Guidance Notes for DC Converter Stations

GB User Issue 3

May 2024

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Foreword

These Guidance Notes have been prepared by the National Grid Electricity System Operator (ESO) to describe to DC Converter Station owners and other Users on the system how the Grid Code Compliance Processes is intended to work. Throughout this document National Grid refers to National Grid ESO unless explicitly stated otherwise.

These Guidance Notes are prepared, solely, for the assistance of prospective DC Converter Station owners connecting directly to the National Electricity Transmission System or (if the installation has a rating of 50MW or more) to a User's System.

In the event of dispute, the Grid Code and Bilateral Agreement documents will take precedence over these notes. Owners of installations rated 50MW or less should contact the relevant Distribution Network Operator (DNO) for guidance.

These Guidance Notes are based on the Grid Code, Issue 6, Revision 23, effective from the 22 April 2024. They have been developed from Issue 1 of the Guidance Note of February 2013 and reflect the major changes brought about by Grid Code revision to facilitate compliance with the European Requirements for Generators and GC0141: Compliance Processes and Modelling amendments following 9th August Power Disruption.

Definitions for the terminology used this document can be found in the Grid Code.

The Engineering Compliance Manager (see contact details below) will be happy to provide clarification and assistance required in relation to these notes and on Grid Code compliance issues.

ESO welcomes comments including ideas to reduce the compliance effort while maintaining the level of confidence. Feedback should be directed to the ESO Engineering Compliance team at:

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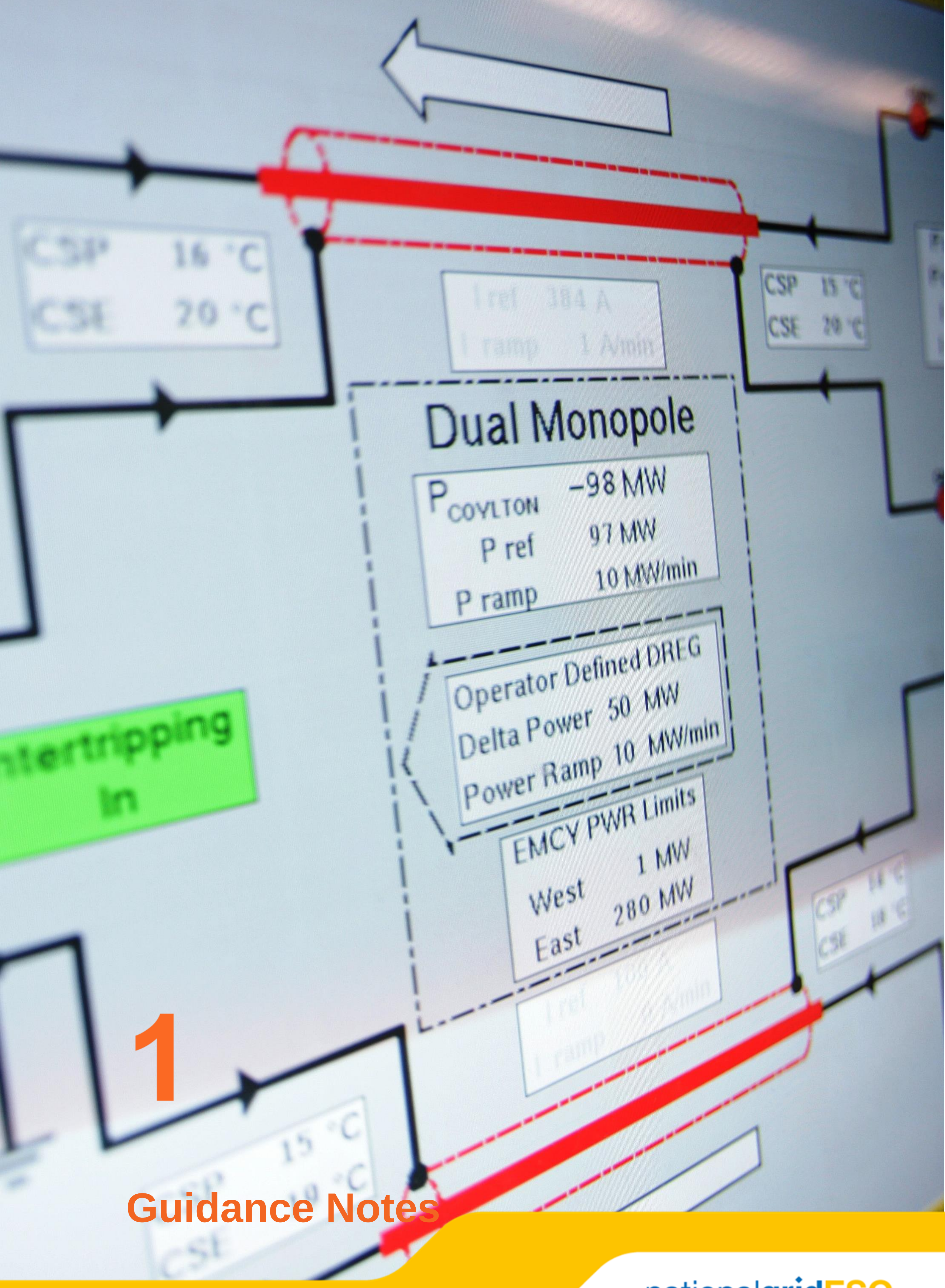
Abbreviations

This section includes a list of the abbreviations that appear in this document.

Abbreviation	Description
AVC	Automatic Voltage Control (on transformers)
BC	Balancing Code
BMU	Balancing Mechanism Unit
CC / CC.A	Connection Conditions / Connection Conditions Appendix
CCGT	Combined Cycle Gas Turbine
CP	Compliance Processes
CSC	Current Sourced Converter
DC	Direct Current
DNO	Distribution Network Operator
DMOL	Design Minimum Operating Level
DRC	Data Registration Code
ECCs	European Connection Conditions
ESO	National Grid Electricity System Operator
FAT	Factory Acceptance Test
FON	Final Operational Notification
FSM	Frequency Sensitive Mode
GB	Great Britain
HVDC	High Voltage Direct Current
ION	Interim Operational Notification
LFSM	Limited Frequency Sensitive Mode
LON	Limited Operational Notification
MEL	Maximum Export Limit
MG	Minimum Generation
MLP	Machine Load Point
MSOL	Minimum Stable Operating Level
OC	Operating Code
OFGEM	Office of Gas and Electricity Markets
PC	Planning Code
PSS	Power System Stabiliser

TO	Transmission Owner
UDFS	User Data File Structure
VSC	Voltage Sourced Converter



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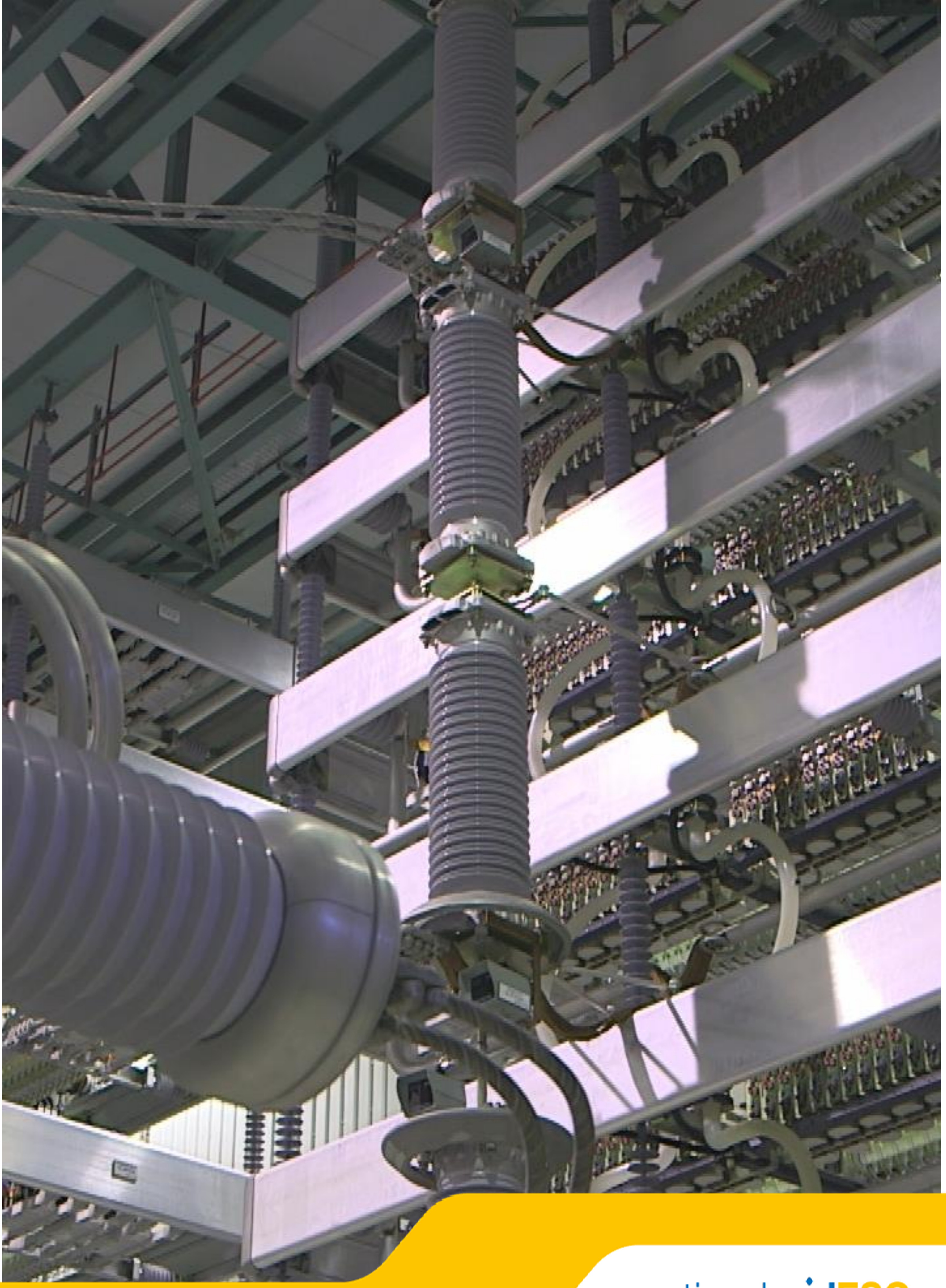

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Introduction

This document complements the Compliance Processes included in the Grid Code providing additional description of the technical studies and testing set out within the Grid Code.

To achieve Operational Notification the DC Converter Station owner must demonstrate compliance with the Grid Code and Bilateral Agreement. The Grid Code is a generic document which specifies requirements regardless of local conditions. The Bilateral Agreement is a site-specific document agreed between ESO and the Interconnector Owner, which for technical reasons, may specify additional/alternative requirements or specific parameters within a range indicated in the Grid Code. The total requirements placed on DC Converter Stations are therefore the aggregation of those specified in the Grid Code and Bilateral Agreement.

This particular edition of the guidance notes has been written for DC Converter Station owners, and those existing connections where the owner is categories as a GB User with separate guidance documents exists for Synchronous Generating Units and Power Park Modules and for future connections of all types of plant who are deemed EU Code Users.

For existing connections, the DC Converter Station owner will be deemed a GB User and the requirements contained in the European Connection Conditions (ECCs) will not apply. However, if a DC Converter Station owner with an existing connection undertakes a significant modification to its plant or apparatus new requirements, for example ECC /ECP requirements, may become applicable. Where a DC Converter Station owner is undertaking, or planning to undertake, a modification to its plant or apparatus this should be discussed with the appropriate connection account manager as soon as practical. CSC technology which needs to meet the ECC/ECP requirements, please refer to EU user HVDC guidance document.

DC Converter Station owners may, if they wish, suggest alternative tests or studies, which they believe will demonstrate compliance in accordance with the requirements placed on themselves and ESO.

New Requirements

The GB Grid Code was updated in Dec 2023 to introduce requirements consistent with the European Code Requirements for HVDC systems. These new rules are set out in the new European Connection Conditions / European Compliance Processes sections and apply to EU Code Users only. Separate documents provide guidance on these new requirements for each type of connection.

A DC Converter Station owner is considered a GB User if their Main Plant and Apparatus was connected to the System before September 8, 2019, or if they had concluded Purchase Contracts for their Main Plant and Apparatus before September 28, 2018. Additionally, if their Plant and Apparatus has not undergone a Substantial Modification effective on or after September 8, 2019, they still fall under the GB User. category. The final decision on whether a modification is deemed to apply EU Code User or GB User requirements lies with the Regulator, Ofgem, in the event of a dispute.

Compliance Processes within the Grid Code

The process for DC Converter Station owners to demonstrate compliance with the Grid Code and Bilateral Agreement is included in the Grid Code Compliance Processes (CP). In addition to the process and details of the documentation that is exchanged to control the process an appendix to the Compliance Processes includes the technical details of the simulation studies that a DC Converter Station owner should carry out. The Compliance Processes cross reference heavily with the Planning Code, the Connection Conditions and Operating Code 5 (OC5). Similarly, the European Compliance Processes cross reference with other sections of the Grid Code, namely the Planning Code (PC) and the European Connection Conditions (ECC).

The Grid Code Planning Code (PC) sets out the data and information that a DC Converter Station owner is required to submit prior to connection and then maintain during the lifetime of the DC Converter station. The format for submission of the majority of this information is set out in the Data Registration Code (DRC).

The Grid Code Connection Conditions (CC) set out the majority of the technical performance requirements that a DC Converter Station owner is required to meet with site specific variations laid out in the Bilateral Agreement.

The Grid Code Operating Code 5 (OC5) sets out the technical details of the tests which ESO recommends demonstrating compliance with the Grid Code.

Compliance Repeat Plan

Further guidance on Compliance Repeat Plan will be published on ESO website.

GC0141 has introduced the requirement for the User to restate compliance every 5 years, from the issue of a FON (CP.8). No later than 4 calendar years and 6 months after the issue of a FON, the ESO will notify the User to confirm continued compliance with the requirements of the Grid Code and/or the Bilateral Agreement. The User must confirm the compliance by submitting the following:

- A Compliance Statement and a User Self Certification of Compliance signed by the User. If there are any requirements that have not been met, then a statement of these, together with a copy of the derogation.
- Details of any changes to relevant Planning Code data (both Standard Planning Data and Detailed Planning Data) and DRC schedules

In the case where all requirements have been satisfactorily fulfilled, the ESO will issue the User with a FON and the User can continue operation as before. In case of embedded plants, the notification will also be sent to the relevant Transmission Owner. However, in the case where requirements are not fulfilled and the User is deemed non-compliant, the ESO will issue a LON, and the relevant process will be followed. Some restriction may be imposed until the User resolves the issues.

Simulation Studies

Simulation studies are required from the DC Converter Station owner to provide evidence that the plant and apparatus comply with the provisions of the Grid Code. Section of the Grid Code CP.A.3 describes the simulation studies which need to be carried out before any DC Converter Station is issued an Interim Operational Notification (ION) as indicated in CP.6.3.

In general simulation studies are required where:

- It is necessary to predict the DC Converter behaviour before tests are carried out.
- It is impractical to demonstrate capability through testing as the effects on other system users would be unacceptable.
- It is necessary to demonstrate the model supplied is a true and accurate reflection of the plant as built.

CP.A.3 outlines simulation studies that are required to verify compliance with Grid Code requirements. The simulations must be based on the models supplied to ESO in accordance with Grid Code Planning Code Appendix section 5.4.2 (PC.A.5.4.2) except for the load rejection simulations in CP.A.3.6 where a more complex model may be utilised if appropriate provided a validation study as specified in CP.A.3.6.6 is also provided. Fault Ride Through studies are encouraged to be done using electromagnetic transient (EMT) models.

Simulations should be submitted in the form of a report (CP.A.3.1.2) to demonstrate compliance in sufficient time to allow ESO to review the content and validity of the report and models utilised prior to the planned synchronisation date (typically 3 -6 months).

Factory Acceptance Tests (FAT)

Factory Acceptance Tests, or FATs, are conducted at the manufacturer's site prior to delivery and installation and these tests help to identify any issues and correct them prior to shipment. FAT is not required in the Grid Code however, FATs are beneficial not just for the ESO and Customers but for the manufacturer as well to simplify the process of on-site witness tests, the Compliance Engineers in ESO will discuss the FAT process, and where appropriate, witness relevant parts of the test.

Voltage Control, Frequency Control and Fault Ride Through tests can be witnessed in FAT. Following successful FATs of the Grid Code tests, the onsite test process of frequency test may be able to be simplified in the compliance process.

Compliance Testing

Tests identified in OC5. A.4 of the Grid Code are designed to demonstrate where possible that the relevant provisions of the Grid Code and Bilateral Agreement have been met. However, if the test requirements described in OC5. A.4 are at variance with the Bilateral Agreement, or the test requirements are not relevant to the plant type the DC Converter Station owner should contact ESO to discuss and agree an alternative test program and success criteria.

For each test to be carried out the description and purpose of the test, results required, the relevant Grid Code clause(s) and criteria of assessment are given in OC5. The DC Converter Station owner is responsible for drafting test procedures for the DC Converter station as part of the compliance process prior to the issue of the ION. Grid Code OC5 and the appendices of these Guidance Notes provide outline test schedules which may assist the DC Converter Station owner with this activity.

ESO may require further compliance tests or evidence to confirm site-specific technical requirements (in line with the Bilateral Agreement) or to address compliance issues that are of particular concern. Additional compliance tests, if required, will be identified following ESO's review of submissions of User Data File Structure.

The tests are carried out by the DC Converter Station owner, or by their agent, and not by ESO. However, ESO will witness some of the tests as indicated in OC5. Tests should be completed following the test procedures supplied in the UDFS prior to the issue of the ION unless otherwise agreed by ESO.

The DC Converter Station owner should also provide suitable digital monitoring equipment to record all relevant test signals needed to verify the DC Converter Station performance in parallel with ESO's recording equipment.

ESO Data Recording Equipment

ESO will provide a digital recording instrument on site during the tests witnessed by ESO. A generic list of signals to be monitored during ESO witnessed tests is tabulated in OC5.A.1.2. This will be used to monitor all plant signals at the sampling rates indicated in CC.6.6.2. The station should provide its own digital recording equipment to record the same plant variables. This will provide a back up to the test results should one of the recording instruments fail at the time of testing.

The station is responsible for providing the listed signals to the User's and ESO's recording equipment. For ESO 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 the ESO equipment is in the region of 1MOhm and its loading effect on the signal sources should be negligible.

The station should advise ESO of the signals and scaling factors prior to the test day. The form of a typical test signal schedule is shown below:

Signal	Unit	Voltage Range	Signal Representation
Active Power Output	MW	0 to 8V	0 to at least Reg. Capacity
Reactive Power Output	MVAr	-8V to +8V	- Reg Capacity to +Reg Capacity
Terminal Voltage	kV	0 to 8V	Nominal Voltage –10% to Nominal Voltage +10%
System Frequency	Hz	-8V to 8V	48.0Hz – 52Hz
List of other signals ……			

Table 1: A typical test signal schedule

It may be appropriate for ESO to set up the recording equipment on the day prior to the test date. The station representatives are asked to ensure that a 230V single phase AC power supply is available and that the signals are brought to robust terminals at a single sampling point. Examples of ideal connection points with BNC or 4mm banana plug connections are shown below.

Figure 1 – Example of Compliance Test Signal Connections

The station must inform ESO if the signal ground (0V) is not solidly tied to earth or of any other potential problems.

Compliance Test Signals

The Grid Code requires that serval signals are provided from compliance tests to ESO to allow assessment of the compliance. The list of these signals is set out in OC5. A.1 for GB Users.

Where these signals are provided to ESO following witness tests or instead of witnessing there is a need to provide them in a consistent electronic format with a time stamp in a numerical format which can be interpreted in Excel. To facilitate efficient analysis the test results should include signals requested by ESO set out in the columns order as indicated in the tables in Appendix E.

- Signals for non-witness tests should be provided in excel format and in the order and format presented in Appendix E unless otherwise agreed, in advance, with ESO.
- Where any additional test signals to those indicated in the tables are presented these should only be added with the agreement of ESO and be entered within the files as additional columns to the right of the required signals.
- Where a signal cannot be provided, and this has been agreed with ESO in advance of the tests, a blank column should be retained within the data.
- Where additional signals are included, or the signals are presented but not in the arrangement detailed above the data may be rejected and the customer will be asked to resubmit the data in the agreed format.

Compliance Test Log sheet

Where test results are completed without any ESO presence but are relied upon as evidence of the compliance they should be accompanied by a log sheet. This sheet should be legible, in English and detail the items in Appendix E.

Future Development of Compliance Testing

ESO recognises that organising of witness site tests can lead to delays in progressing connections through the compliance process. We are looking at options to deliver the same confidence while reducing the need to attend site and witness tests in the future. This would require the support of manufacturers and owners in serval areas which are summarised below:

- A suitable interface which allows ESO a view of the key test parameters graphically in real-time from the ESO office. This would effectively provide the view of tests currently achieved by ESO connecting its recording equipment while at site.
- Where ESO has decided to allow testing without real-time witnessing for compliance testing with lower materiality, such as repeat tests. In such circumstances manufacturers or developers must provide all the test data to ESO in the standard format set out in this guidance note complete with an appropriate test log sheet.
- Where ESO has decided that the design of a Generators plant and apparatus is standardised, and the compliance can be evidenced by reference to a generic set of tests completed and accepted previously. This could be reference to Equipment Certificates where these have been accepted by ESO. This process will be offered provided in ESO's opinion it does not pose a material risk in terms of the specific site installations.

ESO will raise this during the compliance process and are open to suggestions from Developers. For manufacturers looking to suggest options or develop systems to facilitate remote witnessing please discuss with your compliance contact or contact ESO using the details in this guidance note.

Interim Operation

Prior to the issue of an Interim Operational Notification, the DC Converter owner must submit a list of data to ESO to ESO's satisfaction, according to CP.6.3

It is also recommended to execute Voltage Injection tests under the STATCOM mode prior to fully export/import, this is only applicable for VSC technology.

Test Notification to Control Room

The station is responsible for notifying the 'ESO Control Centre' of any tests to be carried out on their plant, which could have a material effect on the National Electricity Transmission System. The procedures for planning and co-ordinating all plant testing with the 'ESO Control Centre is detailed in OC7.5 of the Grid Code (i.e., Procedure in Relation to Integral Equipment Tests). For further details relating to this procedure, refer to "Integral Equipment Tests - Guidance Notes" which can be found on ESO's Internet site in Grid Code, Associated Documents.

The DC converter station should be aware that this interface with ESO transmission planning will normally be available in weekday working hours only. As best practice, the station should advise the 'ESO Control Centre' and in Scotland the relevant Transmission Owner, or Distribution Network Operator (if embedded) of the times and nature of the proposed tests at the earliest stage possible. If there is insufficient notice or information provided by the station, then the proposed testing may not be allowed to proceed.

Model Submission

To comply with the planning code requirements of the Grid Code, users are required to provide to NGESO validated model(s) which adequately represent the dynamic performance of their systems as demonstrated during the compliance process.

For connections in possession of a FON or an EON before the 1st of September 2022 the requirements detailed in PC.A.5.4.2 (a to h) of the Grid Code still apply.

For future connections, or those that had started the compliance process but had not received an EON by 1st September 2022 the modelling requirements detailed under PC.A.9 of the Grid Code apply.

For the avoidance of doubt, the user is also required to comply with any additional modelling requirements that might be included in the BCA, regardless of the planning code modelling section applicable to the connection.

For detailed recommendations and advice on the model(s) submission aimed at complying with PC.A.9 of the Grid Code please refer to "Guidance Notes on Modelling Requirements – GC0141 Grid Code Modification" by following the link below.

Guidance Notes on Modelling Requirements - GC0141 Grid Code Modification

Protection Requirements

Under section CC.6.2.2.2 of the Grid Code the DC Converter Station owner must meet a set of minimum protection requirements. As part of the User Data File Structure (UDFS) section 2 the DC Converter Station owner should submit a Protection Settings report together with an overall trip logic diagram.

The DC Converter Station owner should provide details of all the protection devices fitted to the DC Converter Station together with settings and time delays, including:

Protection Fitted	Typical Information Required
Under / Over Frequency Protection	Number of stages, trip characteristics, settings and time delays
Under / Over Voltage protection	Number of stages, trip characteristics, settings and time delays
Over Current Protection	Element types, characteristics, settings and time delays
Control Trip Functions	Functional Description, Control Characteristic and trip settings

Table 2: Typical Information Requirement of Protection Fitted

ROCOF protection should be disabled for directly connection and if islanding protection is required, an inter-tripping scheme is recommended. For Embedded generation, Islanding protection should be set in line with the G59/G99 requirement.

As stated in CC.6.1.3, the System Frequency could rise to 52Hz or fall to 47Hz. The station must continue to operate within this Frequency range for at least the periods of time given in CC.6.1.3, unless ESO has specified any other requirements. Station Owners will be responsible for protecting their equipment. If the frequency range is outside the range 52Hz to 47Hz, it is up to the station Owner to decide whether to disconnect their apparatus in England and Wales, in Scotland shall be tripped according to the Grid Code.

Power Quality Requirements

For DC Converter Stations that are to be connected to the National Electricity Transmission System, the harmonic distortion and voltage fluctuation (flicker) limits are set out in accordance with the Grid Code and Bilateral Agreement. The Transmission Owner is required to meet the relevant terms of the Grid Code.

With respect to harmonics, the Grid Code CC.6.1.5(a) requires that the electromagnetic Compatibility Levels for harmonic distortion on the Transmission System from all nonlinear sources under both planned outage and fault outage conditions, (unless abnormal conditions prevail) shall comply with the compatibility levels given in Appendix A of Engineering Recommendation G5/4. The Grid Code further requires that the planning criteria contained within Engineering Recommendation G5/4 be applied for the connection of non-linear sources to the Transmission System, which result in harmonic limits being specified for these sources in the relevant Bilateral Agreement.

With respect to voltage fluctuations, it is also a requirement of the Grid Code that voltage fluctuations are kept within the levels given in Grid Code CC.6.1.7 and/or Table 1 of Engineering Recommendation P28 and therefore limits on voltage fluctuations are also specified in the relevant Bilateral Agreement. The DC Converter Station Owner will be required to comply with the voltage fluctuation limits specified in the Bilateral Agreement. The Transmission System or Distribution Network Operator will monitor compliance with these limits.

Development schemes with non-linear element(s) are assessed by the Transmission Owner for their expected impact on the harmonic distortion and voltage fluctuation levels. For harmonic voltage distortion, the process detailed in Stage 3 of Engineering Recommendation G5/4 is applied. For the voltage fluctuation, the principles outlined in Engineering Recommendation P28 are used. Both assessments may lead to a requirement within the Bilateral Agreement specifying maximum permissible limits not to be exceeded.

Specific information required for the assessment of harmonic voltage distortion and voltage fluctuation is detailed in Grid Code DRC.6.1.1. Any component design parameters for planned reactive compensation for the DC Converter as detailed in Grid Code PC.A.6.4.2 should also be included giving due attention to tuned components. For DC Converters that are to be connected to Distribution Systems, Distribution Network Operators may undertake similar assessments to comply with the requirements of the Distribution Code in terms of harmonic distortion and voltage fluctuation.

A

Appendices

Appendix A Reactive Power Capability

Summary of Grid Code Requirements

The reactive capability requirements for DC Converter Stations are specified in Grid Code CC.6.3.2.

In summary, the requirements of an Offshore DC Converter Station and Onshore DC Converter Station and those Converters using different technology such as Voltage Source Converters (VSC) and Current Source Converters (CSC) are different as follows:

- The Grid Code requirement CC.6.3.2(b) applies to Onshore DC Converter Stations, both to those stations using Current Source Converter (CSC) technology and Voltage Source Converter (VSC) technology.
- The Grid Code requirement CC6.3.2(c) applies to Onshore DC Converters Stations using VSC.
- The Grid Code requirement CC.6.3.2(e) applies to Offshore DC Converter Stations.

CC.6.3.2 (b) requires the Onshore DC Converter (including CSC and VSC) to be capable of operating with zero reactive power exchange to the public power system (with a tolerance) from zero active power output to full active power output.

CC6.3.2(c) requires the DC Converter Station (excluding current source technology) to be capable of operating with a range of reactive power outputs when producing more than 20% real power. This reactive power capability at the connection point (or HV side of the connection transformer for a “Transmission” connection site in Scotland) is illustrated in the diagram CC.6.3.2. fig 1. Below 20% real power output the Onshore DC converter may continue to modulate reactive power transfer under voltage control or switch to zero reactive power transfer. If there is a switch to zero reactive power transfer the Grid Code requires that there is a smooth transition between Voltage Control at active power levels greater than 20% and reactive power control at active power levels less than 20%.

CC6.3.2(e) requires that zero transfer or an agreed transfer capability for the Offshore DC Converters to be specified. The agreed transfer to be specified in the Bilateral Agreement.

CC.6.3.3 requires:

- Continuously maintaining constant Active Power output for System Frequency changes within the range 50.5 to 49.5 Hz
- When DC convert operates in a mode analogous to Generator, the DC converter should maintain its Active Power output at a level not lower than the figure determined by the linear relationship shown in Grid Code Figure 2 for System Frequency changes within the range 49.5 to 47 Hz, such that if the System Frequency drops to 47 Hz the Active Power output does not decrease by more than 5%.
- When DC convert operates in a mode analogous to demand, the responses of DC was determined in Figure 3. When System Frequency changes within the range 49.5 to 47 Hz, the DC converter should maintain its active power output. if the System Frequency drops to 47.8 Hz the Active Power input decreases by more than 60%.

Grid Code CC.6.3.4 states that the reactive power capability must be fully available and vary based on different voltage levels. The CC.6.3.4 capability is not normally tested but is instead demonstrated by simulation. CP.A.3.3 details the requirements for a simulation study.

In the event that during system incidents, the voltage is <95% or >105%, DC Converter should deliver the maximum (lagging or leading respectively) reactive power possible, while remaining within its design limits.

Contractual Opportunities Relating to Reactive Power Services

For some technologies, there is an opportunity to provide an optional reactive service (beyond the basic mandatory reactive service). Developers interested in providing such a service should take the opportunity of reactive capability testing to demonstrate any additional reactive capability. The delivery of additional reactive power would be expected to be dynamic, i.e., responding to changes to system voltage in the same manner as the mandatory reactive service provided.

Reactive Capability Compliance Tests

Grid Code OC5. A.4.2 describes the Reactive Capability testing for DC Converter Stations using Voltage Source Converter (VSC). For the VSC technology plant, required tests should demonstrate the maximum capability of the DC Converter beyond the corners of the envelope shown in Grid Code CC.6.3.2 Figure 1. Given the steady state nature of the Reactive Capability requirements implying that reactive output can be maintained indefinitely, the tests are carried out over a longer period than other compliance tests. The Reactive Capability test is not usually witnessed by a ESO compliance engineer, so where a DC Converter Owner is recording the tests, they should record details such as the HV system voltage and transformer tap position and equipment in service, as applicable, across the test period.

In order to demonstrate that a DC Converter can satisfy the reactive capability requirements it is necessary to perform reactive capability tests as set out in OC5.A.4.2.5. The following should be completed for both importing and exporting of Active Power. An example of a test schedule follows.

Test	Description	Notes
1	Operation at Rated MW and maximum continuous lagging Reactive Power for 60 minutes.	
2	Operation at Rated MW and maximum continuous leading Reactive Power for 60 minutes.	
3	Operation at 50% Rated MW and maximum continuous leading Reactive Power for 5 minutes.	
4	Operation at 20% Rated MW and maximum continuous leading Reactive Power for 5 minutes.	
5	Operation at 20% Rated MW and maximum continuous lagging Reactive Power for 5 minutes.	
6	Operation at less than 20% Rated MW and unity Power Factor for 5 minutes. This test only applies to systems which do not offer voltage control below 20% of Rated MW	
7	Operation at 0% Rated MW and maximum continuous leading Reactive Power for 5 minutes. This test only applies to systems which offer voltage control below 20% and hence establishes actual capability rather than required capability.	
8	Operation at 0% Rated MW and maximum continuous lagging Reactive Power for 5 minutes. This test only applies to systems which offer voltage control below 20% and hence establishes actual capability rather than required capability.	

Table A-1 Reactive Power Compliance Tests

For the avoidance of doubt, lagging Reactive Power is the export of Reactive Power from the DC Converter to the Total System and leading Reactive Power is the import of Reactive Power from the Total System to the DC Converter.

Grid Code OC5.A.4.3 describes the Reactive Control Testing for DC Converter Stations using Current Source Converter (CSC) technologies .

The Reactive control testing for DC Converters employing current source technology shall be for both importing and exporting of Active Power and shall demonstrate that the Reactive Power transfer limits specified in the (BCA) Bilateral Agreement are not exceeded. The example was shown in the below:

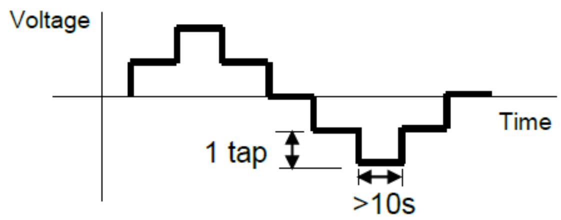
Maximum allowed reactive power consumption (var from the AC system) =   Mvar

Maximum allowed reactive power generation (var to the AC system) =   Mvar

The two reactive power limits stipulated above apply across the complete DC converter station power range from the maximum import to maximum export and across the AC voltage operation range.

Power control system shall be perturbed by a series of system voltage changes, for example auto switch in / out filter banks, to the Active Power output of the DC Converter and changes of system voltage where possible. The DC Converter Station owner is responsible for ensuring that suitable arrangements are in place with the Externally Interconnected System Operator to facilitate the Active Power changes required by these tests.

According to the requirement of OC5.A.4.3.2. the Active Power output of the DC Converter should be also varied by applying a sufficiently large step to the frequency controller reference/feedback summing junction to cause at least a 10% change in output of the Registered Capacity of the DC Converter in a time not exceeding 10 seconds. Where possible, System voltage changes should be created by a series of multiple upstream transformers taps. The DC Converter station owner should coordinate with The Company or the relevant Network Operator in order to conduct the required tests. The time between transformer taps should be at least 10 seconds as per OC5.A.4.3 Figure 1.



OC5.A.4.3 Figure 1 – Transformer tap sequence for reactive transfer tests

Appendix B Voltage Control Testing

Summary of Grid Code Requirements

The generic requirements for voltage control are set out in the Grid Code Connection Conditions with any site-specific variations included in the Bilateral Agreement. This section summarises the key requirements using the generic values included in the Grid Code that are applicable to DC Converters Stations using VSC technology.

Grid Code CC.6.3.8(a)(iii) requires provision of a continuously acting automatic voltage control which is stable at all operating points. The point of voltage control is the Grid Entry Point or User System Entry Point if Embedded.

Grid Code CC.6.3.8(a)(iv) States that the performance requirements will either be stated in the Bilateral Connection Agreement (pre-1 January 2009) or in CC Appendix 7.

Grid Code CC Appendix 7 requires:

- CC.A.7.2.2.2 The voltage set point should be adjustable over a range of +/-5% of nominal with a resolution of better than 0.25%.
- CC.A.7.2.2.3 The voltage control system should have a reactive slope characteristic which must be adjustable over a range of 2 to 7% with a resolution of 0.5%. The initial setting should be 4%.
- CC.A.7.2.3.1 The speed of response to a step change should be sufficient to deliver 90% of the reactive capability within 1 second with any oscillations damped out to less than 5% peak to peak within a further 1 second.
- CC.A.7.2.2.5 The control system should deliver any reactive power output correction due from the voltage operating point deviating from the slope characteristic within 5 seconds.
- CC.A.7.2.2.6 The DC Converter Station must continue to provide voltage control through reactive power modulation within the designed capability limits over the full connection point voltage range +/-10% (CC.6.1.4) however the full reactive capability (CC.6.3.2) is only required to be delivered for voltages within +/-5% of nominal in line with CC6.3.2 and CC.A.7.2.2 (b) or Figure 4 of CC.6.3.4 if applicable.

Grid Code Figure CC.A.7.2.2(b) Illustrates the operational envelope required. The DC Converter Station Owner must provide ESO with a transfer block diagram illustrating the DC Converter voltage control scheme and include all associated parameters. This forms part of Schedule 1 of the Data Registration Code and should be included in part 3 of the User Data File Structure (UDFS). The information will enable ESO to review the suitability of the proposed test programme to demonstrate compliance with the Grid Code.

Setpoint Voltage and Slope

The ESO Control Centre issues voltage control instructions to all Balancing Market participants. For DC Converter Stations the usual instruction is to alter Setpoint Voltage and should be carried out in the usual 2 minutes required for Ancillary Service instructions. The slope may also be varied by control instruction, but the DC Converter Station Owner has up to a week to complete the change. Slope is usually expected to be set at 4%. The procedures for Voltage Control instructions are included in Grid Code Balancing Code (BC) 2.

Delivery of Reactive Capability

Connection Conditions CC.6.1.4 requires that the full Reactive Capability is capable of being delivered for voltages at the Grid Entry Point as below:

- Voltage on the 400kV part of the National Electricity Transmission System at each Connection Site with a GB Code User (and in the case of OTSDUW Plant and Apparatus, a Transmission Interface Point) will normally remain within +-5% of the nominal value unless abnormal conditions prevail.
- Voltages on the 275kV and 132kV parts of the National Electricity Transmission System at each Connection Site with a User (and in the case of OTSDUW Plant and Apparatus, a Transmission

Interface Point) will normally remain within the limits +-10% of the nominal value unless abnormal conditions prevail.

- At nominal System voltages below 132kV the voltage of the National Electricity Transmission System at each Connection Site with a User (and in the case of OTSDUW Plant and Apparatus, a Transmission Interface Point) will normally remain within the limits +-6% of the nominal value unless abnormal conditions prevail.

Outside this range the DC Converter must be capable of continuing to contribute to voltage control by delivering Reactive Power. However, the level of reactive power delivered may be limited by the design of the plant and apparatus. There is no low or high limit on this obligation, but plant must continue to provide maximum reactive power within its design limits.

Transient Response

The connection conditions CC.A.7.2.3 sets out serval criteria for acceptable transient voltage response that shown in the Figure CCA.7.2.3. This section applies only to VSC technology.

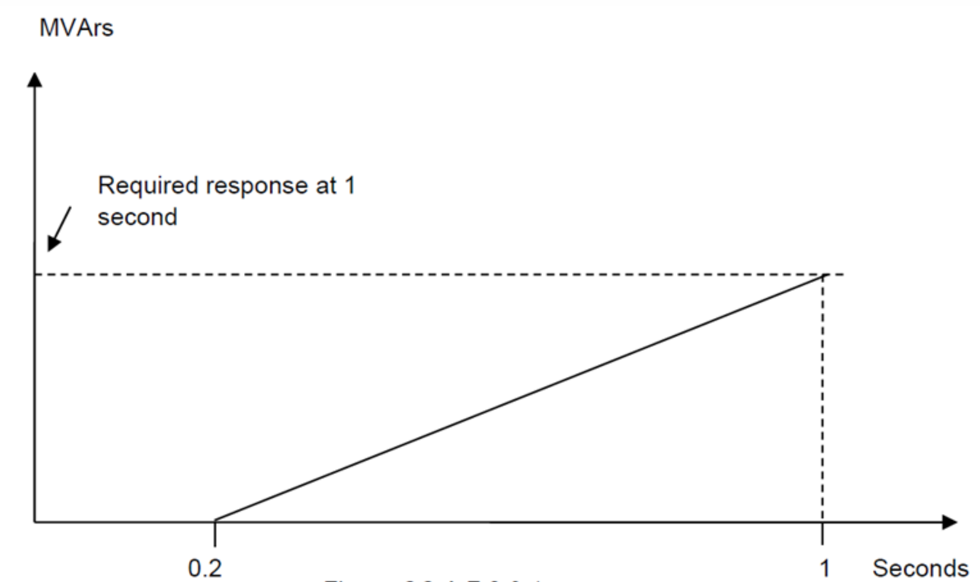


Figure CC.A.7.2.3.1a

Grid Code CC.A.7.2.3.1 requires:

- The dead time is less than 200ms
- The response shall be such that 90% of the change in the Reactive Power output will be achieved within

  ---- 1 second, where the step is sufficiently large to require a change in the steady state Reactive Power output from zero to its maximum leading value or maximum lagging value, as required by CC.6.3.2 (or, if appropriate, CC.A.7.2.2.6 or CC.A.7.2.2.7); and

  ---- 2 seconds, for Plant and Apparatus installed on or after 1 December 2017, where the step is sufficiently large to require a change in the steady state Reactive Power output from its maximum leading value to its maximum lagging value or vice versa.

- The magnitude of the Reactive Power output response produced within 1 second shall vary linearly in proportion to the magnitude of the step change.
- Within 2 seconds from achieving 90% of the response as defined in CC.A.7.2.3.1 (ii), the peak-to-peak magnitude of any oscillations shall be less than 5% of the change in steady state Reactive Power.

Compliance Test Description

The voltage control tests for a DC Converter (excluding current source technology) are set out in the Grid Code OC5. A.4.4. As described testing should be by tapping of an upstream grid transformer and by injection to the control system reference.

Where steps can be initiated using an upstream grid transformer tap changers, the DC Converter will need to coordinate with the host Transmission or Distribution Network Operator. Consideration should also be given to switching the associated tap changer Automatic Voltage Control (AVC) from auto to manual for the duration of the test.

Suggested DC Converter Station Voltage Control Test Procedure

The following generic procedure is provided to assist DC Converter Stations in drawing up their own site-specific procedures for the ESO witnessed -DC Converter Voltage Control Tests.

Test	Describes	Notes
	DC Converter in Voltage Control at Maximum Export/Import Power Output and near Unity Power Factor	
V1	• Record steady state for 10 seconds • inject +1% step to Voltage control System Setpoint • Hold for at least 10 seconds • Remove injection as a step • Hold for at least 10 seconds	
V2	• Record steady state for 10 seconds • Inject -1% step to Voltage control System Setpoint • Hold for at least 10 seconds • Remove injection as a step • Hold for at least 10 seconds	
V3	• Record steady state for 10 seconds • Inject +2% step to Voltage control System Setpoint • Hold for at least 10 seconds • Remove injection as a step • Hold for at least 10 seconds	
V4	• Record steady state for 10 seconds • Inject -2% step to Voltage control System Setpoint • Hold for at least 10 seconds • Remove injection as a step • Hold for at least 10 seconds	
V5	• Record steady state for 10 seconds • Inject +4% step to Voltage control System Setpoint • Hold for at least 10 seconds • Remove injection as a step • Hold for at least 10 seconds	
V6	• Record steady state for 10 seconds • Inject -4% step to Voltage control System Setpoint • Hold for at least 10 seconds • Remove injection as a step • Hold for at least 10 seconds	

Tests	Describes	Notes
	DC Converter Station in Voltage Control at Maximum Export/Import Power Output and near Unity Power Factor	
T1	• Record steady state for 10 seconds • Tap up 1 position on external upstream tap changer • Hold for at least 10 seconds	
	• Tap up 1 position on external upstream tap changer i.e. up 2 positions from starting position. • Hold for at least 10 seconds	
	• Tap down 1 position on external upstream tap changer i.e. up 1 positions from starting position. • Hold for at least 10 seconds	
	• Tap down 1 position on external upstream tap changer i.e. at starting position. • Hold for at least 10 seconds	
	• Tap down 1 position on external upstream tap changer i.e. down 1 positions from starting position. • Hold for at least 10 seconds	
	• Tap down 1 position on external upstream tap changer i.e. down 2 positions from starting position. • Hold for at least 10 seconds	
	• Tap up 1 position on external upstream tap changer i.e. down 1 positions from starting position. • Hold for at least 10 seconds	
	• Tap up 1 position on external upstream tap changer i.e. return to starting position. • Hold for at least 10 seconds	

When operating below 20% **Rated MW** the automatic control system may continue to provide voltage control utilising any available reactive capability. If voltage control is not being provided, the automatic control system shall be designed to ensure a smooth transition between the shaded area bound by CD and the non-shaded area bound by AB in Figure 1 of CC.6.3.2 (c).

Demonstration of Slope Characteristic

The DC Converter Station voltage control system is required to follow a steady state slope characteristic. This should be demonstrated by recording voltage at the controlled bus bar (usually the Grid Entry Point or User System Entry Point if Embedded) and the reactive power output at the same point over several hours. Plotting the values of Voltage against Reactive Power output should demonstrate the slope characteristic.

Additional Power System Stabiliser Testing

Additional tests are required if a Power System Stabiliser is fitted. Although the fitting of Power System Stabilisers on non-synchronous plant is a rarity, one may be provided within the control system by a manufacturer or ESO may specify the requirement in the Bilateral Agreement. The testing process outlined in this section is based largely on that employed on synchronous plant, which is believed to be comparable. However, DC Converter Station Owners should anticipate the possibility that an alternative testing regime may be developed in discussion with ESO.

ESO will not permit PSS commissioning until the tuning methodologies and study results used in any PSS settings proposal have been provided to ESO. A report on the PSS tuning should be provided along with the proposed test procedure in the User Data File Structure (Part 3). Based on the information submitted, ESO will meet with the DC Converter Station Owner to discuss and agree the initial PSS settings for commissioning.

The suitability of the tuning of any PSS is checked in both the time and frequency domains. In the time domain, testing is achieved by applying a small voltage step change on a module basis. Comparisons are made between performance with and without the power system stabiliser in service.

For analysis in the frequency domain, a bandwidth-limited (200mHz-3Hz) random noise injection should be made to the DC Converter Station Voltage control System Setpoint. The DC Converter Station Owner should provide a suitable band limited (200mHz-3Hz) noise source to facilitate noise injection testing. The random noise injection will be carried out with and without the PSS in service to demonstrate damping. The PSS gain should be continuously controllable (i.e. not discrete components) during testing.

The suitability of the PSS gain will also be assessed by increasing the gain in stages to 3x the proposed setting.

The tests will be regarded as supporting compliance if:

- The PSS gives improved damping following a step change in voltage.
- Any oscillations are damped out within 2 cycles
- The PSS gives improved damping of frequencies in the band 300mHz – 2Hz.
- The gain margin is adequate if there is no appreciable instability at 3x proposed gain

PSS testing is additional to the Module Voltage Control Tests.

Suggested DC Converter PSS Test Procedure. The following generic procedure is provided to assist DC Converter Station owners in drawing up their own site-specific procedures for the ESO PSS Tests.

Test	Describes	Notes
	DC Converter in Voltage Control at Maximum Power Output (>65% Rated MW) and near Unity Power Factor PSS Not in Service	
1	• Record steady state for 10 seconds • Inject +1% step to Voltage control System Setpoint and hold for at least 10 seconds • Remove step returning Voltage control System Setpoint to nominal and hold for at least 10 seconds	
2	• Record steady state for 10 seconds • Inject +2% step to Voltage control System Setpoint and hold for at least 0 seconds • Remove step returning Voltage control System Setpoint to nominal and hold for at least 10 seconds	
3	• Inject band limited (0.2-3Hz) random noise signal into Voltage control System Setpoint and measure frequency spectrum of Real Power. • Remove noise injection.	
	Switch On Power System Stabiliser	
4	• Record steady state for 10 seconds Inject +1% step to DC Converter Voltage control System Setpoint and hold for at least 10 seconds • Remove step returning Voltage control System Setpoint to nominal and hold for at least 10 seconds	
5	• Record steady state for 10 seconds Inject +2% step to Voltage control System Setpoint and hold for at least 10 seconds • Remove step returning Voltage control System Setpoint to nominal and hold for at least 10 seconds	
6	• Increase PSS gain at 30second intervals. i.e. x1 – x1.5 – x2 – x2.5 – x3 • Return PSS gain to initial setting	
7	• Inject band limited (0.2-3Hz) random noise signal into Voltage control System Setpoint and measure frequency spectrum of Real Power.	

	• Remove noise injection.	
8	Repeat Voltage Control Tests with PSS in service.	

Appendix C Frequency Control

Summary of Grid Code Requirements

The National Electricity Transmission System is an island network with no AC connections to mainland Europe. In order to manage the system frequency within the normal operating range 49.5 to 50.5Hz (CC.6.1.2) ESO requires generating units, power park modules and DC converter station to be able to continuously modulate their output in relation to frequency across this range. In order to maintain a stable system frequency, it is important that response from plant is achieved without undue delay.

The Grid Code sets out Frequency Control requirements in serval separate places, notably the Glossary & Definitions (GD), the Connection Conditions (CC) and Balancing Code (BC) 3. This section summarises the key requirements GD of the Grid Code defines Primary, Secondary and High frequency response including the requirement that the response is progressively delivered with increasing time.

CC.6.3.3 of the Grid Code specifies that the DC Converter must be capable of maintaining a minimum level of active power (see Figure 2 of CC.6.3.3) in the frequency range 47Hz to 50.5Hz.

It also states CC6.3.3 (d) that when in Rectifier mode (acting as a demand) that active power exported from the system should reduce as system frequency falls below 49.5 Hz in line with Figure 3, for ease replicated here as fig C1b Limited frequency Sensitive Mode Rectifier Mode operation.

CC.6.3.7 of the Grid Code specifies the minimum frequency control capability, in particular the frequency control must be:

- Stable over the entire operating range from 47Hz to 52Hz.
- Able to contribute to controlling the frequency on an islanded network to below 52Hz.
- Capable of a frequency droop of between 3 and 5%.
- Capable of providing frequency control against a target set in the range of 49.9Hz and 50.1Hz.
- Have a frequency control dead band of less than ±0.015Hz.
- Capable of delivering a minimum level of frequency response.

Grid Code Figure CC.A.3.1 specifies a minimum requirement for frequency response of 10% of Registered Capacity achievable for Primary, Secondary and High Frequency response. This minimum value is designed to ensure that plant provides a suitable contribution to maintain frequency correction when connected to the system and selected to Frequency Sensitive Mode (FSM) and response capability more than 10% is encouraged.

The speed of response is an important criterion and the Grid Code Figures CC.A.3.2 and CC.A.3.3 indicate typical responses from plant with no delay in response from the start of the frequency deviation. Practically there is a permissible dead band and ESO accepts a delay of up to but not exceeding 2 seconds before measurable response is seen from a generating unit in response to a frequency deviation.

BC3 of the Grid Code specifies how plant should be operated and instructed to provide frequency response. The section also sets out the requirements on how all plant should respond to the system frequency rising above 50.4/50.5Hz, by progressively reducing output power.

Details of the tests required for the preliminary and main governor response tests are provided in OC5.A.4.5 but additional guidance is provided in this Appendix including outline test procedures.

Modes of Frequency Control Operation

Balancing Code (BC) 3 of the Grid Code defines operation in Limited Frequency Sensitive Mode and Frequency Sensitive Mode. . DC Converter can be in either FSM or LFSM. DC Converter in LFSM mode are required to operate in LFSM at all times unless instructed by The Company to operate in FSM mode.

For DC Converter Systems which act as interconnectors between different AC systems there must be agreement in place with the external Grid to accept the impact of the changes in output caused by the action of Limited Frequency Sensitive and Frequency Sensitive Modes of response.

- Inverter mode (acting as the generator) with Limited Frequency Sensitive Mode

When in Inverter mode exporting power onto the main GB network and in Limited Frequency Sensitive Mode the DC Converter is not required to provide any increase in active power output if frequency reduces below 50Hz and is only required to maintain active power output in accordance with CC.6.3.3. Should the frequencies rise above 50.4Hz it must reduce the active power output by a minimum of 2% of output for every 0.1Hz rise above 50.4Hz (see figure C1). Should this cause power output to be forced below Designed Minimum Operating Level (DMOL) then the DC Converter may disconnect after a time if operation is not sustainable.

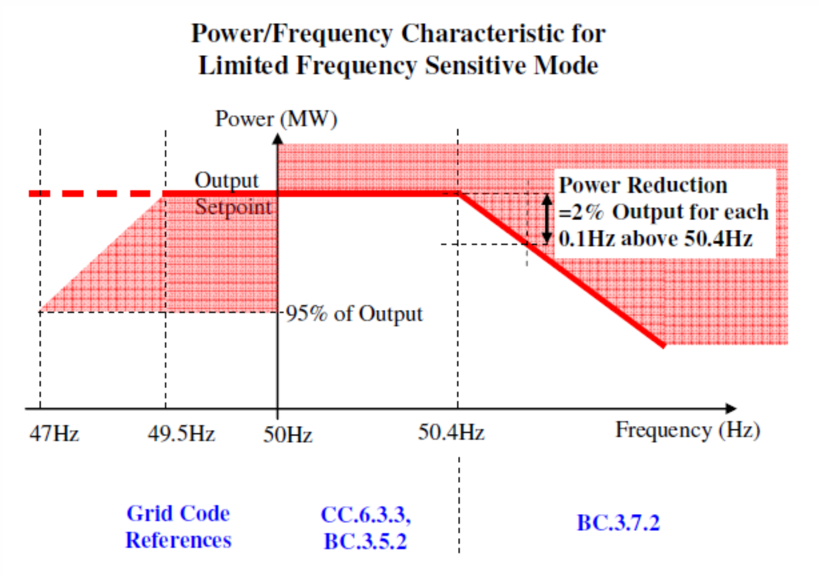


Figure C1: Limited Frequency Sensitive Mode Inverter Operation

- In Rectifier mode (acting as a demand) with Limited Frequency Sensitive Mode

When in Rectifier mode exporting power from the main GB network and in Limited Frequency Mode, the DC Converter is not required to change its export from the network should the frequency rise above 50 Hz but should the frequency fall below 49.5 Hz export from the network should be decreased in accordance with figure C1b.

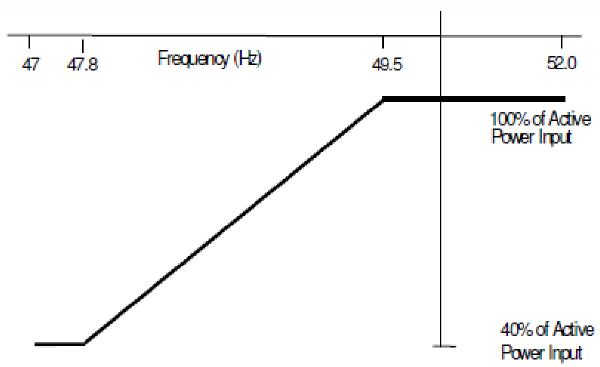


Figure C1b – Limited Frequency Sensitive Mode Rectifier Operation

- In Inverter mode (acting as the generator) and in Rectifier mode (acting as a demand) with Frequency Sensitive Mode

When selected for Frequency Sensitive Mode by ESO the DC Converter Station must adjust the active power output in response to any frequency change (within the range 49.5 Hz to 50.5 Hz) according to the agreed droop characteristic (between 3- 5%). For the purposes of the Mandatory Services Agreement the frequency response performance is measured in terms of the response achieved after a given duration. Clearly there will be an Ancillary Services Agreement Frequency Response matrix for both directions of active power flow, 1. Inverter mode (import) and 2. Rectifier mode (export).

When system frequency exceeds 50.5Hz the requirements of Limited Frequency Sensitive Mode apply so that the HVDC system must further reduce output by a minimum of 2% of output for every 0.1Hz rise above 50.5Hz. To avoid the confusion, the control mode cannot be changed from FSM mode to LFSM mode unless instructed by The Company.

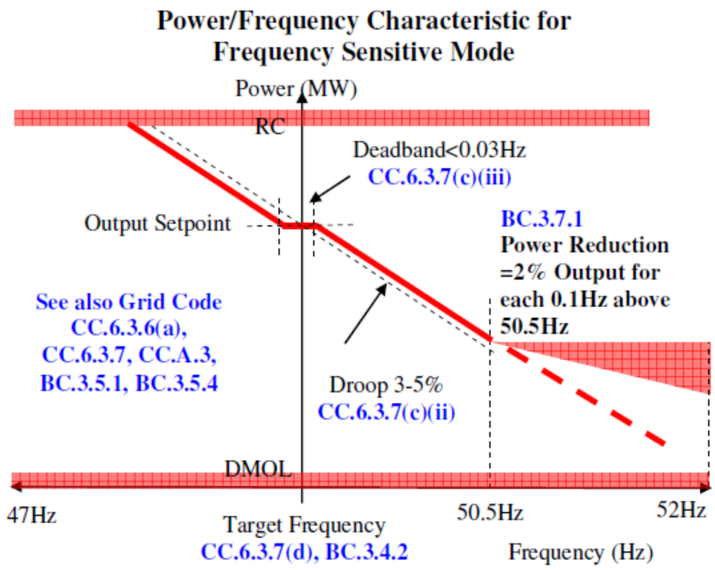


Figure C2: Frequency Sensitive Operation Inverter Mode

Target Frequency

All Balancing Market Units (BMUs), irrespective of the plant type (wind, thermal, CCGT or DC Converter, whether directly Grid Connected or Embedded), are required to have the facility to set the levels of output power and frequency. These are generally known as Target MW and Target Frequency settings.

The ESO Control Centre instructs all Active Balancing Market Units to operate with the same Target Frequency, normally 50.00 Hz. In order to adjust electric clock time, the System Operator may instruct Target Frequency settings of 49.95Hz or 50.05Hz. However, under exceptional circumstances, the instructed settings could be outside this range. The connection condition requires a minimum setting range from 49.90Hz to 50.10Hz.

De-load Instructions

System balancing is a separate issue to that of frequency response. A de-load instruction is to a fixed MW value rather than a delta MW value from available power. Typically, Deloads may be instructed say from full output to enable both high and low frequency response to be available.

Summary of Steady State Load Accuracy Requirements

Connection conditions CC.6.3.9 requires a DC Converter Station to be able to control output to a target with an accuracy specified as a standard deviation.

To demonstrate compliance, the DC Converter should self-dispatch for 30 minutes whilst in Limited Frequency Sensitive mode. The active power output and power available should be recorded with a sampling rate not less than once per minute.

Compliance Testing Requirements

The main objectives of the frequency controller response tests are to establish the plant performance characteristics for compliance with the Connection conditions technical requirements (including the validation of plant data/models). They are also required as a measured set of plant response values that will verify the response matrices for the Mandatory Services Agreement.

In order to verify the plant behaviour, it is essential that the DC Converter is tested in normal operating modes. A frequency disturbance can be simulated by injecting the required frequency variation signals to the frequency reference/feedback summing junction. The results obtained from reducing frequency ramps will be used to verify primary and secondary frequency response. Similarly, the results obtained from increasing ramps will be used to verify the high frequency response. Robust and stable response to islanding events can be demonstrated by injecting large and rapid frequency disturbances and observing the response. ESO recommends tests are outlined in Grid Code OC5, specifically in sections A.4.5, Figures 1 and 2, and Figures 1 and 2 illustrate the importing of active power; the simulated frequency polarity should be reversed when exporting active power. There should be sufficient time allowed between tests for control systems to reach steady state. A reasonable time gap is mandatory between test cases. According to OC5. A.4.5.8, it is suggested to have sufficient HOLD time, to allow the DC Converter system to stabilise or be longer than 90 seconds, whichever is the longer when ESO is not witnessed. Upon agreed with ESO, the frequency test plan could follow ECP.A.7.5. Figure 1 and ECP.A.7.5. Figure 2.

Typical Frequency Control Test Injection

A frequency injection signal is needed to undertake all frequency related capability tests. Ideally the injected signal will be directly added into the raw frequency feedback as shown in the diagram below.

Ideally the signal will be software programmable with start/stop initiation via local or remote software interfaces or local digital inputs. Alternatively, the signals should be a ±10V analogue input where 1 volt represents 0.2 Hz frequency change.

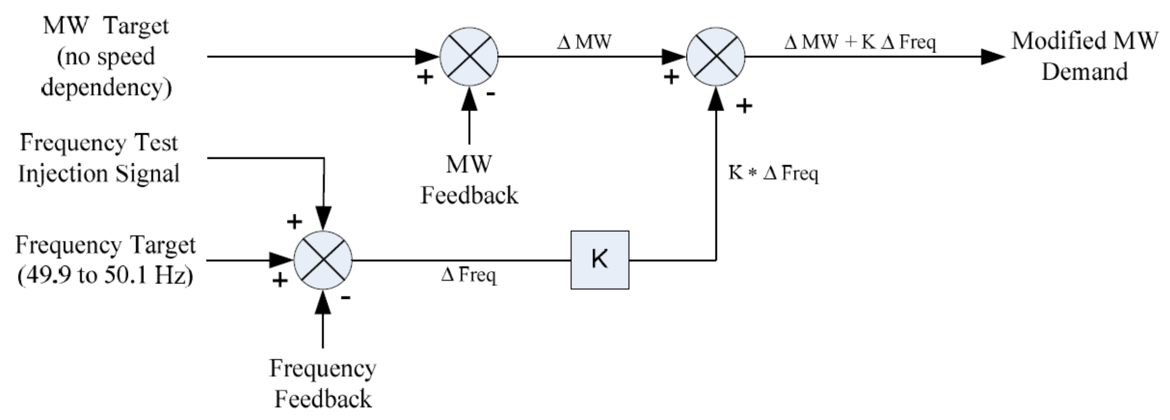


Figure C3: Typical Frequency Test Injection Scheme

Preliminary Frequency Response Testing

Experience has demonstrated that significant delays can occur during testing because of problems associated with the frequency controller setup or frequency injection method. Frequently this results in considerable lost time and additional expense for both parties. Consequently, this test has been drawn up and has been shown to help in preventing such situations arising.

Typical injection locations at the frequency controller are shown in Figure C4. To avoid the risk of re-testing, it is important that the injection method and the plant control are proved well in advance of the main tests by the DC Converter Station owner. A preliminary test is therefore required with details given in Grid Code OC5. A.4.5.4 and illustrated below. For all tests, the target frequency selected on the generating plant is that instructed by the ESO Control Centre. This should normally be 50.00 Hz.

For both Import and Export modes of operation, with the plant running at a level approximately halfway between full maximum output and Designed Minimum Operating Level, the following frequency injections should be applied.

The recorded results (e.g., Freq. injected, MW, Freq.sys) should be sampled at a minimum rate of 0.1 Hz to allow ESO to assess the plant performance from the initial transients (seconds) to the final steady state conditions (which may typically take 2-3 minutes depending on the plant design).

The preliminary frequency response test results should be sent to ESO for assessment at least two weeks prior to the final witnessed tests.

Test No (Figure1)	Frequency Injection	Notes
8	• Power output at MLP4 • Inject -0.5Hz frequency fall over 10 sec • Hold for a further 20 sec • At 30 sec from the start of the test, Inject a +0.3Hz frequency rise over 30 sec. • Hold until conditions stabilise	Plant in FSM

	• Remove the injected signal as a ramp over 10 seconds	
13	• Inject - 0.5Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injected signal as a ramp over 10 seconds	Plant in FSM
14	• Inject +0.5Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injected signal as a ramp over 10 seconds	Plant in FSM
H	• Inject -0.50Hz frequency fall as a step change • Hold until conditions stabilise • Remove the injection signal as a step change	Plant in FSM
I	• Inject +0.50Hz frequency rise as a step change • Hold until conditions stabilise • Remove the injection signal as a step change	Plant in FSM

Table C1: Preliminary Frequency Response Testing

Witnessed Frequency Response Testing Sequence in Compliance Processes

OC5. A.4.5. Figure 1. Figure 2 give the ramps and step frequency injection tests required at different loading levels (i.e., MLP 6 to MLP 1). The corresponding test sequence is outlined below with the initial test establishing the maximum steady state output condition of the plant (i.e., MLP 6). A full generic procedure is provided as an example. The load points may be adjusted subject to agreement with ESO. As agreed by Compliance engineer, the ECC test process can be apply to GB user.

1. **Establish Maximum Plant Capacity as Loading Point MLP6**

- Switch DC Converter controller to manual and raise load demand to confirm the maximum output level at the base settings.
- Record plant and ambient conditions.

2. Response Tests at Loading Point MLP6 (100% MEL)

- Operate the plant at MLP 6
- Inject ramp/profiled frequency changes simultaneously into the DC Converter controller (i.e., Tests 1-4 in OC5. A.4.5. Figure 1) and record plant responses.
- Conduct test BC1 – BC4 and L as shown in OC5. A.4.5. Figure 2 to establish the de-loading capability as could occur under system islanding or system split conditions.

3. Response Tests at Loading Point MLP5 (95% MEL)

- Operate the plant at MLP5.
- Conduct tests 5-7 as shown in OC5. A.4.5. Figure 1and record plant responses.
- Conduct test A as shown in OC5. A.4.5. Figure 2 to establish the robustness of the control system under simulated extreme disturbances (as could occur under system islanding or system split conditions).

4. Response Tests at Loading Point MLP4 (80% MEL)

- Operate the plant at MLP4.
- Conduct tests 8-14 as shown in OC5. A.4.5. Figure 1and record plant responses.
- Conduct tests D – N as shown in OC5. A.4.5. Figure 2 to establish the DC Converter controller, and step response characteristics for DC Converter controller modelling purposes.

- Conduct test J as shown in OC5. A.4.5. Figure 2 to establish the robustness of the control system under simulated extreme disturbances (e.g., system islanding or system split).

5. Response Tests at Load Point MLP3 (70%)

- Operate the plant at MLP3.
- Conduct tests 15 to 17 as shown in OC5. A.4.5 Figure 1 and record plant responses.

6. Response Tests at Load Point MLP2 (MG or MSOL)

- Operate the plant at MLP2.
- Conduct tests 18 - 22 as shown in OC5. A.4.5 Figure 1 and record plant responses.

7. Response Tests at Designed Minimum Operating Level MLP1 (DMOL)

- Operate the plant at DMOL.
- Conduct tests 23 - 26 as shown in OC5. A.4.5 Figure 1 and record plant responses.
- Conduct test K as shown in OC5. A.4.5.Figure 2 to establish the step response characteristics for DC Converter controller modelling purposes.

Note:

- BC1 and BC3 in Figure 2 will generally be +2.0Hz unless an injection of this size causes a reduction in plant output that takes the operating point below Minimum Stable Operating Level in which case an appropriate injection should be calculated in accordance with the following:

  For example, 0.9Hz is needed to take an initial output 65% to a final output of 20%. If the initial output was not 65% and the Minimum Stable Operating Level is not 20% then the injected step should be adjusted accordingly as shown in the example given below

  Initial Output 65%

  Minimum Stable Operating Level 20%

  Frequency Controller Droop 4%

  Frequency to be injected = (0.65-0.20) x0.04x50 = 0.9Hz

- Tests L and M in Figure 2 shall be conducted if in this range of tests, the system frequency feedback signal is replaced by the injection signal rather than the injection signal being added to the system frequency signal. The tests will consist of monitoring the Power Park Module in Frequency Sensitive Mode during normal system frequency variations without applying any injection.
- Test N in Figure 2 shall be conducted in all cases. All three tests should be conducted for a period of at least 10 minutes.

Since the governor response tests described above are to be arranged and conducted by the DC Converter Station owner, it is their responsibility to propose a test programme to suit their site-specific requirements. A typical example of the test procedure based on OC5. A.4.5 Figures 1 and 2 is given below. This procedure is required to be submitted to ESO for approval before an ION is issued. The tests should be carried out in both export and import active power directions.

Injection Tests at MLP6,		
Test No (Figure 1)	**Action**	**Notes**
1	• Inject 0.10Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 6	
2	• Inject -0.20Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 6	
3	• Inject 0.20Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 6	
4	• Inject 0.50Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 6	
BC1	• Inject +2.0 Hz frequency rise over 1 sec • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 6	Plant In FSM
BC2	• Inject +0.6 Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 6	Plant in FSM

L	• Record normal system variation in frequency and active power of the DC Converter over at • least 10 minutes. Load setpoint at maximum.	Plant in FSM
BC3	• Inject +2.0 Hz frequency rise over 1 sec • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 6	Plant in LFSM
BC4	• Inject +0.6 Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 6	Plant in LFSM

Injection Tests at MLP5,		
Test No (Figure 1)	**Frequency Injection**	Notes
5	• Inject -0.50Hz frequency fall over 10 sec • Hold for 20 sec • Inject +0.3Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 5	
6	• Inject -0.20Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 5	
7	• Inject 0.50Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 5	
A	• Inject 1.0Hz/sec frequency fall over 2 sec • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 4	

Injection Tests at MLP4,		
Test No (Figure 1)	**Frequency Injection**	Notes
8	• Inject -0.50Hz frequency fall over 10 sec • Hold for 20 sec • Inject +0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
9	• Inject -0.10Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
10	• Inject 0.10Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
11	• Inject -0.20Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
12	• Inject 0.20Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
13	• Inject -0.50Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
14	• Inject +0.50Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 4	
D	• Inject +0.02Hz frequency fall as a step change • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 4 •	

E	• Inject -0.02Hz frequency rise as a step change • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 4	
F	• Inject -0.20Hz frequency fall as a step change • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 4	
G	• Inject 0.20Hz frequency rise as a step change • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 4	
H	• Inject -0.50Hz frequency fall as a step change • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 4	
I	• Inject 0.50Hz frequency rise as a step change • Hold until conditions stabilise at MLP 4 • Remove the injection signal • Hold until conditions stabilise at MLP 4	
J	• Inject 1.0Hz/sec frequency fall over 2 sec • Hold for 30 sec • Remove the injection signal • Hold until conditions stabilise at MLP	
M	• Record normal system variation in frequency • and active power of the DC Converter over at • least 10 minutes	
N	• Record normal system variation in frequency • and active power of the DC Converter over at • least 10 minutes • Switch plant to Frequency Sensitive Mode	Plant in LFSM

Injection Tests at MLP3,		
Test No (Figure 1)	**Frequency Injection**	Notes
15	• Inject -0.50Hz frequency fall over 10 sec • Hold for 20 sec • Inject 0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 2	
16	• Inject 0.50Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 3	
17	• Inject -0.80Hz frequency fall over 10 sec • Hold for 20 sec. • Inject 0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 3	

Injection Tests at MLP2,		
Test No (Figure 1)	**Frequency Injection**	Notes
18	• Inject -0.50Hz frequency fall over 10 sec • Hold for 20 sec • Inject 0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 2	
19	• Inject -0.20Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 2	
20	• Inject 0.20Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP	
21	• Inject -0.50Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 2	
22	• Inject -0.80Hz frequency fall over 10 sec • Hold for 20 sec • Inject 0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 2	

Injection Tests at MLP1,		
Test No (Figure 1)	**Frequency Injection**	Notes
23	• Inject -0.50Hz frequency fall over 10 sec • Hold for 20 sec • Inject 0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 1	
24	• Inject -0.20Hz frequency fall over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 1	
25	• Inject 0.20Hz frequency rise over 10 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 1	
26	• Inject -0.80Hz frequency fall over 10 sec • Hold for 20 sec • Inject 0.30Hz frequency rise over 30 sec • Hold until conditions stabilise • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 1	
K	• Inject 0.5Hz frequency fall over 1 sec • Hold until conditions stabilise • Remove the injection signal • Hold until conditions stabilise at MLP 1	

Control Requirements that may be witnessed

During attendance on site for witness testing of frequency response, ESO may request that the DC Converter Station owner alters the Target Frequency setpoint from the DC Converter Station owners Control Room as an indication of controllability. This may be combined with tests M.

Target Frequency setting changes

During attendance on site for witness testing of frequency response, ESO will request that the DC Converter Owner alters the Target Frequency setpoint from the DC Converter or embedded DC Converter system Control Room as an indication of controllability. The following test procedure indicates the steps of target frequency required in OC5.A.2.8. =

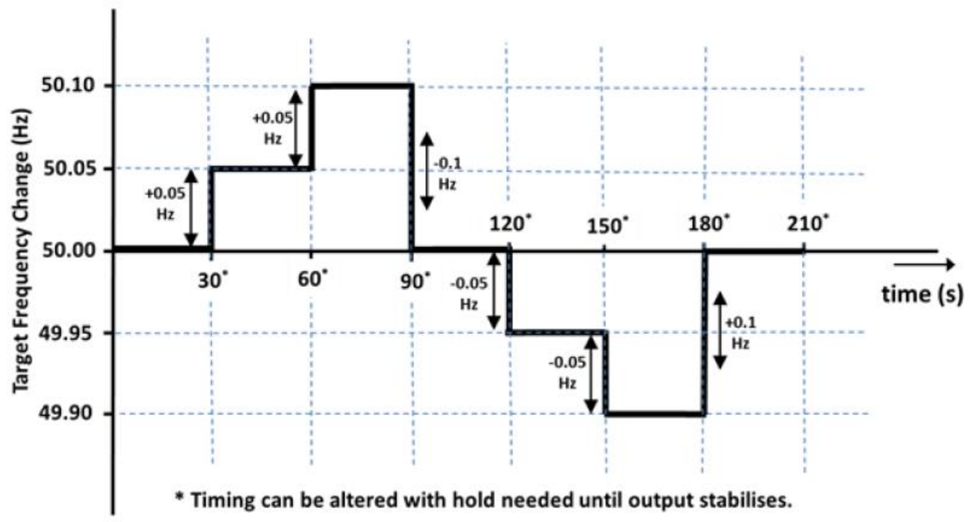


Figure 3 – Target Frequency setting changes

Appendix D Other Technical Information

Technical Information on the Connection Bus Bar

This section illustrates the technical information relating to the connection bus bar that is provided by ESO

Busbar on GB Transmission System operating at Supergrid Voltage:	**Example 1 (Scottish Power Area 275kV)**	**275kV**

Item	Max	Min	Unit
Symmetrical Three-phase short circuit level at instant of fault from GB Transmission System (based on transient impedance)	19000	1300	MVA
Equivalent system reactance between the Super grid Busbar and DC Converter Point of Connection	3.9	3.6	% on 100MVA
Total clearance time for fault on GB Transmission System operating at Super grid Voltage, cleared by System Back-up Protection (C.C.6.3.15 (c))	800	N/A	msec

Equivalent Circuit between Supergrid Busbar and DC Converter Station Point of Connection

(showing transformer vector groups):

[For CC6.3.15.3(ii) assume system 'nps' impedance pre-and post-fault such that CC6.1.6 limits met]

Equivalent Sequence Impedances for Calculating Unbalanced Short-Circuit Current Contribution

The DC Converter Station owner is required to provide the fault infeed from the DC Converter Station into the public transmission/distribution network. The data should be submitted in Grid Code DRC Schedule 14. The following transmission/distribution system equivalent sequence impedances may be used by the DC Converter Station owner in calculating unbalanced short-circuit current contribution from the DC Converter Station at the entry point unless site specific values have been given. The DC Converter Station owner should confirm the system equivalent sequence impedances that have been used in the submission.

33kV: $Z1 = Z2 = 14.580\angle 88.091^{o}$ % on a 100 MVA base

$Z0 = 159.1\angle 26.565^{o}$ % on a 100 MVA base

These impedances are based on the following assumptions:

- The PPS and NPS X/R ratio of the 33kV system is equal to 30
- The ZPS X/R ratio of the 33kV system is equal to 0.5
- The short-circuit current contribution from the 33kV distribution system for a 3-phase fault at the entry point is approximately 12kA
- The short-circuit current contribution from the 33kV distribution system for a 1-phase fault at the entry point is approximately 3kA

132kV: $Z1 = Z2 = 3.650\angle 84.289^{o}$ % on a 100 MVA base

$Z0 = 1.460\angle 84.289^{o}$ % on a 100 MVA base

These impedances are based on the following assumptions:

- The PPS, NPS and ZPS X/R ratio of the transmission/distribution system is 10.
- The short-circuit current contribution from the transmission/distribution system for a 3-phase fault at the entry point is approximately 12kA
- The short-circuit current contribution from the transmission/distribution system for a 1-phase fault at the entry point is approximately 15kA

275kV: $Z1 = Z2 = 0.700\angle 85.236^{o}$ % on a 100 MVA base

$Z0 = 1.120\angle 85.236^{o}$ % on a 100 MVA base

These impedances are based on the following assumptions:

- The PPS, NPS and ZPS X/R ratio of the 275kV system is equal to 12
- The short-circuit current contribution from the 275kV transmission system for a 3-phase fault at the entry point is approximately 30kA
- The short-circuit current contribution from the 275kV transmission system for a 1-phase fault at the entry point is approximately 25kA

400kV: $Z1 = Z2 = 0.361\angle 85.914^{o}$ % on a 100 MVA base

$Z0 = 0.516\angle 85.914^{o}$ % on a 100 MVA base

These impedances are based on the following assumptions:

- The PPS, NPS and ZPS X/R ratio of the 400kV system is equal to 14
- The short-circuit current contribution from the 400kV transmission system for a 3-phase fault at the entry point is approximately 40kA
- The short-circuit current contribution from the 400kV transmission system for a 1-phase fault at the entry point is approximately 35kA

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Appendix E Test Signal Schedules and Test Log sheet

Compliance Test Signal Schedules **Table 1 - DC Converters Voltage Control**

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	Time (10ms)	Active Power	Reactive Power	Connection Voltage	Frequency #	Freq Injection #	Logic / Test Start#	Statcom #
	Col 9	Col 10	Col 11	Col 12	Col 13	Col 14	Col 15	Col 16
1	State of Charge #	Current #	Voltage Setpoint #	Terminal Voltage if applicable #	DC converter owner tap position or Grid Transformer tap position, if applicable #	Control Mode #		
2								

Columns may be left blank, but the column must still be included in the files

Compliance Test Signal Schedules **Table 2 - DC Converters Reactive Capability**

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	Time (1s)	Active Power	Reactive Power	Connection Voltage	Frequency #	Freq Injection #	Logic / Test Start#	Statcom #
	Col 9	Col 10	Col 11	Col 12	Col 13	Col 14	Col 15	Col 16
1	State of Charge #	Current #	Voltage Setpoint #	Terminal Voltage if applicable) #	DC converter owner tap position or Grid Transformer tap position, if applicable #	Control Mode #		
2								

Columns may be left blank, but the column must still be included in the files

Compliance Test Signal Schedules **Table 3 - DC Converters Frequency Control**

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	Time (100ms)	Active Power	Reactive Power #	Connection Voltage #	Frequency	Freq Injection	Logic / Test Start	Statcom #
	Col 9	Col 10	Col 11	Col 12	Col 13	Col 14	Col 15	Col 16
1	State of Charge #	Current #	Voltage Setpoint #	Terminal Voltage if applicable #	DC converter owner tap position or Grid Transformer tap position, if applicable #	Control Mode #		
2								

Columns may be left blank, but the column must still be included in the files

Compliance Test Log sheet

Where test results are completed without any ESO presence but are relied upon as evidence of the compliance they should be accompanied by a log sheet. This sheet should be legible, in English and detail the items set out below. Some of the items listed may not be relevant to all technology type addressed by guidance notes.

- Time and Date of test
- Name of Power Station and module if applicable.
- Name of Test engineer(s) and company name.
- Name of Customer(s) representative and company name.
- Type of testing being undertake e.g., Voltage Control.
- Controller settings, e.g., Voltage slope, Frequency droop, Voltage setpoint.

For each test the following items should be recorded as relevant to the type of test being undertaken. Where there is uncertainty on the information to be recorded, this should be discussed with ESO in advance of the test.

Voltage Control Tests

- Start time of each test step.
- Active Power.
- Reactive Power.
- Connection Voltage.
- Voltage Control Setpoint, if applicable or changed.
- Voltage Control Slope, if applicable or changed.
- Terminal Voltage if applicable.
- DC converter owner tap position or Grid Transformer tap position, if applicable.

Reactive Power Capability Tests

- Start time of test.
- Active Power.
- Reactive Power.
- Connection Voltage.
- Terminal Voltage if applicable.

Frequency Response Capability Tests

- Start time of test.
- Active Power.
- System Frequency.
- Droop setting of controllers if applicable
- Frequency injection

Material changes during the test period should be recorded e.g., Unit’s tripping / starting, changes to tap changer positions. Thought should be given as to whether such changes invalidate the test, and a repeat test would be appropriate.

Appendix F Contacting National Grid

There are a number of different departments within National Grid that will be involved with this connection. The initial point of contact for National Grid will be your allocated Customer Connection Contract Manager for your Bilateral Agreement. If you are unsure of who your allocated Customer Connection Contract Manager is then the team can be contacted on box.ECC.Compliance@nationalgrideso.com.

For any correspondence relating to testing on the system following the Grid Code the IET process should be followed with notifications made to the '.Box.Tranreq' email address for England and Wales connections and '.Box.TR.Scotland' for all connections in Scotland.

Contact Address:

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

Faraday House, Warwick Technology Park,
Gallows Hill, Warwick, CV346DA

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