites operating all three technical approaches.	Effective
37	WP2.1 - DSR	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	All detection takes place locally and signal chains have been kept to a minimum.	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).	Partially effective
39	WP2.1 - DSR	DSR deployment lead time too long.	Normal delays in dealing with industrial and commercial energy users.	Unable to operate long enough trial; some customers are ready too late for trial.	Flexitricity	1	3	3	3	Project manager	All sites now live for operation.	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	2	2	6	Project manager	Plan tests accordingly.	Partially effective
46	WP5 - dissemination	Knowledge gained from the project is not shared properly with industry and other interested parties.	Not enough dissemination resources. 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.	Project manager	1	3	5	5	Steering Group	Knowledge sharing took place in March 2018 (Cheltenham) and June 2018 (Strathclyde).	Effective
47	WP6 - commercial	Market for EFCC not taken up by possible resource providers.	Knowledge not disseminated so providers can't prepare. Commercial arrangements not attractive.	The successful roll out of the solution will be delayed.	Project manager	4	4	4	16	Steering Group	Make sure knowledge is shared. Establish clear communication channels with interested parties. Develop commercial terms thoroughly before roll-out.	Partially effective

Appendix C: Project risk register, risk management and contingency plans cont.

Risk no.	Work streams/ area	Risk description	Cause	Consequence	Risk owner	Likelihood (1-5)	Financial impact (1 - 5)	Reputational impact (1 - 5)	RAG	Escalation route	Action plan	Control opinion
56	WP2.5 - wind	EFCC project needs to agree with Ørsted and Siemens and associated Joint Venture partners for the use of wind farm (test to be conducted on 6 MW turbines without deloading).	Delay in agreeing use of wind farm.	Delays to work package and overall project outcomes.	National Grid	5	3	4	20	Project manager	Agree a schedule of tests and activities with Ørsted and Siemens and begin contractual discussions in parallel for phase 2. Agree contractual arrangements for trials. Ørsted and Siemens to undertake tests and to submit test report to NG.	Partially effective
61	WP2.5 - wind	Revised timeline for wind workpack does not coordinate with the other workpacks.	Delays caused by the length of time to sign new partner contracts and unforeseen model data validation issues.	Wind test findings not available in time for meaningful inclusion in the project conclusions and recommendations.	Project manager	2	3	4	8	Steering Group	Determine if National Grid is to request further trials on another commercially operational windfarm.	Partially effective
62	WP3 - optimisation	Revised timeline for University of Manchester affects the project's work deliverables.	University of Manchester deliverables slipping due to delays in project recruitment and acquiring the appropriate tools for the systems studies.	Timeline for work deliverables compromised.	Project manager	4	3	4	16	Steering Group	Revised project timeline agreed with University of Manchester, with associated project dependencies identified and managed.	Partially effective
63	General	General back loading of deliverables in the project.	Slippage against baseline for deliverables.	Compromising scope and quality of deliverables.	Project manager	3	3	5	15	Steering Group	NGET and partners have monthly review of planned deliverables, identifying any issues with delivery, investigating alternatives and escalating to Steering Group.	Partially effective
64	General	Handoffs between partners are delayed.	Handoffs are not clear in the plan or not proactively managed to ensure the planned timeline is kept.	Delays compromising other work deliverables.	Project manager	2	3	4	8	Steering Group	Dependencies discussed for decision at Steering Group meetings.	Partially effective
69	WP6 - commercial	Delay in delivering the commercial workpack.	Understanding the nature of the WP deliverables and unable to access specialist resourcing skills.	Work package is not delivered on time, undermining success of project.	Project manager	5	3	5	25	National Grid	Recruited specialist resource who will draw on existing expertise within NGET. Further recruitment ongoing. Will align with FRSO flexibility work stream (product simplification consultation) - resource field trials to input into consultation process. Develop further commercial work packages with EFCC infrastructure.	Partially effective
71	WP2.6	Non delivery of a meaningful NG demonstration (simulation and/or network).	Lack of clarity in original submission and difficulty in differentiating NG demonstration from other partners' demonstrations.	Lack of evidence of how the system would operate in a real operational environment.	Project manager	4	1	5	20	National Grid	Dedicated NG resource secured and developed approach that includes recommendations of data comms requirements. Receive appropriate training from GE. SAT installation and trials planned.	Partially effective
73	WP2.3 - PV power plant	Insufficient time left to complete trials.	Equipment failure and delays installing other components (batteries).	Insufficient data to draw any meaningful conclusions to feed into commercial work package. Delays in project milestones (SDRC).	Belectric	4	3	4	16	Steering Group	Engage with Belectric to develop revised project timeline which mitigates against project risks.	Partially effective
74	WP2.1 - DSR	Delays to dynamic RoCoF trials.	Insufficient operational hours at Dynamic RoCoF sites.	Insufficient data to draw any meaningful conclusions, to feed into commercial work package. Delays in project milestones (SDRC).	Flexitricity	2	3	3	6	Steering Group	Additional resource applied; three sites now progressing well with trials.	Partially effective
75	WP4 - validation	Delay in finishing all the test activities and more staff and PNDC facility time needed.	Issues were identified during tests and need extra time for GE to fix and further tests are required to verify the new versions of the system.	Delay in overall project schedule.	Universities	5	2	3	15	Project manager	Close communication with GE has been maintained to ensure the issues are resolved as soon as possible and the impact on the test schedule is minimised. Repeat the tests to make sure the new function block is fully validated.	Partially effective
77	WP7 - comms	Existing telecommunications network and PMUs unable to support the developed MCS functionality for BaU roll out.	Incompatible communications protocols used plus differing ETO and SO priorities for the same fault recorder equipment with PMU functionality enabled.	Fault recorders and dynamic monitoring equipment process frequency data for system monitoring purposes. The project is unable to achieve the targeted speed of response times.	Project manager	4	4	4	16	National Grid	Make sure outcomes of the NG demonstration are fed into WP7 impact assessment.	Partially effective
78	WP2 - NG demonstration	The data input into the MCS for the NG demonstration is likely to be complicated, manual and time intensive.	The MCS developed to date is only a prototype and is therefore not as user friendly as it could be!	The NG demonstration could be difficult to implement and very time consuming, leading to potential delays.	Charlotte Grant and Nick Martin	5	3	3	15	Project manager	Execute the NG demonstration as per the agreed approach.	Partially effective
82	WP1 - control system	Reason RPV311 (PMU) has shown unexpected behaviour in terms of data jumps.	Reason RPV311 algorithm/time synchronisation issues.	Control scheme may act upon data jumps/spikes which are not related to an event. The RPV data becomes somewhat unreliable for control purposes.	GE (Reason)	4	1	4	16	Project manager	Temporary workaround: adapt PhasorController control scheme (event detection) to deal with certain predefined data jumps/spikes. RPV firmware update: GE Reason team to provide latest firmware upgrade for installation. GE WAMS team to test in Edinburgh lab before making available to partners.	Effective
85	WP5 - dissemination	Lack of market engagement.	Dissemination steps are unclear.	Reputational and potentially undermine commercial implementation.	Project manager	3	1	3	9	National Grid	Confirm findings of trials. Clarification of NG demonstration. Completion of CBA and share with partners. Decision on further dissemination event e.g. WebEx.	Partially effective
86	WP2 - NG demonstration	NG cyber security won't allow a demonstration.	GE boxes are unsecure.	No live demo.	Project manager	4	3	3	12	National Grid	NG to confirm to GE security pre-requisites and liaise with GE on GE testing/proof.	Partially effective
87	WP6 - commercial	Delays to the CBA.	Delay in Baringa starting and/or data inputs required being delayed or incomplete and/or consultant fee delayed sign off.	CBA not being complete or ready for dissemination event and/or ready for frequency market roll out.	Project manager	3	2	4	12	National Grid	Constant communication with Baringa over progress. NGET to report to Baringa promptly.	Partially effective
88	WP2 - NG demonstration	NIA additional funding not approved or other factors prevent the NIA project from going ahead.	Business not comfortable with approach/benefit or contract negotiations with suppliers are unsuccessful etc.	Very limited opportunity for trials and therefore scope of meaningful results.	Project manager	4	2	3	12	National Grid	Use escalation routes accordingly. Explain how the project will benefit the business.	Partially effective

Appendix C: Project risk register, risk management and contingency plans cont.

Risk no.	Work streams/ area	Risk description	Cause	Consequence	Risk owner	Likelihood (1-5)	Financial impact (1 - 5)	Reputational impact (1 - 5)	RAG	Escalation route	Action plan	Control opinion
89	WP4 - validation	Lack of visibility of academic test results.	Delays to academic reports.	Does not validate monitoring and control suite.	Universities, National Grid	5	2	4	20	Project manager	Evaluate draft reports and amend risk actions accordingly. Final reports expected.	Partially effective
91	All	Exceeding budget for project.	Partners exceeding partner/workpack budgets.	Unable to deliver extended scope of project.	National Grid	3	5	5	15	Project manager	Manage partners and expectations of scope. Close out remaining invoices with partner. Manage remaining budget during closure write-up.	Partially effective
92	WP2.3 - PV power plant	Lack of access to solar farms to complete tests.	Inability to gain use of solar farm from owner (contractual issues).	Inability to complete the trials and reduce learning from workstream.	Belectric	4	2	4	16	Project manager	Negotiate contract with solar farm owners.	Partially effective
94	WP6 - commercial	New EFCC balancing service is not developed.	SNAPS and product road map specifying different requirements for frequency services, than expected at the start of the project.	Not meeting project objectives and limited commercial participation in future innovation projects.	National Grid	5	1	5	25	Project manager	Work with SNAPS and product road map for alignment. Continue to work with all project partners to ensure their opinions are fully considered and addressed where appropriate.	Partially effective
95	WP2.3 - PV power plant	Hybrid solar PV and battery storage trials not concluding within EFCC timeframes.	Installation and commissioning delays of the battery storage unit and the NIA project in general.	Lack of necessary data included in EFCC results and conclusions.	Belectric, National Grid	5	3	5	25	Project manager	Work closely with Belectric on installations and commissioning. The option of computational simulations are also being investigated.	Partially effective

Closed risks

Risk no.	Work streams/ area	Risk description	Cause	Consequence	Risk owner	Likelihood (1-5)	Financial impact (1 - 5)	Reputational impact (1 - 5)	RAG	Escalation route	Action plan	Control opinion
17	General	Delays in installing key control scheme components.	Supplier of TO/TSO delays base installation. 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 trial, leaving less time for reports, tuning and dissemination.	National Grid	5	2	3	15	Project manager	Closed, no longer applicable. LC7 installed, PMUs in process of being installed, controllers installed in test bed.	Effective
21	General	Capital costs.	Costs higher than anticipated.	Project budget exceeded.	National Grid	4	3	4	16	Project manager	Capital assets have be purchased within budget.	Effective
31	WP1 - control system	Additional testing and tuning.	The controller may require additional tests and fine tuning based on real system measurements from the UK network to ensure robust operation. Data will need to be gathered over enough time to determine the control scheme performance.	The selected control scheme will be unable to effectively deploy resources to arrest a frequency excursion.	National Grid	3	3	3	9	Project manager	Additional tuning and patches completed MCS development for the project scope.	Effective
40	WP2.2 - large scale generation	CCGT operators struggle to get relevant technical input from OEM.	Lack of communication or timely response from OEM.	The project is delayed.	Centrica	1	2	2	2	Project manager	Draw up 'heads of terms' with OEM. Pay OEM (from funding) for relevant 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. This means that true and simulated performances will not align.	Universities	5	2	2	10	Project manager	Universities developed own models; risk closed.	Effective
48	WP1 - control system	Demonstration partner fails to install and configure demonstration set-up on time for SAT.	Challenges with installation and configuration or lack of understanding/training.	Demonstration is delayed, which is likely to affect other activities.	GE, National Grid	4	1	3	12	Project manager	NG SAT part of NIA demo. All other partner SAT completed.	Effective
65	WP4 - validation	System testing is delayed.	Additional trial equipment requirements identified, which are not immediately available. Identifying an issue in MCS and communication with GE to receive a new frame-work of AFBs about unexpected behaviour might also cause a delay in HiL-testing.	Delay in testing phase, which delays the general project timeline.	University of Manchester	3	3	3	9	Steering Group	First report for HiL testing submitted to NG. This is based on the standard two-area test system model for assessing a range of system cases and operational conditions to test the functionality of developed AFB. Feb-Mar 2018: first draft of second report for testing the entire MCS using Manchester HiL testing facilities will be prepared for NG. Issues regarding resource allocation AFB, which has been discussed at a face-to-face meeting in Edinburgh, will be addressed by GE and testing progress will move forward. Closed and merged into risk 75.	Effective
66	WP2 - all	Test programme and schedule not clearly defined.	Test programme format not clearly defined, impacting scheduling of commercial trials.	Delays in test plan starting and quality of test outputs.	Project manager	5	3	4	20	Steering Group	Test programme and schedule agreed and started.	Effective
67	WP2.2 - large scale generation	Trial timeline delayed due to potentially volatile market prices.	Recent high market prices creates reluctance to carry out non-essential work on plant.	Centrica delays testing programme.	Centrica	1	3	3	3	Project manager	Centrica planned works completed.	Effective
68	WP7 - comms	Delay in delivering the workpack WP7.	Understanding the nature of the WP deliverables and unable to access specialist resourcing skills.	Work package is not delivered on time, undermining success of project.	Project manager	4	3	5	20	National Grid	WP7 planned works completed.	Effective
70	WP2.2 - large scale generation	Centrica unable to participate in project and deliver WP2.2.	Centrica selling CCGT which is earmarked for trials.	Centrica do not complete trials, putting WP2.2 at risk of non delivery.	Centrica	5	3	4	20	Steering Group	Centrica negotiated contact with EPH.	Effective
76	WP3 - optimisation	UoM workload is too broad to demonstrate application system outcomes from EFCC.	Scope of WP3 was unclear.	Project closure report not having enough information on effects of EFCC in the future.	University of Manchester, National Grid	5	2	3	15	Project manager	Closed; work scope redefined to ensure concise EFCC outputs.	Effective
79	WP4 - validation	Delay in completing stage 2 physical testing due to fault in MG set. Replacement part has a 2-3 week lead time.	The MG set tachometer has developed a fault that prevents the MG set from running.	Delays in overall test completion schedule.	UoS	5	1	1	5	Project manager	Replacement part received and testing underway; risk closed.	Effective
80	WP2.3 - PV power plant	Lack of contract with new solar farm owners means that the solar trials do not take place.	Belectric have sold the solar farm to new owners who are not contracted with NG to carry out the trials.	Project doesn't meet one of original aims.	Belectric	5	4	4	20	Project manager	Contract signed; risk closed.	Effective
81	General	Project extension request is refused by Ofgem.	Project extension request is expansion of scope and/ or budget that is rejected by Ofgem.	Project has to complete on time, on original scope and to budget.	Project manager	3	5	5	15	National Grid	Ofgem approved extension; risk closed.	Effective
83	WP2.2 - large scale generation	Centrica and EPH don't agree on project continuation.	Likely to be down to split of monies still outstanding.	Formal conclusion of project would not be reached. The project and various companies would suffer reputational damage.	Centrica	2	2	3	6	Project manager	Agreement reached between EPH and Centrica.	Effective
84	WP5 - dissemination	Dissemination materials are not ready in time or up to standard.	Partners and NG workpacks develop materials behind schedule without time for a thorough review cycle.	Potential contradictory messaging between presenters and/or incomplete messaging on the day.	Project manager	4	1	5	20	National Grid	Dissemination materials ready on time, delegates gave good feedback on two-day dissemination event.	Effective
90	WP4 - validation	Delays to UoS's academic testing schedule.	Continuing monitoring and control boxes not operating as expected. Extra upgrades to functionality needed.	UoS is having to perform retesting/ reworking.	UoS, National Grid	5	3	4	20	Project manager	UoS testing schedule agreed and underway.	Effective
93	WP2.6 - NG demonstration	South Humber Bank does not take part in NG WP2.6 demonstration.	No agreement between contractual partners.	Reduced scope of WP2.6 trial (no transmission connected participation).	Centrica, National Grid	4	2	3	12	Project manager	Centrica trial completed.	Effective

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