Technical Guidance and Testing Procedure for Static and Dynamic Demand Response and Battery Storage Providers of Frequency Balancing Services

SMARTer System Performance, Transmission Network Strategy

Signatures

Written by:	Reviewed by:	Approved By:
Nikola Gargov Jingling Sun	Owen Lloyd Andrew Dixon Graham Stein Mark Horley Neil Rowley	Vandad Hamidi
Signature (Date)	**Signature (Date)**	**Signature (Date)**

Revision History

Ver	Date	Description	Author
1.00	20/08/14	Draft - DSR	JS
2.00	12/09/14	Draft - DSR	NG
3.00	30/01/15	Draft – DSR	NG
4.00	19/02/15	Draft – DSR+Storage	NG

Table of Contents

Summary

This document aims to provide guidance to Demand Side Response (DSR) and Battery Storage providers of frequency balancing services to National Grid. The report provides a description of what frequency balancing is, how it normally operates and how it has to be provided to National Grid. Further, the tests required to demonstrate the capability for providing frequency response are explained in the document (limited to DSR and Battery Storage). Where plant is required to demonstrate compliance with the Grid Code other testing will also be required

For any further enquiries or questions please contact:

Email: commercial.operation@nationalgrid.com

Telephone: +44 (0)1926 65 4611

1. Demand Side Response

The National Electricity Transmission System is an islanded network with no AC connections to other networks. In order to manage the system frequency within the normal operating range 49.5Hz to 50.5Hz (CC.6.1.2), National Grid relies on frequency balancing service providers to modulate their active power output or consumption[1] in order to minimise the imbalance between generation and demand on the system. The extent of the required modulation is determined by the deviation of the system frequency from 50Hz.

The Glossary & Definitions section of the Grid Code defines Primary, Secondary and High frequency response including the requirement that the response is progressively delivered with increasing time. This section summarises the definition of additional key terms used in this document.

Demand Side Response: A deliberate change to an end user's natural pattern of metered electricity consumption brought about by a signal from another party. This may be either a shift in demand in a flexible timescale or a permanent modification in electrical power usage. Modification may be executed by either managing electrical load or by the self-supply of electrical load from local generation sources enabled by direct control and/or market signals. Under this definition, DSR only occurs because the consumer has pro-actively chosen to take part in a DSR programme and does not include planned load shifting to avoid price differential periods[2].

Relevant Parties in DSR: Figure 1 illustrates graphically one way in which DSR parties can interact with National Grid. However, it should be noted that DSR parties can also interact directly with National Grid. In effect any load or self-supply generation can theoretically provide a response service to National Grid, provided the service requirements are met. This therefore includes: industrial, commercial and domestic loads that can deliver deliberate change in demand on a single or multiple sites basis. The way of providing response should be coordinated in a way that all loads (at all sites) can modify their demand at the same time or in other words act as a "virtual power plant".

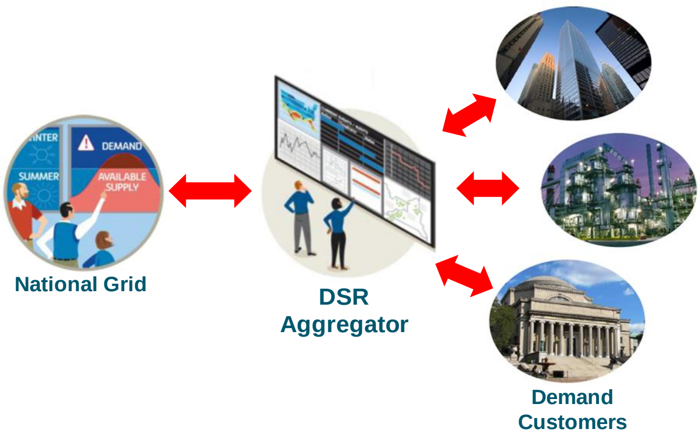

Figure 1 Relevant parties in a DSR-aggregation model

1 http://www2.nationalgrid.com/uk/services/balancing-services/frequency-response/mandatory-frequency-response/
2 Demand Side Response Shared Services Framework Concept Paper For Industry Consultation- April 2014

A "virtual power plant" can be achieved by:

- A centralised system that controls all load sites at the same time by appropriate communication systems;

- Sites that can make an independent action by monitoring the grid frequency and act uniformly based on the grid frequency (assuming that this is uniform across all sites).

2. Battery Storage

Battery storage can be connected at transmission and distribution terminals and consists of batteries that can store energy and are able to release or absorb energy from the power network[3]. Being able to absorb and release energy, battery storage may be used to provide frequency balancing services, where the power is being generated or absorbed statically or dynamically depending on the system frequency.

The configuration of battery storage may vary in location and capacity but a single service provider (sometimes referred as an "aggregator") has to be able to respond in a coordinated manner in order to achieve "virtual power plant" performance (if batteries are connected at different locations).

3. Frequency Services that DSR and Battery Storage may provide to the System Operator (SO) – National Grid

National Grid purchases balancing services (reserve and response) to control the grid frequency in GB. The following two response services are seen as relevant:

3.1. Firm Frequency Response

This service is open to all parties that can pre-qualify against the service requirements. This service is a continuous[4] and proportional modulation of generation or demand. More information can found on National Grid's website and in National Grid's Grid Code:

Firm Frequency response	http://www2.nationalgrid.com/uk/services/balancing-services/frequency-response/firm-frequency-response/
Firm Frequency response Information	http://www2.nationalgrid.com/UK/Services/Balancing-services/Frequency-response/Firm-Frequency-Response/Firm-Frequency-Response-Information/
Grid Code	http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-Code/

3.2. Frequency Control by Demand Management

Frequency Control by Demand Management (FCDM) provides frequency response through the interruption of supply of demand customers. The service triggers automatically when the system frequency crosses the low frequency relay setting. More information on FCDM can be found on National Grid's website:

FCDM:	http://www2.nationalgrid.com/uk/services/balancing-services/frequency-response/frequency-control-by-demand-management/

[3] Subject to installed capacity and release/absorb rates
4 Continues for period of time defined in the contractual agreement

4. Providing Frequency Response to National Grid

In this chapter it is explained how dynamic and static frequency responses normally operate.

4.1. Dynamic High and Low Frequency Response

In Figure 2, Figure 3 and Figure 4 the main types of frequency response are demonstrated graphically. The green dotted graph represents demand (DSR) and the blue dotted graph represents generation. The generation graph may be response provided by battery storage that generates power and feeds it into the power network.

Dynamic frequency response is a continuously provided service used to manage the normal second by second frequency changes on the system. The expected dynamic frequency response service is illustrated in Figure 2 (fully dynamic response) and in Figure 3 (partially dynamic response), where the main principles of delivering the response are:

- Proportionality of the response means that active power increase/decrease has to be proportional to the frequency deviation from 50Hz. This capability is also referred to as proportional response.
- Delay in executing the frequency response (marked as K in Figure 2 and Figure 3) is the time delay that occurs from the frequency deviation to delivering the MW response to the grid. This time delay includes the time that the frequency monitoring device takes to detect a frequency deviation plus the time for instructing a response and the time for the "virtual power plant" to deliver the MW change in output. The delay K is important to managing the system frequency and needs to be discussed with National Grid. Generally that delay for current frequency balancing providers is typically no more than 2 seconds in time.
- The maximum response has to be delivered within a pre-agreed frequency envelope[5]. The service provider should not over-deliver the agreed amount of MW response (Maximum Demand Increase/Reduction) when the frequency goes out of the pre-agreed envelope.

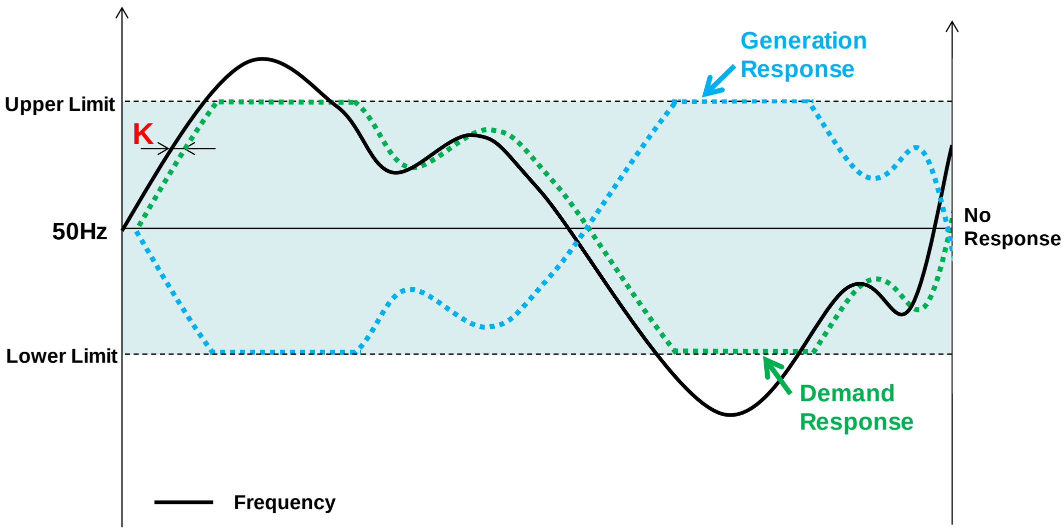

Figure 2: Fully Dynamic Frequency Response

[5] According to the contractual agreement between the service provider and National Grid

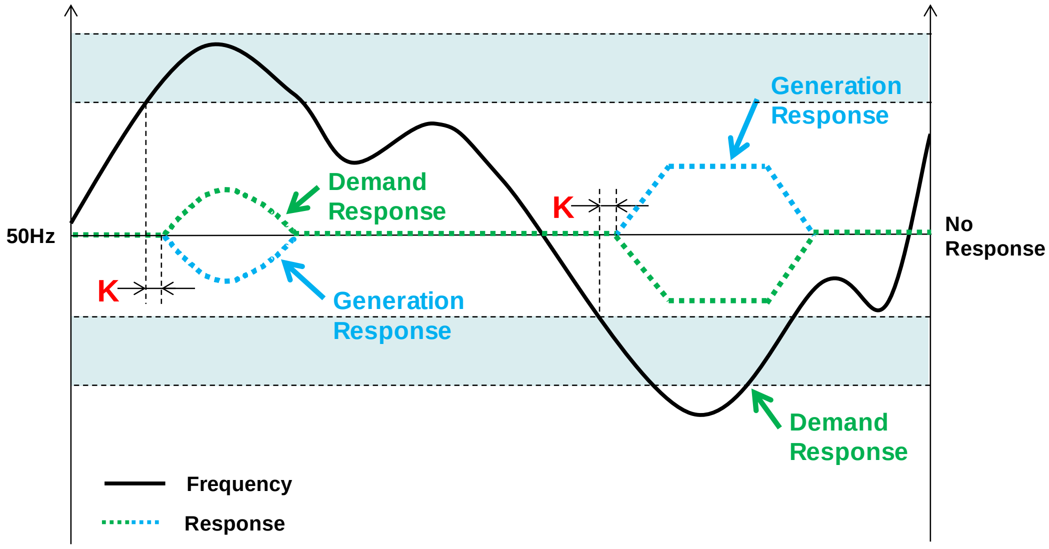

Figure 3: Partially Dynamic Frequency Response

The response shown in Figure 3 is called Partially Dynamic Frequency Response where the frequency response provider provides a linear response to the frequency deviation limited to certain frequency band (between the upper and the lower limit). The frequency band would be agreed in the contractual agreement. The service provider should not provide response to National Grid outside this frequency band. The frequency band can be above or below 50Hz or combination of them as shown in Figure 3.

4.2. Static (Non-Dynamic) Low Frequency Response

Non-Dynamic frequency response is usually a discrete service triggered at a defined frequency (e.g. 49.7 or 49.6Hz). This service is usually referred to as Static Response. The non-dynamic frequency response service is illustrated in Figure 3.

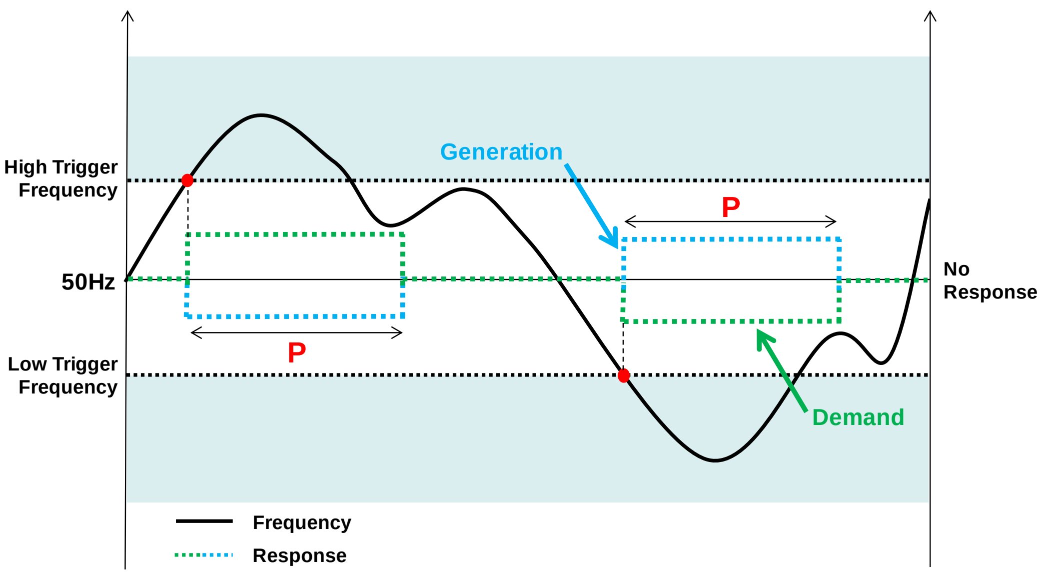

Figure 4 Static Frequency Response Services

The frequency balancing service provider monitors the system frequency and alters its MW generation/consumption when the frequency goes below a pre-agreed frequency trigger[6] (Figure 4). The anticipated delay in delivering the response for a static service is normally assumed to be within hundreds of milliseconds.

In Figure 4, there are two modes of response. The green dotted line represents the DSR providing response which for the low frequency event shown in the figure, the DSR provider would reduce demand from the system[7]. In the case where the response is a generation such as batteries (blue dotted line) the service provider might increase the power that is delivered to the system.

The time period "P" and the "Trigger Frequency" both indicated in Figure 4 are the agreed time for holding the response and agreed frequency that response is expected according to the contractual agreement between the service provider and National Grid. An option to reset the "Trigger Frequency" would also be agreed in the contractual agreement (if applicable).

5. Frequency Response Testing Schedule

The tests identified in this document are designed to demonstrate that the agreed service can be delivered consistently.

National Grid may require further tests or evidence to confirm site-specific technical requirements (in line with the Agreement) or to address performance issues that are of particular concern. If there is such a requirement, then both parties will need to discuss and agree as necessary on a case by case basis.

The tests must be carried out by the service providers, or by their agent, but not by National Grid. However, National Grid may witness some of the tests. This must be discussed and agreed between the parties on a case by case basis. The testing sections should be discussed with National Grid.

A generic list of signals to be monitored during National Grid's witnessed tests is tabulated in OC5.A.1.28. This will be used to monitor all signals at the sampling rates indicated in CC.6.6.2. The service provider should provide its own digital recording equipment to record the same variables. This will provide a backup to the test results should one of the recording instruments fail at the time of testing.

The service provider is responsible for providing the listed signals to the User's and National Grid's recording equipment. For National Grid purposes the signals provided are required to be in the form of dc voltages within the range -10V to +10V (see CC.6.6.2). The input impedance of National Grid equipment is in the region of 1MOhm and its loading effect on the signal sources should be negligible (if applicable).

The service provider should advise National Grid of the signals and scaling factors prior to the test day.

It may be appropriate for National Grid to set up the recording equipment on the day prior to the test date. Service provider representatives are asked to ensure that a 230V AC power supply is available and that the signals are brought to robust terminals at a single sampling point.

The service provider should provide a list of sites (if the provider is a distributed power plant) that have contributed during the tests. The format is shown in Appendix 1.

5.1. National Grid Data Recording Equipment

National Grid will require Ancillary Services Monitoring for all contracted plant above 100MW as identified in CC.8.2. and/or as set out in the Bilateral Agreement.

---

[6] The frequency trigger should be agreed in the contractual agreement between the service provider and National Grid

[7] The volume of demand being reduced would be specified in the contractual agreement

8 http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code/The-Grid-code/

5.2. Test Notification to Control Room

Depending on the size of the response, the service provider is responsible for notifying the Distribution Network Owner Control Centre and/or National Grid's Electricity National Control Centre of any tests to be carried out, which could have a material effect on the electricity transmission or distribution systems. The procedures for planning and co-ordinating all plant testing with the 'National Grid Electricity Control Centre are detailed in OC7.5 of the Grid Code (i.e. Procedure in Relation to Integral Equipment Tests). Please refer to "Integral Equipment Tests - Guidance Notes", which can be found on National Grid's Internet site in Grid Code, Associated Documents, for further details .

5.3. Dynamic Frequency Response Testing Schedule Witnessed by NGET

There should be sufficient time between tests for control systems to reach a steady state (depending on available power resource). It is marked as 'HOLD' in Figure 5 and 6 to illustrate that the current injection should be maintained until the Active Power (MW) provided by service providers has stabilised or a time of at least 30 seconds (whichever is the shorter). The data provided to National Grid has to be with appropriate resolution that would allow National Grid to make a decision based on the test results. The tests below may change for different providers depending on the size of MW response and types of service and this can be discussed with National Grid prior to testing. National Grid may require tests to be repeated should the response volume be affected by the available power, or if tests give unexpected results. The providers should submit reports with the frequency and MW response data in time domain format to National Grid after testing. The desired format should consist of graphs in a report provided in Microsoft Word/PDF format as well as the raw data which should be provided in Microsoft Excel format. The site data shown in Appendix 1 should also be provided in Microsoft Excel format.

The main purposes of the tests are explained below:

- **Speed of delivering the response –** this is the time delay that occurs between the initial frequency change and the MW consumption being increased/decreased. This delay is particularly important in managing the system frequency since rapid frequency deviation is expected after a loss of a big generator/demand on the system. The speed of the response can be demonstrated in Tests 1-8 where the instantaneous frequency deviation would trigger the fastest response from the service provider.
- **Proportionality of the response –** the proportionality of the MW response with regard to the frequency deviation can be demonstrated in Tests 1-12. To manage the frequency predictably, National Grid requires frequency response providers to have a response proportional to the frequency deviation from 50Hz and test ramps up/down would demonstrate the proportionality of the MW response.
- **Sustainability of the response –** National Grid requires a demonstration that maximum response can be sustained for 30 seconds (primary frequency response) and 30 minutes (secondary frequency response). Test 7-8 are intended to show the delivering of maximum response for long time, where time "T min" is the maximum time agreed in the contractual agreement between the service provider and National Grid.

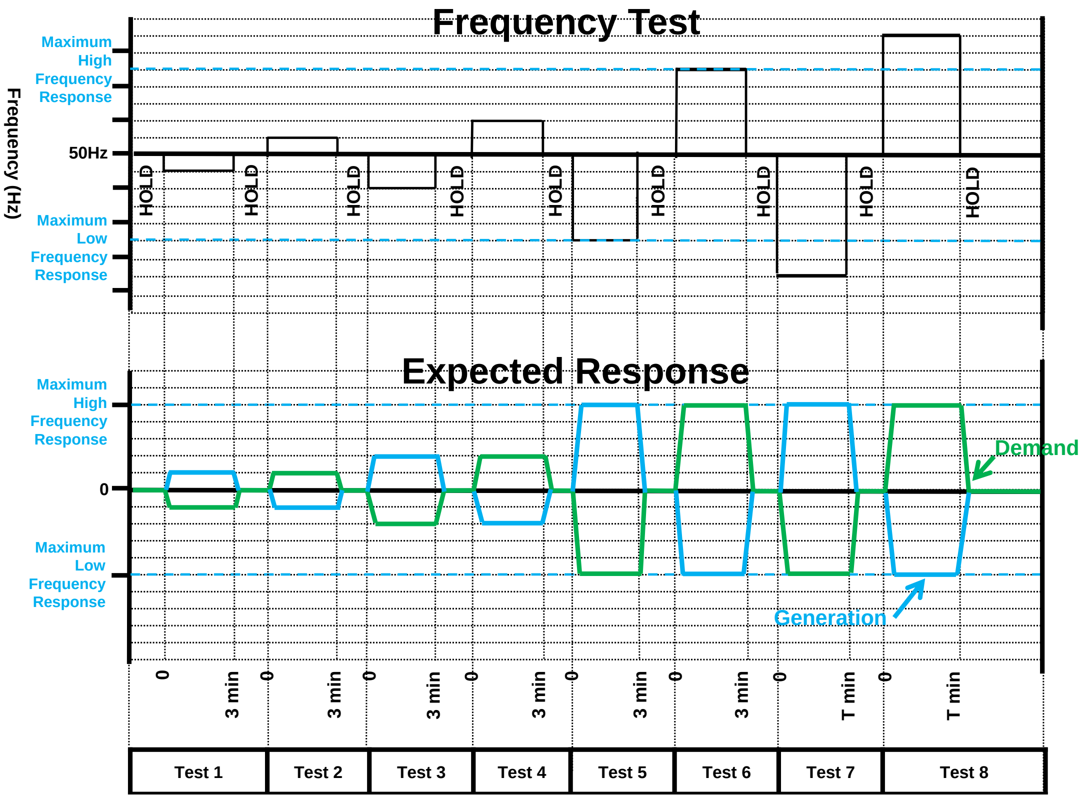

Figure 5: Frequency Response Tests 1-8

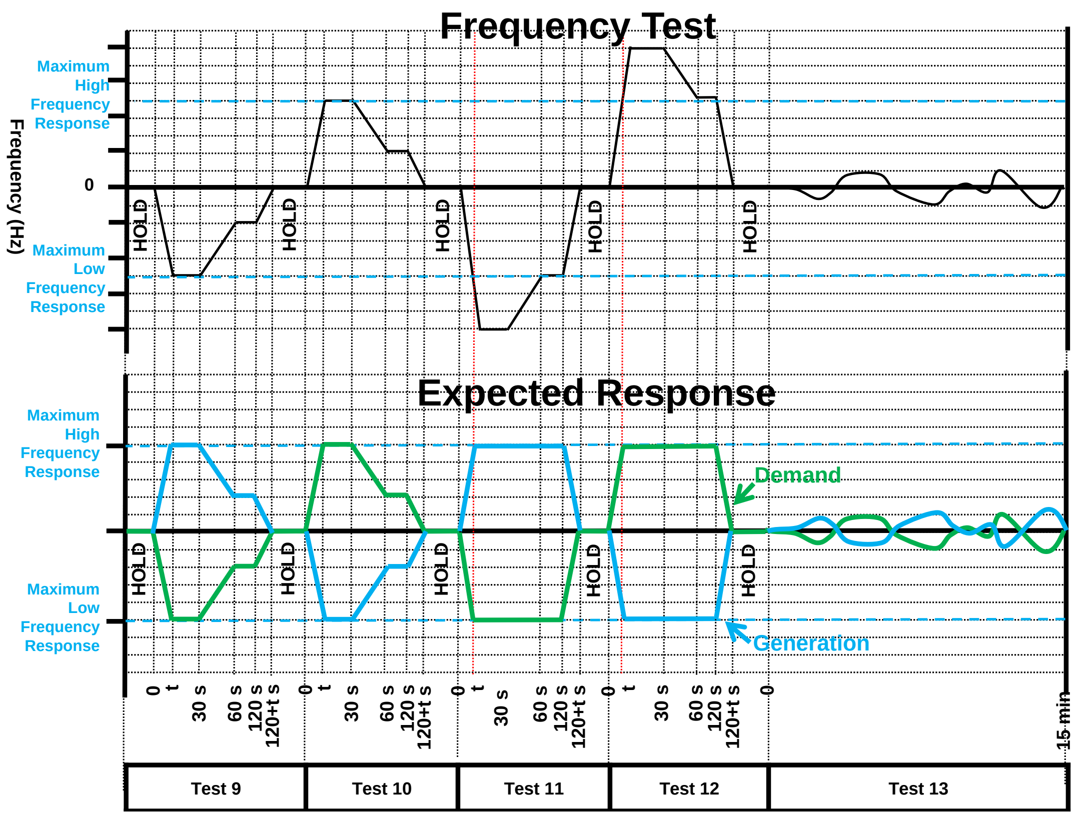

Figure 6: Frequency Response tests 9-13

Time "t" in Figure 6 must be specified in the contractual agreement. By having different ramps, the proportionality of the frequency response at different rates of change of frequency can be tested and it demonstrates the ability of the service provider to provide response in different system conditions. In the proportionality testing the "delay" effect of "K" shown in Figure 2 and Figure 3 should also be taken into account.

In Test 13, the service provider will switch from "test mode" back into "normal frequency response mode" where a response will be provided to offset the frequency deviation at the time of the test for a period of 15 minutes.

The blue dotted lines in Figure 5 and Figure 6 (Maximum High and Maximum Low Frequency Response) denote frequency changes to deliver maximum contracted response.

5.4. Static Frequency Response Testing Schedule Witnessed by NGET

Tests 14 and 15, as shown in Figure 7 and Figure 8 respectively, aim to test the capability of the service provider to provide static frequency response services. The length of both tests is 32 minutes in the case where the providers are providing a 30 min response. If the agreed response time is longer than 30 minutes then the test might be prolonged by an appropriate and agreed time. If the test time is shorter than 30 minutes, all test times have to be reduced proportionally to the times shown at the bottoms of Figure 7 and Figure 8.

National Grid might set up a High and Low Trigger Reset (shown in Figure 7 and Figure 8 respectively). The purpose of the resets is to discontinue the response service if the system frequency has changed significantly for the period of the service.

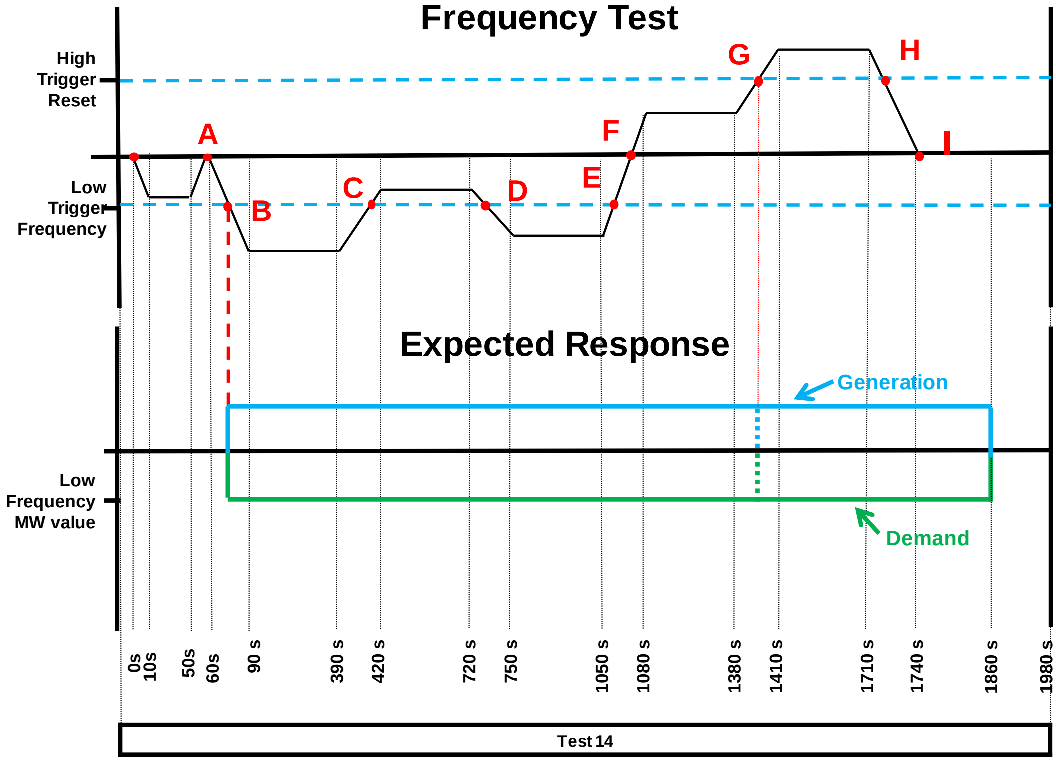

Figure 7. Static Frequency Response Tests 14 – Low Frequency Response

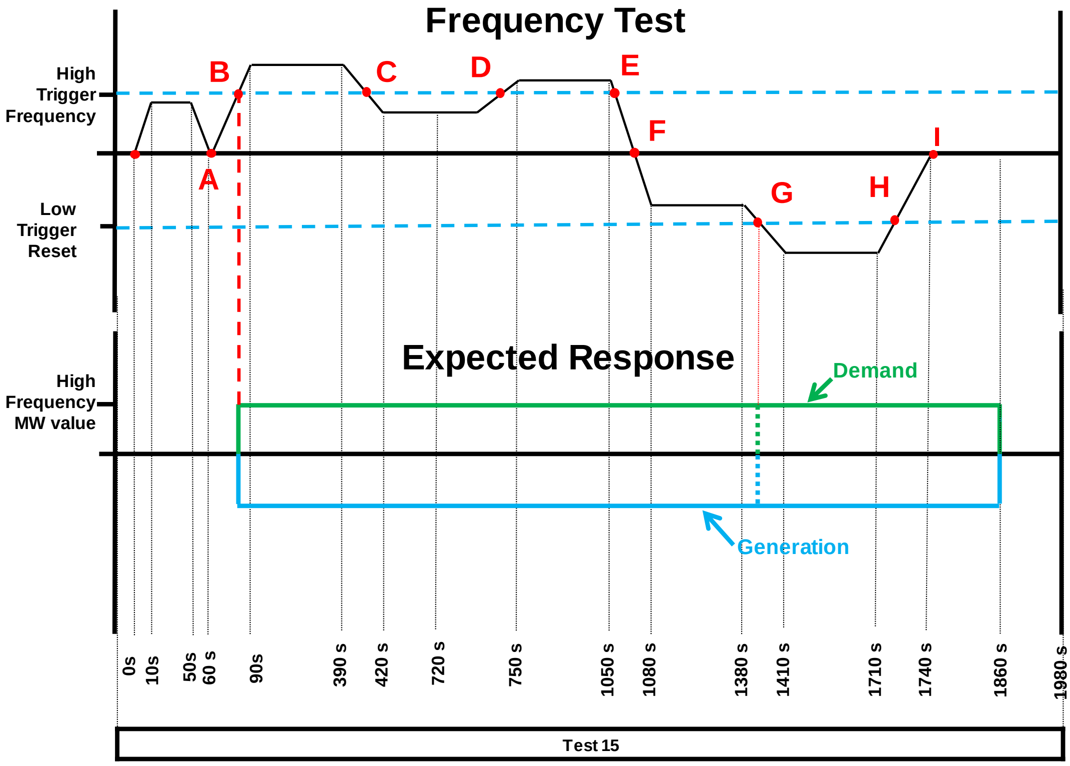

Figure 8. Static Frequency Response Tests 14 – High Frequency Response

The main purposes of tests are listed below:

- **Speed of delivering the response –** The service should normally be provided consistently at the agreed time when the frequency reaches the trigger frequency level (point B at Figure 7 and Figure 8). The speed of the response can be demonstrated in Tests 14 and 15 where the trigger frequency deviation must dispatch a maximum response at point B (Figure 7 and Figure 8).

- **Accuracy of the response –** the accuracy of the MW response with regard to the frequency deviation can be demonstrated in Tests 14 and 15. To manage the frequency securely, National Grid requires frequency response providers to have a full step response when the system frequency reaches the trigger level (point B at Figure 7 and Figure 8). At that point the maximum response must be delivered as described in the above paragraph.

- **Sustainability of the response –** National Grid requires a demonstration that static response must be sustained for a continuous time specified in the bilateral agreement. Tests 14 and 15 are intended to show the delivery of the response service for a certain period regardless of changes in system conditions. The static service is only triggered at point B (Figures 7 and 8) and sustained for the time specified in the bilateral contract. In conditions where the frequency goes back above the triggering point (at points C, D and E) the continuation of the response must not be interrupted (as suggested in the Expected Response in Figures 7 and 8).

  Further, points F, I (50Hz) and G, H (high trigger frequency in Figure 7 and low trigger frequency in Figure 8) intend to test further the response continuity even in conditions where the frequency returns to 50Hz and where it goes above the high trigger. If a high frequency trigger point is not specified in the bilateral agreement, it can be assumed that it is the same as the low frequency trigger mirrored from 50Hz. For example, if the low trigger is 49.5Hz, it should be assumed that the high trigger is 50.5Hz.

5.5. Testing and Aggregation Growth

It is acknowledged that many services offered by frequency service providers may rely upon an aggregated growth model, i.e. the service will commence at an agreed MW level but the unit in question may grow (or reduce) in size over time as more assets join the portfolio. In such a circumstance National Grid and the service provider will need to agree the form and frequency of testing to ensure the continued validity of the unit as new assets join or retire from the portfolio.

Appendix 1 – Site response data

Site Name	Response provided in [kW]	Date and time