

Guidance Notes for Synchronous Generators

GB Users - Issue 14

April 2024



Foreword

These Guidance Notes have been prepared by the National Grid Electricity System Operator (ESO) to describe to Generators 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 (ESO) unless explicitly stated otherwise.

These Guidance Notes are prepared, solely, for the assistance of prospective Generators connecting directly to the National Electricity Transmission System or Large Embedded Power Stations. In the event of dispute, the Grid Code and Bilateral Agreement documents will take precedence over these notes.

Small and Medium Embedded Power Stations 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 3 of the Guidance Note of October 2021 and reflects the major changes brought about by Grid Code workgroup modifications GC0138 and GC0141 as approved by the regulator.

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

The Electricity Customer Connections Manager (see contact details) 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)
AVR	Automatic Voltage Regulator
BA / BCA	Bilateral Agreement / Bilateral Connection Agreement
BC	Balancing Code
BM / BMU	Balancing Mechanism / Balancing Mechanism Unit
CC / CC.A	Connection Conditions / Connection Conditions Appendix
CCGT	Combined Cycle Gas Turbine
CP	Compliance Processes
CUSC	Connection and Use of System Code
DCS	Distributed Control System
DNO	Distribution Network Operator
DMOL	Design Minimum Operating Level
DPD	Detailed Planning Data
DRC	Data Registration Code
EDL/EDT	Electronic Data Logging / Electronic Data Transfer
ELEXON	Balancing and Settlement Code Company
FON	Final Operational Notification
FRT	Fault Ride Through
FSM	Frequency Sensitive Mode
GB	Great Britain
GCRP	Grid Code Review Panel
GT	Gas Turbine
ION	Interim Operational Notification
LSFM	Limited Frequency Sensitive Mode
LON	Limited Operational Notification

MEL	Maximum Export Limit
MLP	Machine Load Point
ESO	Electricity System Operator
NGET	National Grid Electricity Transmission
OC	Operating Code
OCGT	Open Cycle Gas Turbine
OEL	Over Excitation Limiter
OFGEM	Office of Gas and Electricity Markets
PC	Planning Code
PSS	Power System Stabilizer
PSSE	Power System Simulation for Engineering software
RISSP	Record of Inter System Safety Precautions
SEL	Stable Export limit
SO	System Operator (National Grid)
SPT	Scottish Power Transmission
SHET	Scottish Hydro Electric Transmission
ST	Steam Turbine
STC	System Operator Transmission Owner Code
TO	Transmission Owner
TOGA	Transmission Outages, Generation Availability
UDFS	User Data File Structure
UEL	Under Excitation Limiter



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Guidance Note

Introduction

This document complements the Compliance Processes (CP) included in the Grid Code providing additional description of the technical studies and testing set out within the Grid Code applicable to GB Users.

To achieve Operational Notification, the Generator, the company owning and operating a generating unit or power generating module, 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 by ESO and the Generator, 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 Generators 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 conventional synchronous generation technologies. A separate document exists for new generation technologies based on asynchronous plant referred to as power parks and HVDC converter equipment.

For existing connections (connected prior to 27 April 2019 or who had placed purchase contracts for their main plant and apparatus prior to 17th May 2018 the Generator will be deemed a GB User and the new ECC user requirements will not apply. However, if an existing power station undertakes a significant modification to its plant or apparatus new requirements may become applicable. For example, should an existing wind turbine be replaced by a new model of turbine this will be required to meet the ECC.

Generators 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 ECC Requirements

The GB Grid Code was updated in May 2018 to introduce requirements consistent with the European Code Requirements for Generators. 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.

Where an existing power station plans undertakes a modification to its plant or apparatus this should be discussed with the ESO connection account manager at the earliest opportunity as the extent of the modification could result in the application of the new ECC requirement to an existing connection. The table below set out ESO's expectation for some typical modifications, for specific advice please contact ESO using the details in Appendix E.

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 dispute.

	Example Details	This would be classified as 'new' because.....
1	<p>Existing Power Station comprising of Synchronous Generating Units.</p> <ul style="list-style-type: none"> • Like for Like replacements • Replacement of Control Schemes • Upgrading of prime mover without major plant changes • TEC change in isolation 	No – CC Compliant
2	<p>Existing Power Station site</p> <ul style="list-style-type: none"> • old Generating Unit to be replaced with new Gas Turbines • Change Generator & turbine • Change of Technology • Change of Energy Source 	<p>Yes – ECC compliant.</p> <p>There is a material change to the plant – a brand new unit is replacing the existing retired unit</p>
3	<p>An existing 100MW Power Park Module comprises 50 x 2MW turbines. The wind turbines are to be replaced by 20 x 5MW turbines.</p>	<p>Yes – ECC Compliant.</p> <p>The turbines, control systems and performance are all using new plant even though the Grid Connection assets may remain largely unchanged.</p>
4	<p>Generator Transformer replaced at an existing 40 year old coal station with a grey spare</p>	No- CC Compliant
5	<p>Change of Generator Ownership – no change to plant</p>	No- CC Compliant
6	<ul style="list-style-type: none"> • An existing Power Park Module adds additional new turbines. • An existing Power Park Module replaces the separate voltage control equipment with a new device 	<ul style="list-style-type: none"> • New turbines would need to be ECC Compliant. Existing turbines would remain CC Compliant. • New equipment would need to ECC compliant. Existing voltage control equipment would remain CC Compliant.
7	<p>Small Power Station replants with a new bigger unit(s).</p>	<p>Yes – ECC Compliant</p> <p>There is a material change to the plant – a brand new unit is replacing the existing retired unit.</p>
8	<p>New Generator changes its Connection Date beyond April 2019.</p>	<p>Yes – ECC Compliant if main plant not ordered.</p> <p>No – CC Compliant if main plant has been ordered and ESO informed by November 2018.</p>

Table 1 : Examples of modifications to existing sites and how they might be handled.

Compliance Process

The process for Generators to demonstrate compliance with the Grid Code and Bilateral Agreement is included in the Grid Code Compliance Processes (CP) for GB Code Users. In addition to the process and details of the documentation that is exchanged to control the process, an appendix to these Grid Code sections includes the technical details of the simulation studies that a Generator should carry out. The Compliance Processes cross reference with other sections of the Grid Code, namely the Planning Code (PC), the Connection Conditions (CC) 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 PC sets out the data and information that a Generator is required to submit prior to connection and then maintain during the lifetime of the power station. The format for submission of the majority of this information is set out in the Data Registration Code (DRC)

The CC set out the majority of the generic performance requirements that a Generator is required to meet with site specific variations laid out in the Bilateral Agreement.

The OC5 sets out the technical details of the tests which ESO recommends to demonstrate compliance with the Grid Code.

Model

To comply with the planning code requirements of the Grid Code, users are required to provide to ESO 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 modeling 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](#)

Simulation Studies

Simulation studies are required from the Generator to provide evidence that the plant and apparatus comply with the provisions of the Grid Code prior to connection. Section of the Grid Code CP.A.3 describes the simulations studies which need to be carried out before any generating unit will be issued an Interim Operational Notification (ION) as indicated in CP.6.3. Note that in the case of a Synchronous Generating Unit that may operate as demand (e.g. pump storage), simulations detailed

in CP.A.3.2.1 (ii) to (vi) should be carried out in both modes of operation.

In general, simulation studies are required where it is impractical to demonstrate capability through testing as the effects on other system Users would be unacceptable. The simulations must be based on the validated models supplied to ESO in accordance with Grid Code Planning Code Appendix section 5.4.2 (PC.A.5.4.2).

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 5.3.2 (PC.A.5.3.2) except for the load rejection simulations in CP.A.3.6 where a more complex model may be utilized if appropriate provided a validation study as specified in CP.A.3.6.6 is also provided.

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 utilized prior to the planned synchronization date (typically 3 -6 months).

Compliance Tests

Tests identified in OC5.A.2 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.2 are at variance with the Bilateral Agreement or the test requirements are not relevant to the plant type the Generator 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 Generator is responsible for drafting test procedures for the power 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 Generator 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 (UDFS).

The tests are carried out by the Generator, or by their agent, and not by ESO. However, ESO will witness some of the tests as indicated in OC5 or as otherwise agreed during the compliance process. 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 Generator should also provide suitable digital monitoring equipment to record all relevant test signals needed to verify the synchronous generator performance in parallel with ESO 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 1M Ω 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 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 2 : 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 are shown in the following picture..



Figure 1 – Example of Compliance Test Signal Connections

Compliance Test Signals

The Grid Code requires that a number of 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 where tests are not witnessed by ESO, 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 D.

- Signals for non-witness tests should be provided in excel format and in the order and format presented in Appendix D Signal data denoted by “#” is not essential but if not provided, the column should remain in place but without values entered. Where two signal names are given in a column these are alternatives related to the type of plant under test (OC5.A.1.4.1.2)
- Where the company has requested additional signals to be recorded prior to the testing, these signals shall be placed in columns to the right of the spreadsheet.
- 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 as indicated in Appendix D.

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 a number of 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 in Warwick. 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.

Test Notification to Control Room

The Generator 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 National Grid's Internet site in Grid Code, Associated Documents.

The Generator should be aware that this interface with ESO transmission planning will normally be available in week-day working hours only. As best practice, the Generator 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 Generator, then the proposed testing may not be allowed to proceed.

Protection Requirements

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

The Generator should provide details of all the protection devices fitted to the Power 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
Reverse Power Protection	Number of stages, trip characteristics, settings and time delays
Control Trip Functions	Functional Description, Control Characteristic and trip settings
Islanding Protection (see below)	Type, description, settings and time delays

Islanding Protection

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 generator 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. Plant Owners will be responsible for protecting their equipment. If the frequency range is outside the range 52Hz to 47Hz, it is up to the Plant Owner to decide whether to disconnect their apparatus.

Pole Slipping Protection

ESO does not generally ask for Pole Slipping Protection to be fitted to Generating units connected to the transmission system. However, if it is proposed to fit Pole Slip Protection by a Generator, the settings should be agreed with ESO to reduce the risk of mal operation during the clearance of faults on the transmission system. In general the “reach” of the protection should not exceed the impedance based on the generating unit and the worst case impedance of the generating unit step up transformer. Where any setting looks beyond the Generator and Transformer impedance the slip counter setting must be greater than 1.



A

Appendices

Appendix A Reactive Capability

Summary of Requirements

The reactive capability requirements for a generating unit are set out in CC6.3.2 of the Grid Code, and for synchronous plant this establishes a power factor value which must be achievable at the Rated MW value of the generating unit both in terms of leading and lagging Mvars.

Where a generating unit can achieve active power output above the declared Rated MW the lagging capability must be in line with CC.6.3.2(a)(i) or CC.6.3.2(a)(ii). When operating at an active power output other than Rated MW the generating unit performance chart submitted under PC.A.3.2.2(f) indicates the capability of the generating unit.

In addition to the requirement in CC.6.3.2 the Grid Code CC6.3.4 also requires capability that a generating unit is able to deliver the CC.6.3.2 reactive capability across a variation in system voltage to which it is connected of +/-5%. This capability is typically achieved for a synchronous generator by the application of an on load tapchanger in the generating unit step-up transformer. The tapchanger being capable of on-load changes in tap position and having sufficient taps to satisfy the combined requirements of CC6.3.2 and CC.6.3.4.

The GB convention for Mvars is for lagging reactive power representing reactive power supplied by the generating unit into the network.

Reactive Capability Testing

In order to demonstrate that a synchronous generating unit can satisfy the reactive capability requirements it is necessary to perform reactive capability tests as set out in OC5.A.2.7. The plant performance requirements can be found in CC.6.3.2.

Where active power in excess of Rated MW is declared on the performance chart in addition to tests at Rated MW, the reactive capability at maximum active power should also be demonstrated.

During the test the HV Voltage and the transformer tap position at regular intervals need to be recorded.

Reactive Capability tests are not normally witnessed by ESO so where a Generator is recording the tests, the following test procedure is provided.

Test No	Step	Description	Notes
	1	<ul style="list-style-type: none"> Increase Active Power output to Rated MW 	
	2	<ul style="list-style-type: none"> Confirm AVR in control and PSS if fitted commissioned and in service 	
	3	<ul style="list-style-type: none"> Confirm AVR Voltage Setpoint set to 1 per unit. 	
1	4	<ul style="list-style-type: none"> Active power output maintained at Rated MW 	
	5	<ul style="list-style-type: none"> Generating unit transformer tapped to generate maximum continuous leading Reactive Power and hold for 60 minutes. 	
2	6	<ul style="list-style-type: none"> Active power output maintained at Rated MW 	
	7	<ul style="list-style-type: none"> Generating unit transformer tapped to generate maximum continuous lagging Reactive Power and hold for 60 minutes. 	
	8	<ul style="list-style-type: none"> If applicable increase Active Power output to maximum value on performance chart. 	
	9	<ul style="list-style-type: none"> Confirm AVR in control and PSS if fitted commissioned and in service 	
	10	<ul style="list-style-type: none"> AVR Voltage Setpoint set to 1 per unit. 	
3	11	<ul style="list-style-type: none"> Active power output maintained at maximum MW 	
	12	<ul style="list-style-type: none"> Generating unit transformer tapped to generate maximum continuous leading Reactive Power and hold for 60 minutes. 	
4	13	<ul style="list-style-type: none"> Active power output maintained at maximum MW 	
	14	<ul style="list-style-type: none"> Generating unit transformer tapped to generate maximum continuous lagging Reactive Power and hold for 60 minutes. 	

Appendix B Voltage Control and PSS Testing

Summary of Requirements

The requirements for voltage control are set out in a number of parts of the Grid Code with additional parameters specified by ESO within the Bilateral Connection Agreement with the Generator. The relevant sections are CC.6.3.6(a), CC.6.3.8, CC.A.6. The performance requirements are set in CC.A.6. Within sections of CC.A.6 there are ranges indicated associated with positive and negative ceiling voltage, and voltage control rise time. The actual values of these relevant to a specific connection will be provided in the Agreement.

Open Circuit Tests

Prior to first synchronising a new generating unit (or one with a new excitation system) onto the system the Generator should perform open circuit testing as required by CP.6.4,. The details of the test are given in OC.5.A.2.2 and the results should be presented to ESO in the form of graphs with legible axes and scaling plus the data in a form which can readily be imported into Excel. ESO will indicate acceptance of the open circuit tests in writing whereupon the Generator provided there are no other active restrictions may synchronise the relevant generating unit.

Power System Stabiliser Commissioning and Testing

The industry codes (Grid Code, CUSC etc.) in general assume a generating unit is fully operational from the moment of connection. This is not practical as many systems will need on-load commissioning in order to ensure their correct operation. Some systems such as the power system stabiliser (PSS) have been identified as having significant potentially negative impacts on the security of the National Grid transmission system if incorrectly commissioned. The Grid Code BC.2.11 prohibits commissioning of the PSS unless ESO is in attendance.

Where a power station consists of multiple generating units which have to be fitted with PSS an assessment of the risk associated with connection and commissioning of more than one generating unit simultaneously without the PSS in service will be made by ESO. If the system risk is seen as significant a restriction on the maximum active power output, reactive power operating range or number of connected units may be placed within the ION until stabilisers have been commissioned successfully. The Generator will be informed of any such restrictions during the compliance process and ahead of the issue of the ION.

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 Generator 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 by small voltage step changes injected into the AVR voltage reference block. Comparisons are made between performance with and without the PSS in service.

For analysis in the frequency domain, a bandwidth-limited (200mHz-3Hz) random noise injection should be made to the AVR voltage reference. The generator 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 stability of the PSS gain setting will also be assessed by increasing the gain in stages to 3x the proposed setting. This increase is carried out gradually while monitoring the generator for any signs of instability.

The tests will be regarded as supporting compliance of the PSS 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 test demonstrates no appreciable instability at 3x proposed gain

An outline test procedure is provided in OC5.A.2.4.3 to assist Generators in drawing up their own site specific procedures for the ESO witnessed PSS Tests although ESO will be happy to consider an alternative test procedure suggested by the Generator.

Under Excitation (UEL) Testing

This test is carried out to establish the setting of the limiter and to verify its correct operation including adequate damping. If the excitation control system includes a PSS, tests should be carried out with PSS switched on.

As discussed earlier in this Appendix ESO may impose operating limitations on a generating unit prior to completed the PSS commissioning tests. Under these circumstances a Generator may be unable to confirm the correct operation of an under excitation limiter at its true setting. However, a functional test at an operating point consistent with the restriction placed in the ION is possible and should be completed by the Generator. Prior to successful under excitation limiter testing it may be appropriate to apply temporary settings in order to reduce the risk of instability during the commissioning period. This should be discussed with the ESO Compliance Engineer and agreed prior to issue of an ION.

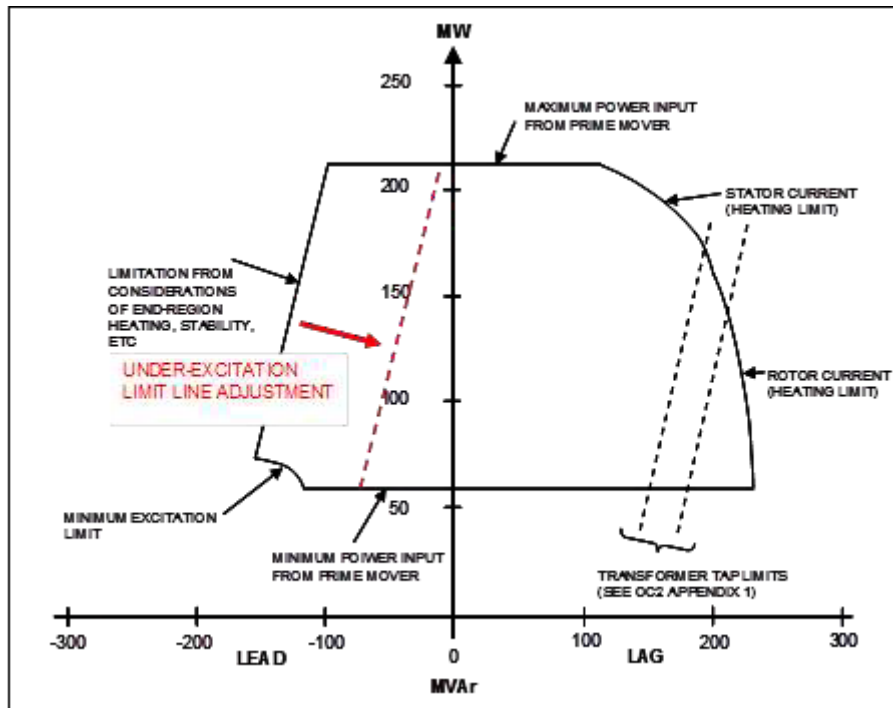


Figure B.1 Example of reducing UEL setting for functionality test

When the generator is operating near the UEL limit the stability margin is less than when it is operating at unity power factor. For safety a preliminary set of tests are specified below with the UEL limit moved towards unity power factor line. If the preliminary tests are successful, then the UEL limit is moved to its design position and the tests are repeated.

The UEL action should be initiated by injecting a negative voltage step of -2% into the AVR voltage reference, with the generator initially operating near the UEL limit. The test procedure given below details the step injection method.

It may prove beneficial to perform an optional test with the PSS off, to understand the interaction between the PSS and limiter.

In addition it is also useful to demonstrate the UEL control action by tapping the generating unit transformer to move the output of the unit into the limiter.

An outline test procedure is provided in OC5.A.2.5.5 to assist Generators in drawing up their own site specific procedures for the ESO witnessed PSS Tests although ESO will be happy to consider an alternative test procedure suggested by the Generator.

Over Excitation Limiter (OEL) Testing

The action of an OEL differs from that of an UEL so the OEL test requirements are normally discussed with ESO prior to testing in order to establish a sensible test procedure, appropriate to the control system design.

ESO are particularly interested in ensuring the OEL is set as high as possible, whilst ensuring the machine design limits are not breached and that the machine protection will not operate before or whilst the OEL is active.

The OEL action is typically initiated by injecting a +2% to +10% positive voltage step into the AVR voltage reference. The OEL would normally be set at the maximum value within the design limit for the generating unit. Excitation at OEL setting is well above excitation at rated MVA. For this reason, the test is not typically carried out at the OEL setting. For the test the OEL setting is typically reduced to a level equivalent to the maximum rated MVA position, i.e. rated MVA and maximum lagging Mvar. A positive step is then applied to the AVR Voltage reference or the generating unit step-up transformer is tapped to take the Mvar output higher. If the OEL is working correctly, the OEL should operate after sufficient time delay to bring back the excitation within limits.

The steady state accuracy of the limit level and any overshoot are of particular interest, as the Generator and ESO may need to determine the limit level once the setting is restored and ensure that any protection does not operate.

If the OEL has multiple levels to account for heating effects, an explanation of this functionality will be necessary and if appropriate, a description of how this can be tested.

An outline test procedure is provided in OC5.A.2.6.3 to assist Generators in drawing up their own site specific procedures although ESO will be happy to consider an alternative test procedure suggested by the Generator.

Appendix C Frequency Control

Summary of 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 of 49.5 to 50.5Hz (CC.6.1.2) ESO requires generating units and power park modules 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 a number of separate places, notably the Glossary & Definitions (GD), the Connection Conditions (CC) and Balancing Code (BC3) . 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 each generating unit must be capable of maintaining a minimum level of active power (see Figure 2 of CC.6.3.3 (b)) in the frequency range 47Hz to 50.5Hz.

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 $\pm 0.015\text{Hz}$.
- Capable of delivering a minimum level of frequency response.
- Able to operate in limited Frequency Sensitive Mode (LFSM)

The 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 in excess of 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 deadband 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 (BC3) of the Grid Code defines operation in Limited Frequency Sensitive Mode and Frequency Sensitive Mode.

Limited Frequency Sensitive Mode is the default mode used when not instructed by ESO to provide Frequency Response Services. In this mode the generating module 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. However, the Power Plant is required to respond to high frequencies above 50.4Hz beyond which the Module must reduce the active power output by a minimum of 2% of output for every 0.1Hz rise above 50.4Hz (see figure C1).

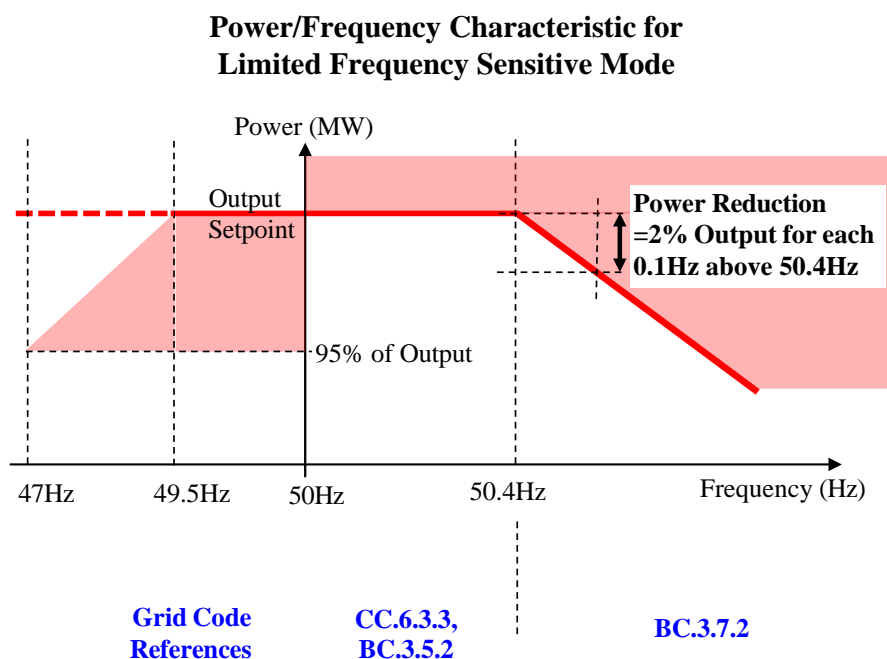


Figure C1 – Limited Frequency Sensitive Mode

Frequency Sensitive Mode is used when selected to provide frequency response services. In this mode, the Synchronous Module must adjust the active power output in response to any frequency change 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. When system frequency exceeds 50.5Hz the requirements of Limited Frequency Sensitive Mode then apply in addition to the FSM requirement so that the Generating Module must further reduce output by a minimum of 2% of output for every 0.1Hz rise above 50.5Hz (see figure C2).

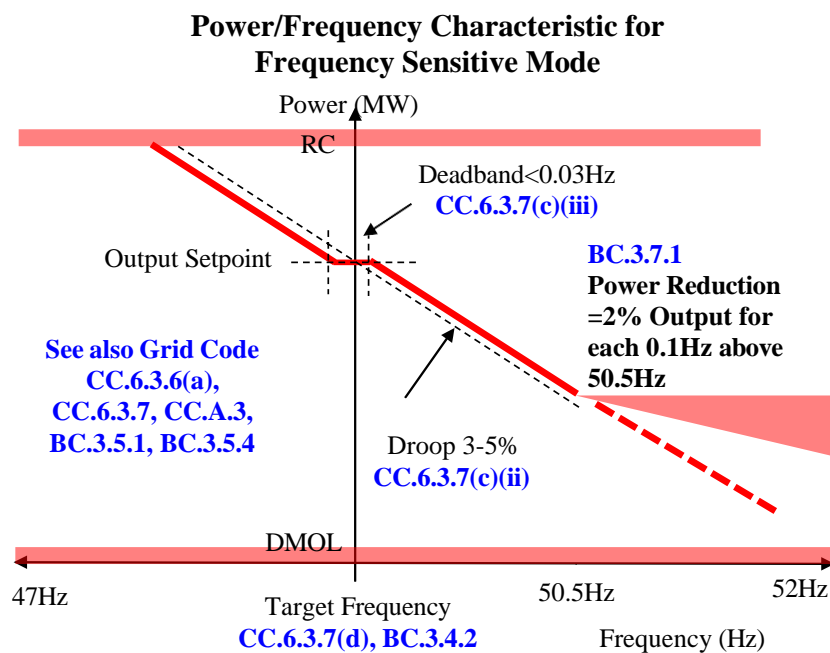


Figure C2 – Frequency Sensitive Mode

Governor / Load Controller

The correct design and coordination of the governor and load controller (or module controller in the case of a Combined Cycle Gas Turbine (CCGT) plant) has been an important issue in compliance of the Grid Code and Mandatory Services requirements. The design details are site specific and there are many ways of meeting the requirements. This section helps to focus on the control issues and gives a simple description on the functional requirements which will help plant designers to appreciate the control needs.

Target Frequency

If a generating unit is required to have a Frequency control device as specified in CC6.3.7. It must also have the facility to accept and act upon Target Frequency instruction from ESO. In order to adjust electric clock time the Grid Operator may instruct settings of 49.95Hz or 50.05Hz. However, under exceptional circumstances, the instructed settings could be outside this range. A minimum setting range from 49.90Hz to 50.10Hz is required.

Where there is concern on the implementation of this function a test may be suggested where target frequency is adjusted and the effect on active power output of the generating unit is recorded.

Operating Configurations

Figure C.13 shows a simplified schematic diagram of a governor/load controller for a gas turbine. The same control concept applies to conventional thermal plant and CCGTs. With the appropriate setting of the Auto/Manual and Frequency Compensated switches, three basic operating configurations (Figures C2A, C2B and C2C) can be obtained.

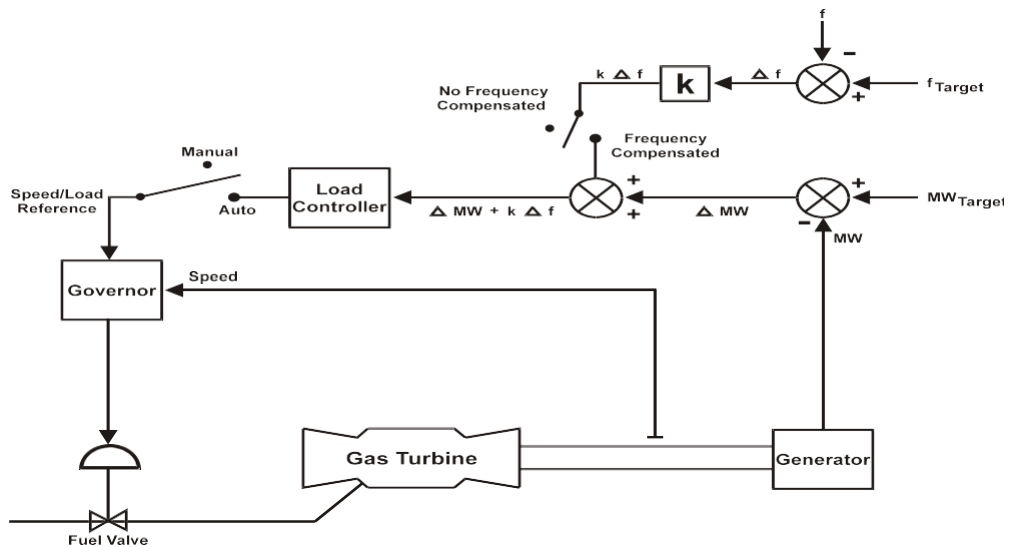


Figure C.3 Schematic Diagram of Gas Turbine Governor / Load Controller

Configuration 'A' (Figure C4A) corresponds to manual governor operation and the generator output can be altered by manually adjusting the speed/load reference setting. This operating configuration is unacceptable since the target frequency setting is unavailable and the secondary response is unreliable (Figure C3) and does not meet the Grid Code/Mandatory Services requirements.

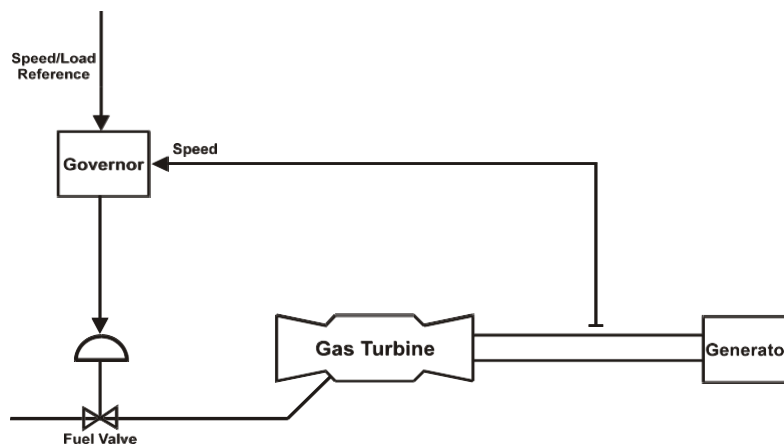


Figure C.4A Governor without Load Controller

Configuration 'B' (Figure C.4B) corresponds to automatic governor and load control. This configuration is unacceptable because of the unavailable target frequency facility and the unsustainable Secondary and High frequency responses (Figure C.3).

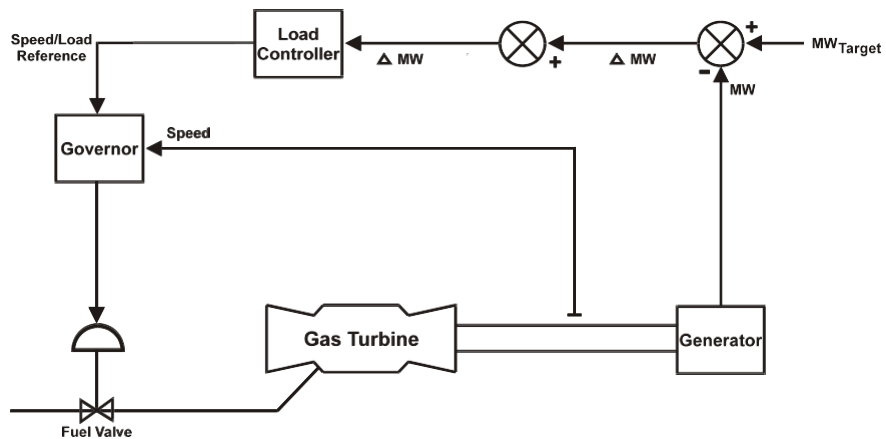


Figure C.4B Governor with MW Target Correction

Configuration 'C' (Figure C.4C) corresponds to an automatic governor with frequency compensated load control. This configuration satisfies both the Grid Code and Mandatory Services requirements.

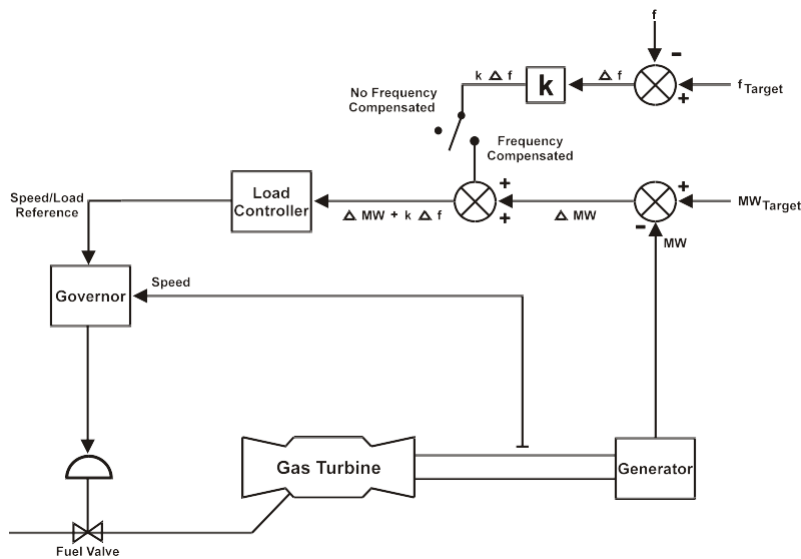


Figure C.4C Governor with Frequency Compensated MW Target Correction

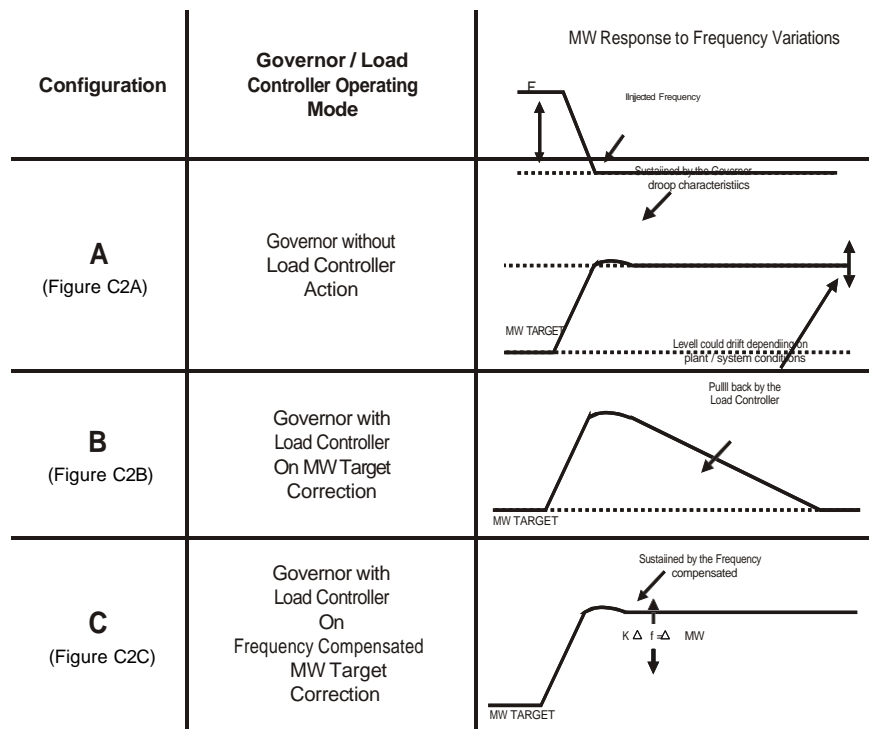


Figure C.5 Effect of Governor / Load Controller Configuration on Plant Response

Mechanical Flyball Governors

Pre-vesting (ex CEGB) conventional plant was originally designed using mechanical flyball governors. The governor acts directly on the primary relay to increase the governor oil pressure and hence open the governor valve. At the same time the load controller demands an increase in oil pressure by controlling the speeder gear motor.

In order to facilitate frequency response deviations correctly the variation will have to be injected to both the inner (flyball governor) and outer (load controller) control loops. Injecting a frequency deviation signal into a flyball governor is difficult but a response has been achieved by manually turning a handwheel. The effect of the handwheel on the output of the unit will need to be understood by the Generator prior to the tests to calibrate the response.

Coordination of the speeder gear and handwheel operation allows the correct implementation of the specified frequency changes into both control loops and successful frequency response tests have been achieved by this method.

Maintaining output with falling Frequency

For Limited Frequency Sensitive operation, as specified in BC.3.5.2 and BC.3.7.2, the output of the generator must achieve the CC.6.3.3 requirement up to 50.4Hz above which a minimum power reduction rate of 2% per 0.1Hz must be achieved. Below 50Hz and to 49.5Hz the generating unit is required to maintain output without influence from the reduction in system frequency.

Below 49.5Hz the output is permitted to reduce but only at a rate not greater than pro-rata with the falling frequency. For example, a 1% fall in system frequency up to a 1% reduction in output is permissible. In an event when the system frequency drops to 47Hz, the MW output must not drop by more than 5%.

As specified in OC5.5.4 the CC.6.3.3 minimum requirement applies up to ambient temperature of 25°C. Above this temperature any special measures employed to maintain the power output at 25°C, need to be kept in service, but the minimum requirement set out in CC.6.3.3 should not be achieved.

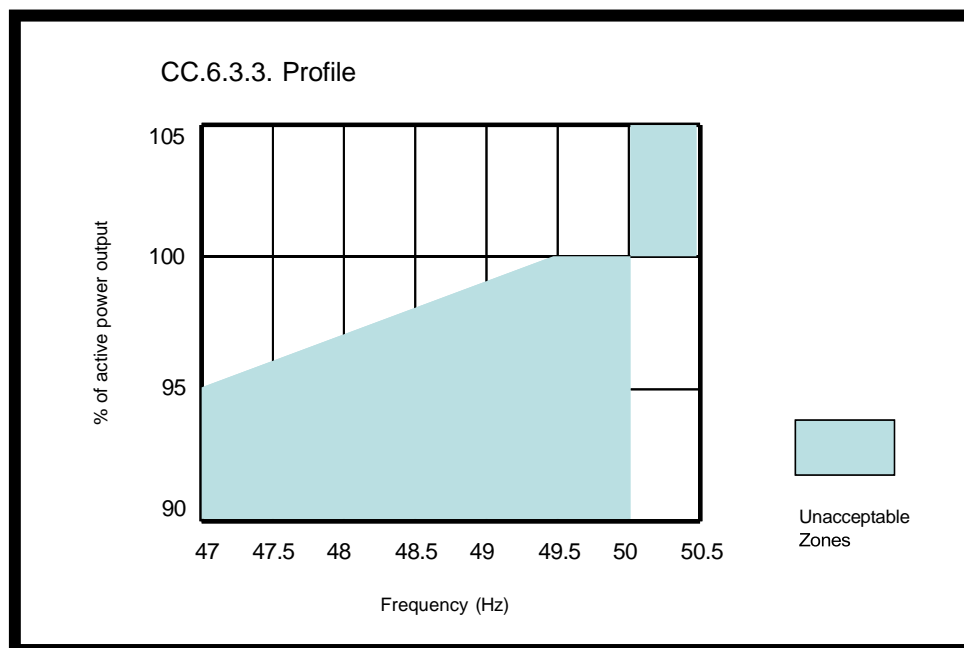


Figure C.6 CC.6.3.3 Profile Indicating Unacceptable Zones.

ESO will require the User to demonstrate a generator unit performance in accordance with the above requirements. This should comprise providing suitable information prior to the connection of the generating unit in support of a Grid Code compliant design strategy, demonstration of capability where possible with functionality testing and ongoing continuous monitoring of performance.

The User will need to supply ESO with information relating to the plants MW output, speed and ambient temperature performance characteristics and the relevant design methodology employed within the control system, to ensure the necessary correction to the plant output to meet the CC.6.3.3 and BC.3.7.2 requirements.

Following design of the control system, the User will propose and agree a test procedure with ESO, which will demonstrate how the plant output power responds to changes in system frequency and ambient conditions (e.g. by frequency and temperature injection methods). This functionality test should be included in a test procedure. On satisfactory conclusion of the above, ESO would consider the Users plant to be compliant.

As part of the ongoing monitoring provision set out in OC.5.4 the performance of a generating unit can be monitored by ESO to confirm compliance with the Grid Code. Where a significant frequency incident occurs or ESO suspects the performance of a generating unit is not maintaining compliance with CC.6.3.3 the Generator may be asked to provide ESO with output data from its generating units. ESO will discuss any concerns with the User as part of the normal and ongoing liaison process.

Compliance Testing Requirements

The main objectives of the governor/load controller response tests are to establish the plant performance characteristics for compliance with the Grid Code technical requirements (including the validation of plant data/models). They are also required to derive a set of reliable plant response values that will form the basis of response matrices for the Mandatory Services Agreement.

It is required that a complete module is tested under normal operating mode (i.e. combined cycle) with the Gas Turbine Inlet Guide Vane (IGV) Control in operation. A frequency disturbance can be simulated by injecting the required frequency variation signals to both the governor speed reference point and the load controller target frequency set point (See Figure C.4). An overview of the generic test sequence is described in C.6. The test procedures are designed to be flexible to accommodate possible site operating conditions. However, any variations have to be agreed with ESO.

If a CCGT station has more than one identical module, all tests will be carried out on one of the complete modules. It is an option to reduce the testing requirements on any subsequent units within the same power station where practical. It will be acceptable to use the test derived matrices to cover the other modules if they have the same design and control characteristics.

Signals should be raw i.e. taken directly from a transducer or signal source. Should there be any problem; ESO should be informed immediately.

Generally, when conducting frequency tests not witnessed by the company, there should be sufficient time allowed between tests for control systems to reach steady state. Where the diagram states 'HOLD' the current injection should be maintained until the Active Power (MW) output of the Synchronous Power Generating Module or CCGT Module has stabilized or 90 seconds, whichever is the longer. When witnessed by The Company, each test should be carried out as a separate injection. (See OC5.A.2.8.8).

Dual Fuelled and Bio-Fuelled Power Stations

For any power stations including CCGT which are capable of running on alternative fuels, additional governor response tests will be required to demonstrate performance when running on these fuels. Depending on plant design, detailed tests will be agreed between ESO and the User at the early stage of the compliance process. This could be a subset of the full set of tests

A power station that runs on bio-fuel all the time and large enough to require frequency response performance, should undergo the full set of governor tests shown in OC5.A.2.8. If bio-fuel is used as a supplement to the main fuel then the tests are necessary if the frequency response performance change. This could be a subset of the tests indicated in OC5.A.2.8 and will be agreed between ESO and the User.

Test Following DCS Replacement

If the DCS (Distributed Control System) of an existing plant is replaced it will be necessary to do some frequency response testing following such replacement to confirm there has been no adverse impact on the previously tested performance. Assuming that there is no major change to response

delivery, this could be a subset of the tests indicated in OC5.A.2.8 and should be discussed and agreed with ESO prior to testing. If the response of the unit has been changed then the full set of response tests will be required.

Tests for CC.6.3.3 functionality

Where additional action is taken to maintain output compliant with CC.6.3.3 the manufacturers should propose tests that demonstrate the functionality by injection of a falling frequency into the control system. Where possible the generating unit control should be adjusted to simulate action as if the ambient conditions are 25°C. Where different control functionality acts at different levels of falling frequency separate injections should be proposed to demonstrate each separate functionality.

Where the functionality involves overfiring of the plant to achieve compliance it is permissible to limit the extent of overfiring to limit the adverse effects on the plant. This is explained in the test procedure and the level of response with limited overfiring is identified in advance.

Tests on ex CEGB Auxiliary GTs

The following is a high level functional description of tests designed to demonstrate the robustness of the ex CEGB auxiliary OCGT's governor control system following refurbishment.

The tests are designed to check the integrity of the limits on the major control elements and to check the response and stability of the control systems to frequency disturbances.

Ref	Step	Description
		TESTS AT 100% LOAD
GSD		<p><u>Governor Speed Droop Test</u></p> <p>Adjust generator speed control loop gain so that a change in generator speed of 120 rpm changes the machine output from 100% load to full speed no load (FSNL). 120 rpm corresponds to 2 Hz and 4% droop.</p> <p>From 100% to FSNL decrease the speed reference in steps of 20rpm until FSNL is achieved.</p>
		TESTS AT 50% LOAD
SC	<ol style="list-style-type: none"> 1 2 3 	<p><u>Speed Control Limit Test (if applicable)</u></p> <p>Reduce speed set point to just above that for the 50% load value.</p> <p>Apply a step increase to the generator speed reference to prompt the speed limit to control.</p> <p>Remove step and return set point to normal value.</p>

CDP	1	<u>Compressor Discharge Pressure (CDP) Control Limit Test</u> Reduce the CDP set point to just above that required for 50% load. Apply a step increase to the generator speed reference to prompt the CDP limit to control. Remove step and return set point to normal value.
	2	
	3	
EGT	1	<u>Exhaust Gas Temperature (EGT) Control Limit Test</u> Reduce the EGT set point to just above that required for 50% load. Apply a step increase to the generator speed reference to prompt the EGT limit to control. Remove step and return set point to normal value.
	2	
	3	
F	1	Apply a -0.2Hz step to the generator speed reference, hold for 60 seconds or until conditions stabilise. Remove step and allow conditions to stabilise.
	2	
G	1	Apply a +0.2Hz step to the generator speed reference, hold for 60 seconds or until conditions stabilise. Remove step and allow conditions to stabilise.
	2	
H	1	Apply a -0.5Hz step to the generator speed reference, hold for 60 seconds or until conditions stabilise. Remove step and allow conditions to stabilise.
	2	
I	1	Apply a +0.5Hz step to the generator speed reference, hold for 60 seconds or until conditions stabilise. Remove step and allow conditions to stabilise.
	2	

The following table give a typical set of signals to be recorded for an ex CEGB Auxiliary OCGT. This list is generic and therefore the schedules may be adjusted to suite site requirements and verification of the appropriate control system model. The list of signals to be provided should be included in the test procedure agreed with ESO.

	Unit	Signal Range	Signal Representation
Active Power Output	MW	0-10V	0 to 1.0pu
Speed	rpm	+/-10V	1.0pu +/-0.1pu
Compressor Discharge Pressure each Engine)	Bar	0-10V	0 to 1.0pu
Exhaust Gas Temperature	oC	0-10V	0.5 to 1.0pu
Fuel Demand	%	0-10V	0 to 1.0pu
Fuel Valve Position (each Engine)	%	0-10V	0 to 1.0pu

Preliminary Frequency Response Testing

Past experience has demonstrated that significant delays can occur during testing because of problems associated with the governor/load controller set up 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 governor and load controller are shown in Figure C.7. In order 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 station or site contractor. A preliminary test is therefore required to demonstrate that the plant responds in a generally correct manner and that the frequency injections can be made correctly.

At all times and for all tests, the target frequency selected on the generating plant is that instructed by the ESO Control Centre. This should normally be 50.00Hz but may occasionally be set slightly high or low to correct electric clock time errors.

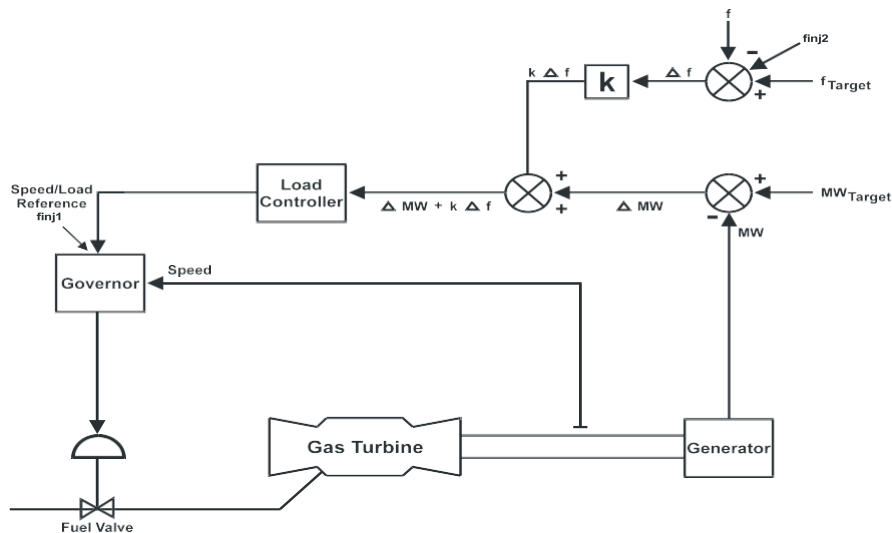
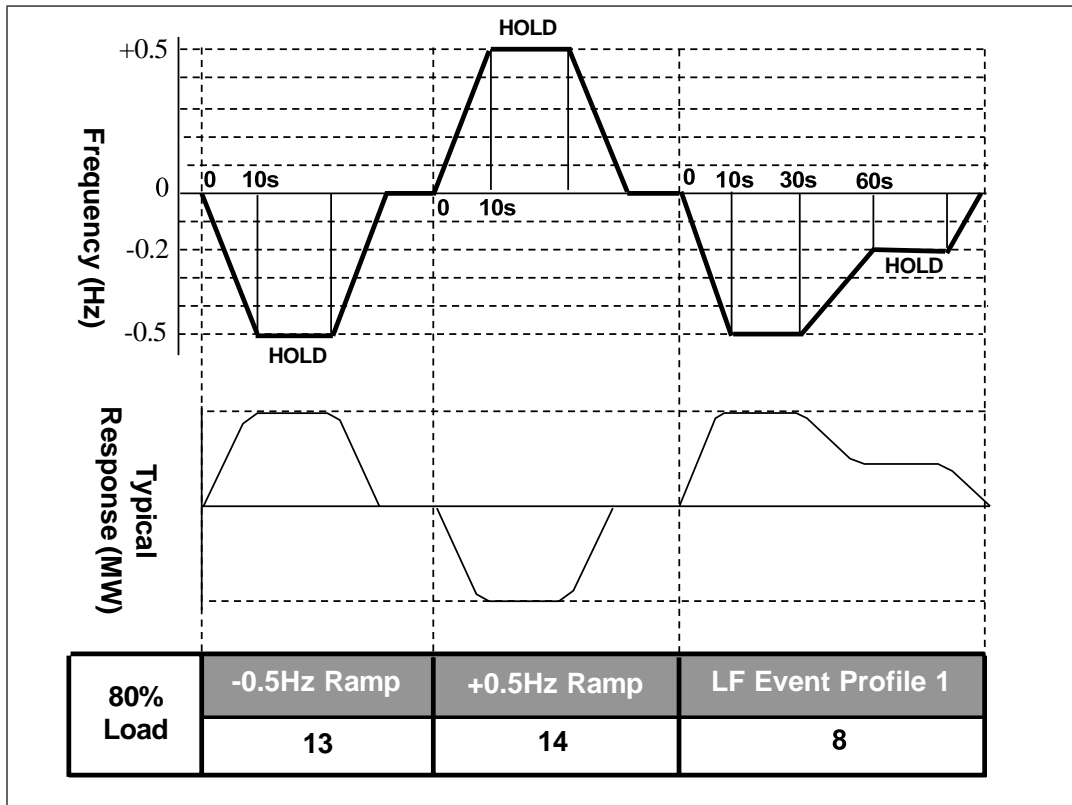


Figure C.7 Governor with Frequency Compensated MW Target Correction

Tests are applied as ramp injections over 10 seconds, 1 second or as step injections depending upon the particular test. In addition, there are profile tests which aim to simulate the effect on the system frequency of a large loss. The simple ramp and more complex profile injection with multiple stages required for the preliminary frequency response tests are indicated in the diagram below.



The generic preliminary frequency response procedure is given in OC5.A.3.6.8

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

ESO Witnessed Frequency Response Testing Schedule

Grid Code OC5.A.3.6.8. Figure 1 and 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.

1. **Establish Maximum Plant Capacity as Loading Point MLP6**
 - (a) Switch GT governors to manual and raise load demand to confirm the maximum output level at the base settings.
 - (b) Record plant and ambient conditions.

2. **Response Tests at Loading Point MLP6 (Maximum Output)**
 - (a) Operate the plant at MLP 6
 - (b) Inject ramp/profiled frequency changes simultaneously into the GT governor and load controller (i.e. Tests 1-4 in OC5.A.3.6 Figure 1) and record plant responses.

- (c) Inject the calculated frequency change simultaneously into the GT governor and load controller to simulate the load rejection (i.e. Tests BC1 in OC5.A.3.6. Figure 1) and record plant responses.
 - (d) Inject ramp rise in frequency over 30 seconds simultaneously into the GT governor and load controller (i.e. Test BC2 in OC5.A.3.6 Figure 2) and record plant responses.
3. **Response Tests at Loading Point MLP6 (Maximum Output) in Limited Frequency Sensitive Mode (LFSM)**
- (a) Operate the plant at MLP 6
 - (b) Inject the calculated frequency change simultaneously into the GT governor and load controller to simulate the load rejection (i.e. Tests BC3 in OC5.A.3.6 Figure 1) and record plant responses.
 - (c) Inject ramp rise in frequency over 30 seconds simultaneously into the GT governor and load controller (i.e. Test BC4 in OC5.A.3.68 Figure 2) and record plant responses.
4. **Response Tests at Loading Point MLP5 (0.95 RC)**
- (a) Operate the plant at MLP5.
 - (b) Conduct tests 5-7 as shown in OC5.A.3.6 Figure 1 and record plant responses.
 - (c) Conduct test A as shown in OC5.A.3.6 Figure 2 to establish the robustness of the control system under simulated extreme disturbances (as could occur under system islanding or system split conditions).
5. **Response Tests at Loading Point MLP4 (0.8 RC)**
- (a) Operate the plant at loading point 4 (MLP 4).
 - (b) Conduct tests 8-14 as shown in OC5.A.3.6 Figure 1 and record plant responses.
 - (c) Conduct tests D - I as shown in OC5.A.3.6 Figure 2 to establish the GT dead band, and step response characteristics for governor modelling purposes.
 - (d) Conduct test J as shown in Figure 2 to establish the robustness of the control system under simulated extreme disturbances (e.g., system islanding or system split).
6. **Response Tests at Load Point MLP3 (0.7 RC)**
- (a) Operate the plant at MLP3.
 - (b) Conduct tests 15 to 17 as shown in OC5.A.3.6 Figure 1 and record plant responses.
7. **Response Tests at Minimum Generation MLP2 (≤ 0.65 RC)**
- (a) Operate the plant at MG.
 - (b) Conduct tests 18 - 22 as shown in OC5.A.3.6 Figure 1 and record plant responses.

8. **Response Tests at Designed Minimum Operating Level MLP1 (0.55 RC)**
- (a) Operate the plant at DMOL.
 - (b) Conduct tests 23 - 26 as shown in OC5.A.3.6 Figure 1 and record plant responses.
 - (c) Conduct test K as shown in OC5.A.3.6 Figure 2 to establish the step response characteristics for governor modelling purposes.

Generic Governor Frequency Response Test Procedure

Since the governor response tests described above are to be arranged and conducted by the Generator, 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.3.6 Figures 1 and 2 is given below. This procedure is required to be submitted to ESO for approval before an ION is issued.

Initial Checks on Maximum Plant Capability at MLP6, Plant in LFSM	
Step	Actions
	Record plant MLP 6 condition including levels for GT's and ST and module MW output, ambient temperature, governor control signals and steam conditions. Change GT governor control to manual and increase output power demand to maximum. Record plant conditions when plant is thermally Stabilised. Reset governor to normal operating mode and allow MLP 6 condition to be established

Injection Tests at MLP6, Plant in FSM			
Test No.	Actions	Frequency Injection	Notes
1	<ul style="list-style-type: none"> • Inject 0.10Hz frequency rise over 10 sec • Hold until conditions stabilise³ • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 6 	+0.10Hz -0.10Hz	
2	<ul style="list-style-type: none"> • Inject -0.20Hz frequency fall over 10 sec • Hold until conditions stabilise³ • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 6 	-0.20Hz +0.20Hz	

3	<ul style="list-style-type: none"> Inject 0.20Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 6 	+0.20Hz -0.20Hz	
4	<ul style="list-style-type: none"> Inject 0.50Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 6 	+0.50Hz -0.50Hz	
BC1	<p><u>Plant in FSM</u></p> <ul style="list-style-type: none"> Inject +2.0* Hz frequency rise over 1 sec Hold until conditions stabilise³ Remove the injection signal Hold until conditions stabilise at MLP 6 	+2.0 Hz * -2.0 Hz	Part of functionality test for islanding CC.6.3.7 (c)(i)
BC2	<p><u>Plant in FSM</u></p> <ul style="list-style-type: none"> Inject +0.6 Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal Hold until conditions stabilise at MLP 6 	+0.6 Hz -0.6 Hz	Part of functionality test for BC.3.7.1
L	<p><u>Plant in FSM</u></p> <ul style="list-style-type: none"> Record normal system variation in frequency and active power of the generating unit over at least 10 minutes 	No injection	Part of functionality test for BC.3.7
Switch to Limited Frequency Sensitive Mode			
BC3	<p><u>Plant in LFSM</u></p> <ul style="list-style-type: none"> Inject +2.0* Hz frequency rise over 1 sec Hold until conditions stabilise³ Remove the injection signal Hold until conditions stabilise at MLP 6 	+2.0 Hz -2.0 Hz	Part of functionality test for islanding CC.6.3.7 (c)(i)
BC4	<p><u>Plant in LFSM</u></p> <ul style="list-style-type: none"> Inject +0.6 Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal Hold until conditions stabilise at MLP 6 	+0.6 Hz -0.6 Hz	Part of functionality test for BC.3.7.2

* This will generally be +2.0Hz unless an injection of this size causes a reduction in plant output that takes the operating point below **Designed Minimum 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 **Designed Minimum Operating Level** is not 20% then the injected step should be adjusted accordingly as shown in the example given below

Initial Output	65%
Designed Minimum Operating Level	20%
Frequency Controller Droop	4%
Frequency to be injected = $(0.65-0.20) \times 0.04 \times 50 =$	0.9Hz

Injection Tests at MLP 5, Plant in FSM			
5	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 5 	-0.50Hz +0.30Hz	
6	<ul style="list-style-type: none"> Inject 0.20Hz frequency fall over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 5 	-0.20Hz +0.20Hz	
7	<ul style="list-style-type: none"> Inject 0.50Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 5 	+0.50Hz -0.50Hz	
A	<ul style="list-style-type: none"> Inject 1.0Hz/sec frequency fall over 2 sec Hold for 30 sec Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 5 	-2.0Hz +2.0Hz	To assess plant performance under islanding and system split Conditions

Injection Tests at MLP 4, Plant in FSM			
8	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> -0.50Hz +0.30Hz +0.20Hz 	<ul style="list-style-type: none">
9	<ul style="list-style-type: none"> Inject -0.10Hz frequency fall over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> -0.10Hz +0.10Hz 	<ul style="list-style-type: none">
10	<ul style="list-style-type: none"> Inject 0.10Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> +0.10Hz -0.10Hz 	<ul style="list-style-type: none">
11	<ul style="list-style-type: none"> Inject -0.20Hz frequency fall over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> -0.20Hz +0.20Hz 	<ul style="list-style-type: none">
12	<ul style="list-style-type: none"> Inject 0.20Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> +0.20Hz -0.20Hz 	<ul style="list-style-type: none">
13	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> -0.50Hz +0.50Hz 	<ul style="list-style-type: none">
14	<ul style="list-style-type: none"> Inject 0.50Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> +0.50Hz -0.50Hz 	<ul style="list-style-type: none">

D	<ul style="list-style-type: none"> Inject -0.02Hz frequency fall as a step change Hold until conditions stabilise Remove the injection signal Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> -0.02Hz +0.02Hz 	<ul style="list-style-type: none"> To assess the governor deadband
E	<ul style="list-style-type: none"> Inject 0.02Hz frequency rise as a step change Hold until conditions stabilise Remove the injection signal Hold until conditions stabilise at MLP 4 	<ul style="list-style-type: none"> +0.02Hz -0.02Hz 	<ul style="list-style-type: none"> To assess the governor deadband
F	<ul style="list-style-type: none"> Inject -0.20Hz frequency fall as a step change Hold until conditions stabilise Remove the injection signal Hold until conditions stabilise at MLP 4 	-0.20Hz +0.20Hz	To assess step response characteristics of plant
G	<ul style="list-style-type: none"> Inject 0.20Hz frequency rise as a step change Hold until conditions stabilise Remove the injection signal Hold until conditions stabilise at MLP 4 	+0.20Hz -0.20Hz	To assess step response characteristics of plant
H	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall as a step change Hold until conditions stabilise Remove the injection signal Hold until conditions stabilise at MLP 4 	-0.50Hz +0.50Hz	To assess step response characteristics of plant
I	<ul style="list-style-type: none"> Inject 0.50Hz frequency rise as a step change Hold until conditions stabilise Remove the injection signal Hold until conditions stabilise at MLP 4 	+0.50Hz -0.50Hz	To assess step response characteristics of plant
J	<ul style="list-style-type: none"> Inject 1.0Hz/sec frequency fall over 2 sec Hold for 30 sec Remove the injection signal Hold until conditions stabilise at OLP 	-2.0Hz +2.0Hz	To assess plant performance under islanding and system split conditions
M	<ul style="list-style-type: none"> Record normal system variation in frequency and active power of the generating unit over at least 10 minutes 	No injection	Part of functionality test for BC.3.6 & BC.3.7

Switch to Limited Frequency Sensitive Mode

N	<p><u>Plant in LFSM</u></p> <ul style="list-style-type: none"> Record normal system variation in frequency and active power of the generating unit over at least 10 minutes Switch to Frequency Sensitive Mode 	No injection	Part of functionality test for BC.3.6 & BC.3.7
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Injection Tests at MLP 3, Plant in FSM			
15	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 3 	-0.50Hz	
		+0.30Hz	
		+0.20Hz	
16	<ul style="list-style-type: none"> Inject 0.50Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 3 	+0.50Hz	
		-0.50Hz	
17	<ul style="list-style-type: none"> Inject -0.80Hz frequency fall over 10 sec Hold for 20 sec. Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 3 	-0.80Hz	
		+0.30Hz	
		+0.50Hz	

Injection Tests at MLP2, Plant in FSM			
18	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 2 	-0.50Hz	
		+0.30Hz	
		+0.20Hz	
19	<ul style="list-style-type: none"> 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 	-0.20Hz	
		+0.20Hz	

20	<ul style="list-style-type: none"> Inject 0.20Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 2 	+0.20Hz -0.20Hz	
21	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 2 	-0.50Hz +0.50Hz	
22	<ul style="list-style-type: none"> Inject -0.80Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 2 	-0.80Hz +0.30Hz +0.50Hz	

Injection Tests at MLP 1, Plant in FSM			
23	<ul style="list-style-type: none"> Inject -0.50Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 1 	-0.50Hz +0.30Hz +0.20Hz	
24	<ul style="list-style-type: none"> Inject -0.20Hz frequency fall over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 1 	-0.20Hz +0.20Hz	
25	<ul style="list-style-type: none"> Inject 0.20Hz frequency rise over 10 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec Hold until conditions stabilise at MLP 1 	+0.20Hz -0.20Hz	
26	<ul style="list-style-type: none"> Inject -0.80Hz frequency fall over 10 sec Hold for 20 sec Inject 0.30Hz frequency rise over 30 sec Hold until conditions stabilise³ Remove the injection signal over 10 sec 	-0.80Hz +0.30Hz +0.50Hz	

	<ul style="list-style-type: none"> • Hold until conditions stabilise at MLP 1 		
K	<ul style="list-style-type: none"> • Inject -0.5Hz frequency fall over 1 sec • Hold for 30 sec • Remove the injection signal over 10 sec • Hold until conditions stabilise at MLP 1 	-0.5Hz +0.5Hz	To assess plant performance under islanding and system split conditions

Note 1: Tests L and M in OC5.A.3.6 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 generating unit and CCGT Module in Frequency Sensitive Mode during normal system frequency variations without applying any injection.

Note 2: 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.

Note 3: Hold period should be at least 90 seconds to permit full assessment of response in secondary timescales.

Appendix D Test Signal Schedule and Logsheet

OC5.A.1.4.2.1 Onshore Synchronous Generating Unit Excitation System and Reactive Capability

	<u>Col 1</u>	<u>Col 2</u>	<u>Col 3</u>	<u>Col 4</u>	<u>Col 5</u>	<u>Col 6</u>	<u>Col 7</u>	<u>Col 8</u>
1	<u>Time</u>	<u>Active Power</u>	<u>Reactive Power</u>	<u>Terminal Voltage</u>	<u>Speed /Frequency #</u>	<u>Freq Injection #</u>	<u>Logic / Test Start #</u>	<u>Field Voltage</u>
	<u>Col 9</u>	<u>Col 10</u>	<u>Col 11</u>	<u>Col 12</u>	<u>Col 13</u>	<u>Col 14</u>	<u>Col 15</u>	<u>Col 16</u>
1	<u>Field Current</u>	<u>PSS Output #</u>	<u>Noise Injection #</u>					
<u># Columns may be left blank but the column must still be included in the files</u>								

OC5.A.1.4.2.2 Onshore Synchronous Generating Unit Frequency Response and CC.6.3.3

	<u>Col 1</u>	<u>Col 2</u>	<u>Col 3</u>	<u>Col 4</u>	<u>Col 5</u>	<u>Col 6</u>	<u>Col 7</u>	<u>Col 8</u>
1	<u>Time</u>	<u>Active Power</u>	<u>Reactive Power #</u>	<u>Terminal Voltage #</u>	<u>Speed /Frequency</u>	<u>Freq Injection</u>	<u>Logic / Test Start</u>	<u>Fuel Demand</u>
2								<u>Guide Vane Setpoint</u>
	<u>Col 9</u>	<u>Col 10</u>	<u>Col 11</u>	<u>Col 12</u>	<u>Col 13</u>	<u>Col 14</u>	<u>Col 15</u>	<u>Col 16</u>
1	<u>Inlet Guide Vane</u>	<u>Exhaust Gas Temp</u>	<u>ST Valve Pos</u>	<u>Fuel Valve Pos</u>	<u>HP Steam Valve Pos</u>	<u>IP Steam Valve Pos</u>	<u>LP Steam Valve Pos</u>	
2	<u>Guide Vane Position</u>	<u>Head</u>						
<u># Columns may be left blank but must still be included in the files</u>								

Compliance Test Logsheet

Where test results are completed without any ESO presence but are relied upon as evidence of the compliance they should be accompanied by a logsheet. This sheet should be legible, in English and detail the items as indicated 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 user representative(s) and company name.
- Type of testing being undertake eg Voltage Control.
- Ambient Conditions eg. Temperature, pressure, wind speed, wind direction; and
- Controller settings, eg Voltage slope, Frequency droop, Voltage setpoint, UEL and OEL settings.

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.
- Generating unit transformer tap position or Grid Transformer tap position, as applicable.

Example Voltage Control / PSS Logsheet

Test No.	Time	Initial Conditions					Noise inj	PSS in/out	PSS Gain	Description	Saved File
		MW	MVAr	Vt	HV	Tap					

Reactive Power Capability Tests

- Start time of test.
- Active Power.
- Reactive Power.
- Connection Voltage.
- Terminal Voltage if applicable.
- Generating Unit transformer tap position or Grid Transformer tap position as applicable.
- For Offshore Connections - Offshore Grid Entry Voltage.

Example Reactive Capability Logsheet

Test No.	Time	Initial Conditions					Description	Saved File
		MW	MVAr	Vt	HV	Tap		

Frequency Response Capability Tests

- Start time of test.
- Module Active Power.
- System Frequency.
- For CCGT modules, Active Power for the individual units (GT &ST).
- For Boiler plant, HP steam pressure.
- Droop setting of controller if applicable
- Offshore Grid Entry Point Active Power for each offshore synchronous Power generating module

Example Frequency Response Logsheet

Time	Test No	Initial Conditions				Description	Saved File
		GT MW	GT MW	ST MW	Module MW		

Material changes during the test period should be recorded eg Units tripping / starting, changes to tapchange positions. Thought should be given as to whether such changes invalidate the test and a repeat test would be appropriate.

Appendix E Contacting ESO

There are a number of different departments within ESO that will be involved with this connection. The initial point of contact for ESO 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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