nationalgridESO

Guidance Notes for Grid Forming Plant

EU Code Users - Issue 2

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Foreword

These Guidance Notes have been prepared by the National Grid Electricity System Operator (NGESO) to describe how the Grid Code Compliance Process is intended to work for Grid Forming Plant including Power Park Module, HVDC System, DC Converter, OTSDUW Plant and Apparatus, Non-Synchronous Electricity Storage Module, Dynamic Reactive Compensation Equipment or any Plant and Apparatus (including a smart load). Throughout this document NGESO refers to National Grid ESO and National Grid refers to the Transmission Owner part National Grid Electricity Transmission (NGET) unless explicitly stated otherwise.

These Guidance Notes are prepared, solely, for the assistance of prospective customers planning to provide Grid Forming service. In the event of dispute, the Grid Code and Bilateral Agreement documents will take precedence over these notes.

These Guidance Notes are based on the Grid Code, Issue 6, Revision 17, effective from the 4 September 2023. They reflect the major changes brought about by Grid Code workgroup modifications GC0137 as approved by the regulator in February 2022.

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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Disclaimer: This document has been prepared for guidance only and does not contain all the information needed to comply with the specific requirements of a Bilateral Agreement with National Grid. Please note that whilst these guidance notes have been prepared with due care, National Grid does not make any representation, warranty or undertaking, express or implied, in or in relation to the completeness and or accuracy of information contained in these guidance notes, and accordingly the contents should not be relied on as such.

Contents

Abbreviations

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

Abbreviation	Description
AC	Alternating Current
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
CP	Compliance Processes
CSC	Current Sourced Converter
CUSC	Connection and Use of System Code
DC	Direct Current
DCS	Distributed Control System
DLL	Dynamic Link Library
DNO	Distribution Network Operator
DPD	Detailed Planning Data
DRC	Data Registration Code
ECC	European Connection Conditions
ECP	European Compliance Processes
EDL/EDT	Electronic Data Logging / Electronic Data Transfer
ELEXON	Balancing and Settlement Code Company
EMT	Electromagnetic Transient
FON	Final Operational Notification
FRT	Fault Ride Through
FSM	Frequency Sensitive Mode
GB	Great Britain
GBGF-I	Great Britain Grid Forming - Inverter
GBGF-S	Great Britain Grid Forming - Synchronous
GCRP	Grid Code Review Panel
GSU	Grid Step Up transformer
HVDC	High Voltage Direct Current
ION	Interim Operational Notification
LSFM(O)	Limited Frequency Sensitive Mode (Overfrequency)
LSFM(U)	Limited Frequency Sensitive Mode (Underfrequency)
LON	Limited Operational Notification
MC	Maximum Capacity
MEL	Maximum Export Limit
MG	Minimum Generation
MLP	Machine Load Point
MRL	Minimum Regulating Level
MSA	Mandatory Services Agreement
MSOL	Minimum Stable Operating Level
NETS	National Electricity Transmission System
NFP	Network Frequency Perturbation
NGESO	National Grid Electricity System Operator

NGET	National Grid Electricity Transmission
OC	Operating Code
OEM	Original Equipment Manufacturer
OFGEM	Office of Gas and Electricity Markets
OTSDUW	Offshore Transmission System Development User Works
PC	Planning Code
POD	Power Oscillation Damping
PSS	Power System Stabiliser
PSSE	Power System Simulator for Engineering software
RfG	Requirements for Generators (EU legislation)
RMS	Root Mean Square
RoCoF	Rate of Change of Frequency
SCL	Short Circuit Level
SEL	Stable Export limit
SO	System Operator (NGESO)
SPT	Scottish Power Transmission
SHET	Scottish Hydro Electric Transmission
STC	System Operator Transmission Owner Code
TGN	Technical Guidance Note
TO	Transmission Owner
TOGA	Transmission Outages, Generation Availability
TOV	Transient Over Voltage
UDFS	User Data File Structure
VSC	Voltage Source Converters

Definitions

	Definitions
Active Control Based Power	The Active Power output supplied by a Grid Forming Plant through controlled means (be it manual or automatic) of the positive phase sequence Root Mean Square Active Power produced at fundamental System Frequency by the control system of a Grid Forming Unit. For GBGF-I, this is equivalent to a Synchronous Generating Unit with a traditional governor coupled to its prime mover. Active Control Based Power includes Active Power changes that results from a change to the Grid Forming Plant Owners available set points that have a 5 Hz limit on the bandwidth of the provided response. Active Control Based Power also includes Active Power components produced by the normal operation of a Grid Forming Plant that comply with the Engineering Recommendation P28 limits. These Active Power components do not have a 5 Hz limit on the bandwidth of the provided response. Active Control Based Power does not include Active Power components proportional to System Frequency, slip or deviation that provide damping power to emulate the natural damping function provided by a real Synchronous Generating Unit.
Active Damping Power	Active Damping Power is the Active Power naturally injected or absorbed by a Grid Forming Plant to reduce Active Power oscillations in the Total System. More specifically, Active Damping Power is the damped response of a Grid Forming Plant to an oscillation between the voltage at the Grid Entry Point or User System Entry Point and the voltage of the Internal Voltage Source of the Grid Forming Plant. For the avoidance of doubt, Active Damping Power is an inherent capability of a Grid Forming Plant that starts to respond naturally, within less than 5ms to low frequency oscillations in the System Frequency.
Active Frequency Response Power	Active Frequency Response Power is the injection or absorption of Active Power by a Grid Forming Plant to and from the Total System during a deviation of the System Frequency away from the Target Frequency. For a GBGF-I Plant this is very similar to Primary Response but with a response time to achieve the declared service capability (which could be the Maximum Capacity or Registered Capacity) within 1 second. For GBGF-I Plant this can rapidly add extra Active Power in addition to the phase-based Active Inertia Power to provide a system with desirable NFP plot characteristics. The Active Frequency Response Power can be produced by any viable control technology.
Active Inertia Power or Inertia Power	Active Inertia Power or Inertia Power is the injection or absorption of Active Power by a Grid Forming Plant to and from the Total System during a System Frequency change. The amount of Active Power supplied or absorbed by the Grid Forming Plant is a function of the energy storage capability of the Internal Voltage Source and RoCoF or, in the case of an HVDC System, is a function of the Active Power provided by either the Remote End HVDC Converter Station or some extra Plant.

	Definitions
	For the avoidance of doubt, this includes the rotational inertial energy of the complete drive train of a synchronous machine Unit. Active Inertia Power is an inherent capability of a Grid Forming Plant to respond naturally, within less than 5ms, to changes in the System Frequency. For the avoidance of doubt the Active Inertia Power has a slower frequency response compared with Active Phase Jump Power.
Active RoCoF Response Power	Active RoCoF Response Power is defined as the Active Inertia Power developed from a Grid Forming Plant plus the Active Frequency Response Power that can be supplied by a Grid Forming Plant when subject to a rate of change of the System Frequency. For avoidance of doubt, this is ∆P defined in the Service Agreement Schedule C Clause 2.2.
Active Phase Jump Power	Active Phase Jump Power is defined as the transient injection or absorption of Active Power transferred from a Grid Forming Plant to the Total System as a result of changes in the phase angle between the Internal Voltage Source of the Grid Forming Plant and the Grid Entry Point or User System Entry Point. In the event of a disturbance or fault on the Total System, a Grid Forming Plant will instantaneously inject supply or absorb Active Phase Jump Power to the Total System as a result of the phase angle change. For GBGF-I Plant as a minimum value this is up to the Phase Jump Angle Limit Power. Active Phase Jump Power is an inherent capability of a Grid Forming Plant that starts to respond naturally, within less than 5ms, and can have frequency components to over 1000Hz.
Control Based Reactive Power	Control Based Reactive Power is the Reactive Power supplied by a Grid Forming Plant through controlled means based on operator adjustment selectable setpoints (these may be manual or automatic).
Damping Factor (ζ)	The ratio of the actual damping to critical damping. For a GBGF-I the open loop phase angle, for an open loop gain of one, is measured from the systems Nichols Chart. This angle is used to define the system's equivalent Damping Factor that is the same as the Damping Factor of a second order system with the same open loop phase angle. Alternatively, the Damping Factor refers to the damping of a specific oscillation mode that is associated with the second order system created by the power to angle transfer function as show in **Error! Reference source not found.** and **Error! Reference so urce not found.**.
Dynamic Reactive Compensation Equipment	Plant capable of supplying or absorbing Reactive Power in a controlled manner which could include but not limited to a Synchronous Compensator, Static Var Compensator (SVC), or STATCOM.
Facility	The whole system which incorporates the Grid Forming Plant Modules.
Grid Entry Point	Refer to Grid Code definition of Grid Entry Point.
Grid Forming Capability	Is the capability of (but not limited to) a Power Generating Module, HVDC Converter (which could form part of an HVDC

	Definitions
	System), Generating Unit, Power Park Module, DC Converter, OTSDUW Plant and Apparatus, Electricity Storage Module, Dynamic Reactive Compensation Equipment or any Plant and Apparatus (including a smart load) whose supplied Active Power is directly proportional to the difference between the magnitude and phase of its Internal Voltage Source and the magnitude and phase of the voltage at the Grid Entry Point or User System Entry Point and the sine of the Load Angle. As a consequence, a Plant which has a Grid Forming Capability is one where the frequency of the Internal Voltage Source is the same as the System Frequency for normal operation, with only the Load Angle defining the relative position between the two. In the case of a GBGF-I Plant a GBGF-I Unit forming part of a GBGF-I Plant shall be capable of sustaining a voltage at its terminals irrespective of the voltage at the Grid Entry Point or User System Entry Point for normal operating conditions. For a GBGF-I Plant, the control system which determines the amplitude and phase of the Internal Voltage Source, shall have a response to the voltage and System Frequency at the Grid Entry Point or User System Entry Point with a bandwidth that is less than a defined value as shown by the control system's NFP Plot. Exceptions to this rule are only allowed during transients caused by System faults, voltage dips/surges and/or a step or ramp changes in the phase angle which are large enough to cause damage to the Grid Forming Plant via excessive currents.
Grid Forming Plant	A Plant which is classified as either a GBGF-S or a GBGF-I.
GBGF-S	Is a Synchronous Power Generating Module, Synchronous Electricity Storage Module or Synchronous Generating Unit with a Grid Forming Capability.
GBGF-I	Is any Power Park Module, HVDC System, DC Converter, OTSDUW Plant and Apparatus, Non-Synchronous Electricity Storage Module, Dynamic Reactive Compensation Equipment or any Plant and Apparatus (including a smart load) which is connected or partly connected to the Total System via an Electronic Power Converter which has a Grid Forming Capability.
Grid Forming Electronic Power Converter	A Grid Forming Plant whose output is derived from a static solid-state Electronic Power Converter with a Grid Forming Capability.
Grid Forming Active Power	Grid Forming Active Power is the inherent Active Power produced by Grid Forming Plant that includes Active Inertia Power plus Active Phase Jump Power plus Active Damping Power.
Grid Forming Unit	A Power Park Unit or Electricity Storage Unit or a Synchronous Power Generating Unit or individual Load with a Grid Forming Capability
Fast Fault Current Injection	The ability of a Grid Forming Plant to supply reactive current, that starts to rise in less than 5ms, into the Total System when the voltage falls below 90% of its nominal value at the Grid Entry Point or User System Entry Point.
Frequency Sensitive Mode	A Genset, or Type C Power Generating Module or Type D Power Generating Module or DC Connected Power Park Module or HVDC System operating mode which will result in Active Power output

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	changing, in response to a change in System Frequency, in a direction which assists in the recovery to Target Frequency, by operating so as to provide Primary Response and/or Secondary Response and/or High Frequency Response.
Inertia Constant H	For a GBGF-S, the Inertia Constant H is measured in MW.seconds / MVA. For a GBGF- I, the Inertia Constant H is measured in MW.seconds / MVA and it is derived from the Active RoCoF Response Power when subject to a rate of change of the System Frequency.
Internal Voltage Source	For a GBGF-S, a real magnetic field, that rotates synchronously with the System Frequency under normal operating conditions, which as a consequence induces an Internal Voltage Source in the stationary generator winding that has a real physical impedance. In a GBGF-I, switched power electronic devices are used to produce a voltage waveform, with harmonics, that has a fundamental rotational component called the Internal Voltage source (IVS) that rotates synchronously with the System Frequency under normal operating conditions. For a GBGF-I Plant there must be a real physical impedance between the Internal Voltage Source and the Grid Entry Point or User System Entry Point. For the avoidance of doubt, a virtual impedance is not permitted in GBGF-I Plant.
Limited Frequency Sensitive Mode	A mode whereby the operation of the Genset or Power Generating Module (or DC Converter at a DC Converter Station or HVDC Systems exporting Active Power to the Total System) is Frequency insensitive except when the System Frequency exceeds 50.4Hz, from which point Limited High Frequency Response must be provided. For Power Generating Modules (including DC Connected Power Park Modules) and HVDC Systems, operation in Limited Frequency Sensitive Mode would require Limited Frequency Sensitive Mode – Over-frequency (LFSM-O) capability and Limited Frequency Sensitive Mode – Underfrequency (LFSM-U) capability.
Load Angle	The angle in radians between the voltage of the Internal Voltage Source and the voltage at the Grid Entry Point or User System Entry Point.
Maximum Capacity	The maximum continuous Active Power which a Power Generating Module can supply to the Total System, less any demand associated

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	solely with facilitating the operation of that Power Generating Module and not fed into the System. In the case of an Electricity Storage Module, the Maximum Capacity is the maximum continuous Active Power which an Electricity Storage Module can export to the Total System less any demand associated with facilitating the operation of that Electricity Storage Module when fully charged and operating in a mode analogous to Generation.
Minimum Stable Operating Level or Minimum Stable Generation	The minimum Active Power, as specified in the Bilateral Agreement or as agreed between The Company and the Generator, at which the Power Generating Module can be operated stably for an unlimited time.
Network Frequency Perturbation (NFP) Plot	A form of Bode Plot which plots the amplitude (%) and phase (degrees) of the resulting output oscillation responding to an applied input oscillation across a frequency base. The plot will be used to assess the capability and performance of a Grid Forming Plant and to ensure that it does not pose a risk to other Plant and Apparatus connected to the Total System. For GBGF-I, these are used to provide data to The Company which together with the associated Nichols Chart (or equivalent) defines the effects on a GBGF-I for changes in the frequency of the applied input oscillation. The input is the applied as an input oscillation and the output is the resulting oscillations in the GBGF-I's Active Power. For the avoidance of doubt, Generators in respect of GBGF-S can provide their data using the existing formats and do not need to supply NFP plots.
Nichols Chart	For a GBGF-I, a chart derived from the open loop Bode Plots that are used to produce an NFP Plot. The Nichols Chart plots open loop gain versus open loop phase angle. This enables the open loop phase for an open loop gain of 1 to be identified for use in defining the GBGF-I's equivalent Damping Factor
Phase Jump Angle	The Phase Jump Angle is the difference in the measured phase angle of the voltage at the Grid Entry Point or User System Entry Point (if Embedded) in a given mains half cycle compared with the measured phase angle of the voltage at the Grid Entry Point or User System Entry Point in the previous mains half cycle.
Phase Jump Angle Limit	The maximum Phase Jump Angle when applied to a GBGF-I Plant which will result in a linear controlled response without activating current limiting functions. This is specified for a System angle near to zero which will be considered to be the normal operating angle under steady state conditions.
Phase Jump Angle Withstand	The maximum Phase Jump Angle when applied to a GBGF-I Plant which will result in the GBGF-I Plant remaining in stable operation with current limiting functions activated. This is specified for a System angle near to zero which will be considered to be the normal operating angle under steady state conditions.
Plant	Solution and Plant are interchangeably used in this document. Solution or Plant refer to the project or Facility with which the Stability Compensation Service Agreement for NOA Stability Pathfinder Phase 3 will be signed.

	Definitions
Point of Connection	An electrical point of connection between the National Electricity Transmission System and a User's System.
Proving Tests	A proving test or tests to verify that the Facility can provide the Stability Compensation Service in accordance with the Technical Performance Requirements stated in Schedule C of the Service Agreement, including the contracted Inertia, Short Circuit Level, and Reactive Power.
Reactive Capability	The ability of the Facility to absorb or produce Reactive Power range as specified in the Service Agreement.
RoCoF	Rate of Change of System Frequency.
Service Agreement	Refers to the commercial contract for NOA Stability Pathfinder Phase 3. It is also referenced as Stability Compensation Service Agreement in this document.
Solution	Solution and Plant are interchangeably used in this document. Solution or Plant refer to the project or Facility with which the Stability Compensation Service Agreement for NOA Stability Pathfinder Phase 3 will be signed.
Total System	The National Electricity Transmission System and all User Systems in the National Electricity Transmission System Operator Area.

Introduction

This document is produced by Electricity System Operator (ESO) and provides additional descriptions of the technical studies and testing set out within the Grid Code for Grid Forming Technology. The other general technical requirements such as reactive power capability, voltage control, PSS Tuning/ Damping control, FSM/LFSM control and FRT are covered by other published Guidance Documents.

This GB Grid Forming Guide aims to provide the necessary guidance on the Transmission Grid Forming Connection Compliance Process following the Grid Code Modification GC0137, "Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability" as shown on the ESO's Grid Code Issue 6 Revision 17 as published on 4 September 2023.

Grid Forming Connection includes (but is not limited to) a Power Generating Module, HVDC Converter (which could form part of an HVDC System), Generating Unit, Power Park Module, DC Converter, OTSDUW Plant and Apparatus, Electricity Storage Module, Dynamic Reactive Compensation Equipment or any Plant and Apparatus (including a smart load) whose supplied Active Power is directly proportional to the difference between the magnitude and phase of its Internal Voltage Source and the magnitude and phase of the voltage at the Grid Entry Point or User System Entry Point and the sine of the Load Angle.

Grid Forming Capability is not a mandatory requirement but one which will be delivered through market arrangements, the details of which shall be published on The Company's Website. Grid Forming Capability can be implemented by any technology including Electronic Power Converters with a GBGF-I ability, rotating Synchronous Generating Units or a combination of the two.

When the Grid Forming controller is switched in or off, the other controllers' performance is not expected to be impacted. This may need to be demonstrated by simulations and tests.

Compliance Process

The Grid Forming Plant must fully comply with the applicable requirements of the Grid Code including but not limited to the Planning Code (PC), Connection Conditions (CC's) or European Connection Conditions (ECC's) (as applicable), Compliance Processes (CP's) or European Compliance Processes (ECP's) (as applicable), Operating Codes (OC's), Balancing Codes (BC's) and Data Registration Code (DRC).

The process for Grid Forming Connection to demonstrate compliance with the Grid Code and Bilateral Agreement are included in the Grid Code European Compliance Processes (ECP). In addition to the process and details of the documentation that is exchanged the appendices to the ECP include the technical details of the simulation studies that a Grid Forming connection should carry out (ECP.A.3.9) and the details of compliance tests applicable to Grid Forming Connection (ECP.A.9.1). For the Electricity Storage Modules and HVDC system, the simulation and tests need to cover both export and import mode.

Point of Compliance

In concept the Grid Forming Connection defines the boundary at which compliance is demonstrated at the interface point. This is the ownership boundary between the Grid Forming Connection and transmission system. This is often the termination point in compact switchgear owned by a network licensee or a short cable owned by the Grid Forming Connection. In practical terms, if the cable has negligible impact on performance, then metering for Grid Forming Connection systems and signals for compliance assessment can be at the end of the short cable of the Grid Forming Connection. If the cable is considered as having a material effect on performance, then control and signal metering needs to be at the network owner's end of the cable. As a rule of thumb connection cables of less than 500m can be considered as negligible. Where cable lengths are significant, line compensation may be considered as an alternative to taking signals directly from the connection point.

System Monitoring

In order to accurately monitor performance, each Grid Forming Plant shall be equipped with a facility to accurately record the following parameters at a rate of 10ms:

- System Frequency using a nominated algorithm as defined by The Company
- The ROCOF rate using a nominated algorithm as defined by The Company based on a 500ms rolling average.
- A technique for recording the Grid Phase Jump Angle by using either a nominated algorithm as defined by The Company or an algorithm that records the time period of each half cycle with a time resolution of 10 microseconds. For a 50Hz System, a 1 degree phase jump is a time period change of 55.6 microseconds.

The detailed specification for Grid Forming Capability Plant dynamic performance including triggering criteria, sample rates, the communication protocol and recorded data shall be specified by The Company in the Bilateral Agreement.

Simulation Studies

The simulation studies are described in the European Compliance Processes (ECP.A.3.9). However, if the study requirements specified in the Grid Code are inappropriate to the technologies employed on a particular project the Grid Forming Plant owner should contact the ESO to discuss and agree an alternative program and success criteria.

In general, simulation studies are required to:

- Demonstrate an expected compliant performance ahead of connection.
- Demonstrate the model supplied is a true and accurate reflection of the plant, as built.
- Demonstrate capability where it is impractical through testing as the effects on other system Users would be unacceptable.

The simulations must be based on the validated models supplied to the ESO in accordance with Grid Code Planning Code Appendix section 5.4.2 (PC.A.5.4.2) and PC.A.9. and be submitted before issuing a ION.

Grid Forming Data Submission

The following data need only be supplied by Users (be they a GB Code User or EU Code User) or Non-CUSC Parties who wish to offer a Grid Forming Capability as provided for ECC.6.3.19.3. Where such a Grid Forming Capability is provided then the following data items and models are to be supplied.

- Each User shall be required to submit a Network Frequency Perturbation Plot and Nichols Chart (or equivalent as agreed with The Company) which shall be assessed in accordance with the requirements of ECP.A.3.9.3.
- Each User or Non-CUSC Party is required to supply a high-level equivalent architecture diagram of their Grid Forming Plant as shown in Figure PC.A.5.8.1 together with the equivalent linear classical block diagram model (using the Laplace Operator) of their Grid Forming Plant which should preferably be in the general form shown in Figure PC.A.5.8.1 (a) or Figure PC.A.5.8.1 (b). When submitting either Figure PC.A.5.8.1 (a) or Figure PC.A.5.8.1 (b), each User or Non-CUSC Party can use their own design, that may be very different to Figures PC.A.5.8.1 (a) or PC.A.5.8.1 (b), but should contain all relevant functions that can include simulation models and other equivalent data and documentation.
- In order to participate in the Grid Forming Capability market, Users and Non-CUSC Parties are required to provide data of their GBGF-I in accordance with Figures PC.A.5.8.1(a) and PC.A.5.8.1(b). Users and Non-CUSC Parties in respect of Grid Forming Plants should indicate if the data is submitted on a unit or aggregated basis. Table PC.A.5.8.1(a) defines the notation used in Figure PC.5.8.1

- In order to participate in a Grid Forming Capability market, Users and Non-CUSC Parties are also required to provide the data of their GBGF-I in accordance with Table PC.A.5.8.1.2 to The Company. The details and arrangements for Users and Non-CUSC Parties participating in this market shall be published on The Company's Website.

The required data format is referred to Appendix A.

Protection Requirements

Power Park Module with a Grid Forming Capability as provided for in ECC.6.3.19, when connected and synchronised to the System, is required to be capable of withstanding without tripping a rate of change of Frequency up to and including 2 Hz per second as measured over a rolling 500 millisecond period.

All other Power Generating Modules when connected and synchronised to the System, shall be capable of withstanding without tripping a rate of change of Frequency up to and including 1 Hz per second as measured over a rolling 500 millisecond period. Voltage dips may cause localised rate of change of Frequency values in excess of 1 Hz per second (or 2Hz/s in the case of Power Park Modules with a Grid Forming Capability) for short periods, and in these cases, the requirements under ECC.6.3.15 (fault ride through) supersedes this clause. For the avoidance of doubt, this requirement relates to the capabilities of Power Generating Modules only and does not impose the need for rate of change of Frequency protection nor does it impose a specific setting for anti-islanding or loss-of-mains protection relays.

As stated in ECC.6.1.2, the System Frequency could rise to 52Hz or fall to 47Hz and the System voltage at the Grid Entry Point or User System Entry Point could rise or fall within the values outlined in ECC.6.1.4. In the case of Grid Forming Plant, Grid Forming Plant Owners are also required to satisfy the System Frequency and System voltage requirements as defined in ECC.6.3.19.

Technical requirements of GBGF

Each GBGF shall be capable of:

- Providing a symmetrical ability for importing and exporting Active ROCOF Response Power, Active Phase Jump Power, Active Damping Power and Active Control Based Power under both rising and falling System Frequency conditions. Such requirements will apply over the full System Frequency range as detailed in ECC.6.1.2
- In addition to meeting the requirements of fault ride through requirement referred to in ECC.6.3.15, each Grid Forming Plant is required to remain in synchronism with the Total System and maintain a Load Angle whose value can vary between 0 and 90 degrees (π/2 radians). When subject to a fault or disturbance, or System Frequency change, each Grid Forming Plant shall be capable of supplying Active ROCOF Response Power, Active Phase Jump Power, Active Damping Power, Active Control Based Power, Control Based Reactive Power, Voltage Jump Reactive Power and GBGF Fast Fault Current Injection.
- Satisfying the requirements of GBGF Fast Fault Current Injection referred to in ECC.6.3.19.5.
- Operating at a minimum short circuit level of zero MVA at the Grid Entry Point or User System Entry Point.
- Providing any additional quality of supply requirements, including but not limited to reductions in the permitted frequency of Temporary Power System Over-voltage events (TOV's) and System Frequency bandwidth limitations, as agreed with The Company.

Moreover, each GBGF-I shall be also capable of:

- Providing a symmetrical ability for importing and exporting Active ROCOF Response Power, Active Phase Jump Power, Active Damping Power and Active Control Based Power under both rising and falling System Frequency conditions. Such requirements will apply over the full System Frequency range as detailed in CC.6.1.2 and CC.6.1.3 or ECC.6.1.2 (as applicable).
- Operating as a voltage source behind an impedance

- Being designed so as not to cause any undue interactions which could cause damage to the Total System or other User's Plant and Apparatus, that may need to be demonstrated by Network Frequency Perturbation (NFP) or impedance scan.
- Include an Active Control Based Power part of the control system that can respond to changes in the Grid Forming Plant or external signals from the Total System available at the Grid Entry Point or User System Entry Point but with a bandwidth below 5 Hz to avoid AC System resonance problems.
- Meeting the requirements of frequency, rate of change of frequency and voltage protection setting referred to ECC.6.3.13 irrespective of being owned or operated by a GB Code User, EU Code User or Non-CUSC Party.
- GBGF-I with an importing capability mode of operation such as DC Converters, HVDC Systems and Electricity Storage Modules are required to have a predefined frequency response operating characteristic over the full import and export range which is contained within the envelope defined by the red and blue lines shown in Figure 1 (referred to Figure ECC.6.3.19.3 in GC). This characteristic shall be submitted to The Company. For the avoidance of doubt, Grid Forming Plants which are only capable of exporting Active Power to the Total System are only required to operate over the exporting power region.

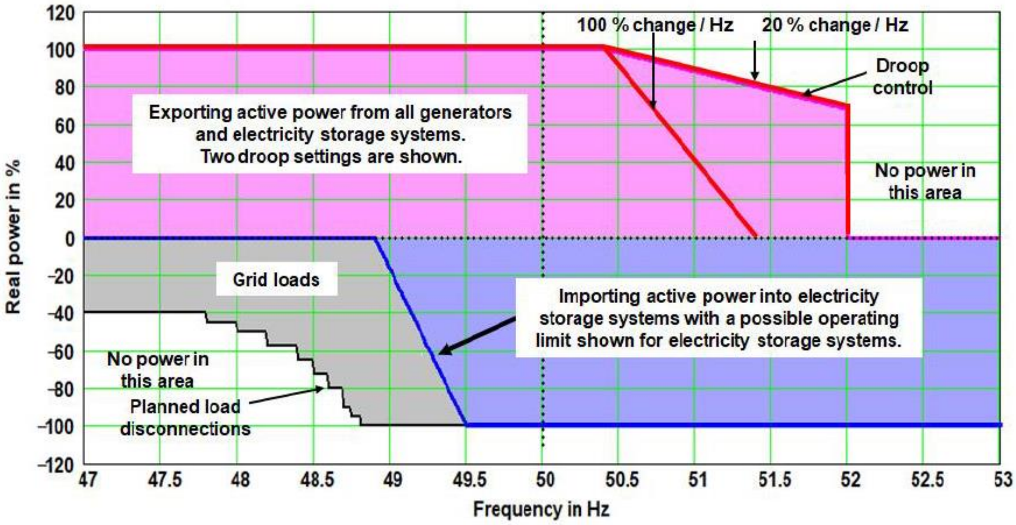


Figure 1: Frequency Response Operating Characteristic

- Each User or Non-CUSC Party shall design their GBGF-I system with an equivalent Damping Factor of between 0.2 and 5.0. It is down to the User or Non-CUSC Party to determine the Damping Factor, whose value shall be agreed with The Company. It is typical for the Damping Factor to be less than 1.0, though this will be dependent upon the parameters of the Grid Forming Plant and the equivalent System impedance at the Grid Entry Point or User System Entry Point. The output of the Grid Forming Plant shall be designed such that following a disturbance on the System, the Active Power output and Reactive Power output shall be adequately damped. The damping shall be judged to be adequate if the corresponding Active Power response to a disturbance decays with a response that is in line with the response of second order system that has the same equivalent Damping Factor.
- Each GBGF-I shall be designed so as not to interact and affect the operation, performance, safety or capability of other User's Plant and Apparatus connected to the Total System. To achieve this requirement, each User and Non-CUSC Party shall be required to submit the data required in PC.A.5.8

Fault Ride Through and Fast Fault Current Injection requirement

Each Type B, Type C and Type D Power Park Module or each Power Park Unit within a Type B, Type C and Type D Power Park Module or HVDC Equipment who is operating in a Grid Forming Capability mode need to meet the requirements of fault ride through requirements referred to CC.6.3.15 or ECC.6.3.15, each Grid Forming Plant is required to remain in synchronism with the Total System and maintain a Load Angle whose value can vary between 0 and 90 degrees (π/2 radians).

In addition to above, the Grid Forming Plant need to meet the Fast current injection requirement referred to ECC.6.3.19.5.

When subject to a fault or disturbance, or System Frequency change, each Grid Forming Plant shall be capable of supplying Active ROCOF Response Power, Active Phase Jump Power, Active Damping Power, Active Control Based Power, Control Based Reactive Power, Voltage Jump Reactive Power and GBGF Fast Fault Current Injection.

For any balanced fault which results in the positive phase sequence voltage falling below the voltage levels specified in CC.6.1.4 or ECC.6.1.4 (as applicable) at the Grid Entry Point or User System Entry Point (if Embedded), a Grid Forming Plant shall, as a minimum be required to inject a reactive current of at least their Peak Current Rating when the voltage at the Grid Entry Point or User System Entry Point drops to zero as shown in the Figure ECC.6.3.19.5(a) . For intermediate retained voltages at the Grid Entry Point or User System Entry Point, the injected reactive current shall be on or above a line drawn from the bottom left hand corner of the normal voltage control operating zone (shown in the rectangular green shaded area of Figure 2 (referred to Figure ECC.6.3.19.5(a)) in GC) and the specified Peak Current Rating at a voltage of zero at the Grid Entry Point or User System Entry Point as shown in Figure 2. Typical examples of limit lines are shown in Figure 2 for a Peak Current Rating of 1.0pu where the injected reactive current must be on or above the black line and a Peak Current Rating of 1.5pu where injected reactive current must be on or above the red line. For the purposes of this requirement, the maximum rated current will be the Peak Current Rating declared by the Grid Forming Plant Owner in accordance with Table PC.A.5.8.2.

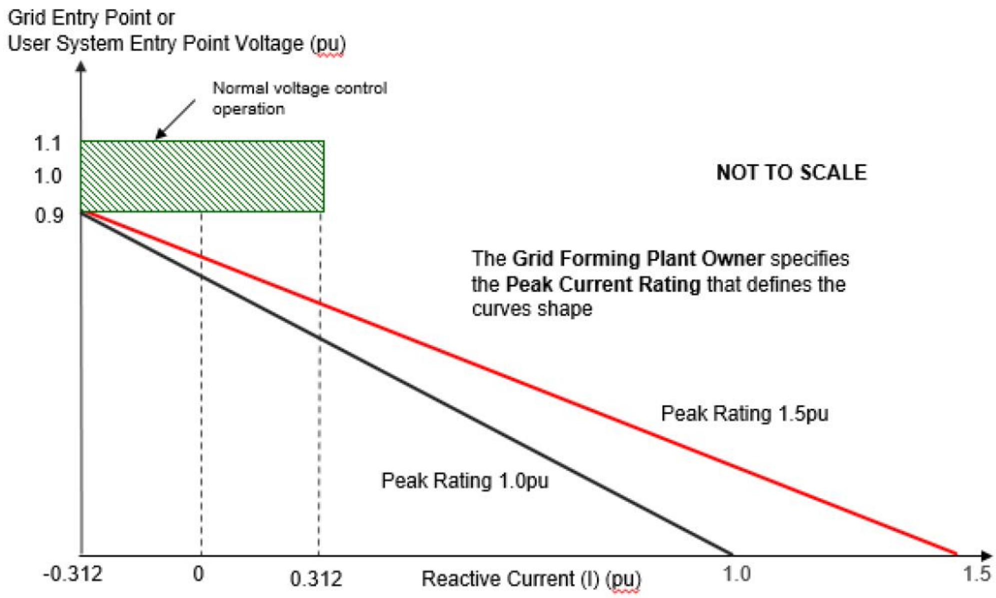


Figure 2: Injected Reactive Current Requirement

Figure 2 defines the reactive current to be supplied under a faulted condition which shall be dependent upon the pre-fault operating condition and the retained voltage at the Grid Entry Point or User System Entry Point voltage. For the avoidance of doubt, each Grid Forming Plant (and any constituent element thereof), shall be required to inject a reactive current which shall be not less than its pre-fault reactive current.

Each Grid Forming Plant shall be required to inject reactive current above the shaded area shown in Figure 3 (referred to ECC.6.3.19.5(b) in GC) when the retained voltage at the Grid Entry Point or User System Entry Point falls to 0pu. Where the retained voltage at the Grid Entry Point or User System Entry Point is below 0.9pu but above 0pu (for example when significant active current is drawn by loads and/or resistive components arising from both local and remote faults or disturbances from other Plant and Apparatus connected to the Total System) the injected reactive current component shall be in accordance with Figure 2. The injected current shall be above the shaded area shown in Figure 3 for the duration of the fault clearance time which for faults on the Transmission System cleared in Main Protection operating times shall be up to 140ms.

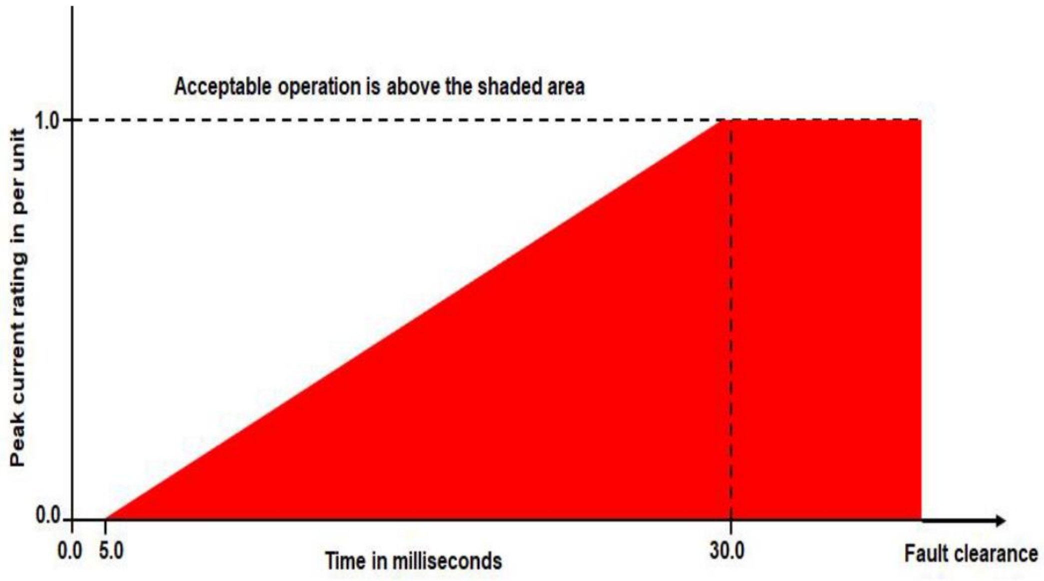


Figure 3: Acceptable Operation of Injected Reactive Current

Each Grid Forming Plant shall be designed to ensure a smooth transition between voltage control mode and Fault Ride Through mode in order to prevent the risk of instability which could arise in the transition between the steady state voltage operating range.

Each Grid Forming Plant shall be designed to reduce the risk of transient over voltage levels arising following clearance of the fault and in order to mitigate the risk of any form of instability which could result. The requirements for the maximum transient overvoltage withstand capability and associated time duration, shall be agreed between the User or Non-CUSC Party and The Company as part of the Bilateral Agreement.

Each Grid Forming Plant Owner is required to confirm to The Company, their repeated ability to supply GBGF Fast Fault Current Injection to the System.

In the case of an unbalanced fault, each Grid Forming Plant, shall be required to inject current which shall as a minimum increase with the fall in the unbalanced voltage without exceeding the transient Peak Current Rating of the Grid Forming Plant (or constituent element thereof). And they shall confirm to The Company their ability to prevent transient overvoltage arising on the remaining healthy phases and the control strategy employed.

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 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

Model Validation

Before issuing ION from Company, validation of models before commissioning may be against test results at other comparable sites, Factory Acceptance Tests of comparable equipment, or type test results to show that the responses shown by the models are representative of the Users Plant and Apparatus.

Factory Acceptance Testing is to be carried out details of any additional model validation. Tests should generally include steady state Reactive Power capability, voltage control, Fault Ride Through and Frequency response. If these tests show the models are not representative of the User's Plant and Apparatus, the User shall provide updated models, supporting documentation and associated data to ensure the responses shown by the model is representative of the responses shown by User's Plant and Apparatus during testing.

In the event The Company identifies through lifetime monitoring (OC5) that that the response of the models are not representative of the User's Plant and Apparatus, The Company shall notify the User. The User shall provide the revised models, supporting documentation and associated data whose response is representative of the Users Plant and Apparatus as soon as reasonably practicable, but in any case no longer than 54 days after notification by The Company. In the event of revised models not being made available a Limited Operational Notification (as detailed in CP.9 or ECP.9 as applicable) may be issued with appropriate restrictions.

The Company recognise that it is not possible in a large number of cases to adjust the network frequency of the network to which the Grid Forming Plant is connected, therefore, the tests of demonstration of Grid Forming Capability will be completed as part of a type test on an isolated network. Moreover, other tests, for example voltage injection and frequency tests also expected to be covered. The test results can be as the benchmark data to validate the model functions. The compliance engineers will discuss with Grid Forming provider to advise the expected tests.

Compliance Tests

Tests identified in ECP.A.9 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 ECP.A.9 are at variance with the Bilateral Agreement or the test requirements are not relevant to the plant type, the Grid Forming provider should contact the ESO to discuss and agree an alternative test program and success criteria.

In addition to the dynamic signals supplied in ECP.A.4, the User or Non-CUSC Party shall inform The Company of the following information prior to the commencement of the tests and any changes to the following, if any values change during the tests: (i) All relevant transformer tap numbers, if used. (ii) Number of Grid Forming Units in operation.

Prior to any GBGF-I tests taking place, the User or Non-CUSC Party shall have completed the relevant compliance tests on the GBGF-I, Power Generating Module or Generating Unit as required under ECP.A.5 or OC5. A.2 (as relevant) or Power Park Module as required under ECP.A.6 or OC5. A.3 (as applicable) or HVDC Systems or DC Converters as required under ECP.A.7 or OC5. A.4 (as applicable).

For each test to be carried out the description and purpose of the test to be carried out, results required, the relevant Grid Code clause(s) and criteria of assessment are given in ECP.A.9. The Grid Forming Plant responsible for drafting test procedures for the power station as part of the compliance process prior to the issue of the Interim Operational Notification (ION). ECP.A.9 and the appendices of these guidance notes provide outline test schedules which may assist the Grid Forming Plant with this activity.

The 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 Grid Forming Plant, or by their agent, and not by the ESO. However, the ESO may witness some of the tests as indicated in ECP.A.9. Tests should be completed following the test procedures referred in Appendix C supplied in the UDFS prior to the issue of the ION unless otherwise agreed by the ESO.

The Grid Forming Plant should also provide suitable digital monitoring equipment to record all relevant test signals needed to verify the Grid Forming Plant performance in parallel with the ESO recording equipment.

If the Grid Forming tests will be carried out as part of a type test, the electrical and communication setups need to be agreed and approved by Company.

Compliance Test Signals

The Grid Code requires that a number of signals are provided from compliance tests to the ESO to allow assessment of the compliance. The list of these signals is set out in ECP.A.4 for EU Code Users.

Where these signals are provided to the ESO it should be done in a consistent electronic format with a time stamp in a numerical format.

The signals which shall be provided by the User to The Company for onsite monitoring shall be of the following resolution, unless otherwise agreed by The Company:

- 1 Hz for reactive range tests
- 10 Hz for frequency control tests
- 100 Hz for voltage control tests
- 1 kHz for Grid Forming Plant signals including fast fault current measurements
- 100Hz for the other Grid Forming Plant tests carried out in accordance with ECC.6.6.1.9

Co-located Site

In the case of a co-located site, for example Electricity Storage Modules or Grid Forming Plant connected within a new or existing Power Station, The Company will accept demonstration of compliance at the Grid Entry Point or User System Entry Point (if Embedded) through a combination of the capabilities of the Power Generating Modules and Electricity Storage Modules (which could include Grid Forming Plant) or Electricity Storage Modules and Generating Units or Power Park Modules (which could include Grid Forming Plant). Generators or Grid Forming Plant Owners should however be aware that for the purposes of compliance, full Grid Code compliance should be demonstrated when, for example, the Electricity Storage Module or Grid Forming Plant is out of service and the remaining Power Generating Module is in service or the Electricity Storage Module or Grid Forming Plant is in service and the Power Generating Module is out of service. Equally, The Company will accept Manufacturer's Data & Performance Reports for the purposes of proving compliance at co-located sites.

Test Notification to Control Room

The Grid Forming Plant Owner 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 Grid Forming Plant Owner should be aware that this interface with ESO transmission planning will normally be available in weekday working hours only. As best practice, the Grid Forming Plant Owner 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 and were possible with 28 days' notice. If there is insufficient notice or information provided by the HVDC Owner, then the proposed testing may not be allowed to proceed.

Appendices

Appendix A: Required Data Submission of Grid Forming Plant

ECP.A.3.9.2 states the required data of Grid Forming Plant to The Company:

a) The representation of their Grid Forming Plant in a format either the same as Figure A-1 (referred to Figure PC.A.5.8.1 in GC) of PC.A.5.8.1 or in an equivalent format.

b) The data associated with their Grid Forming Plant as required in PC.A.5.8.1

c) A linearised model and parameters of the Grid Forming Plant in the frequency domain in the same format as required in PC.A.5.8.1 or equivalent.

d) A Network Frequency Perturbation Plot with a Nichols Chart demonstrating the equivalent Damping Factor.

e) For the items a) to d) the User or Non-CUSC Party can submit the data in any equivalent format as agreed with The Company.

For GBGF-I, the User or Non-CUSC Party may be required to supply other versions of the Network Frequency Perturbation Plot for different input and output signals as defined by The Company.

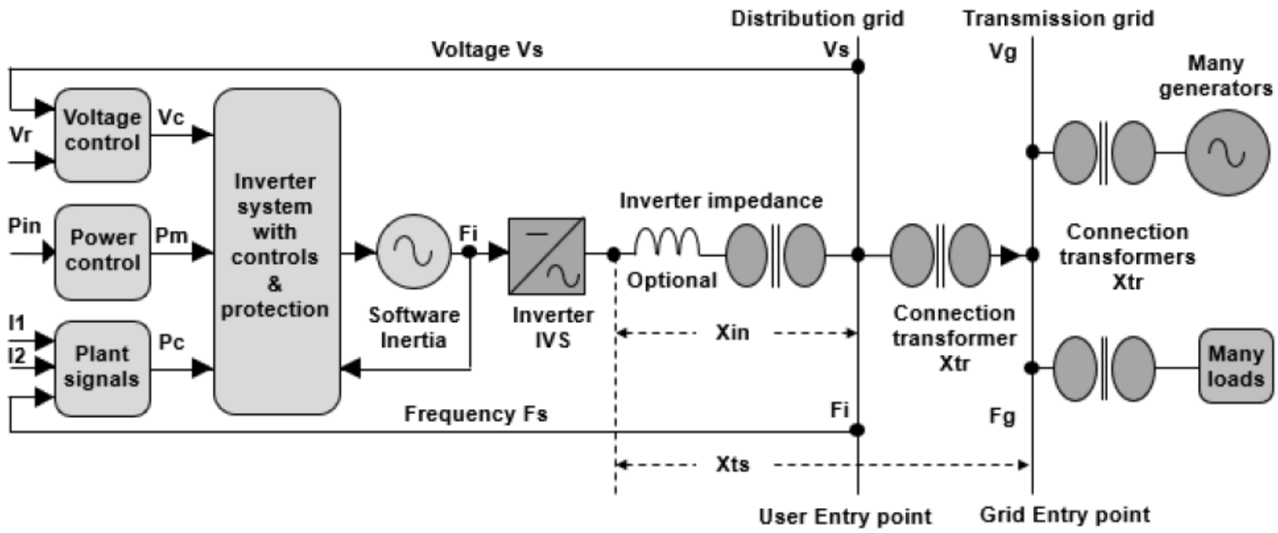


Figure A-1 : Example of Grid Forming Plant

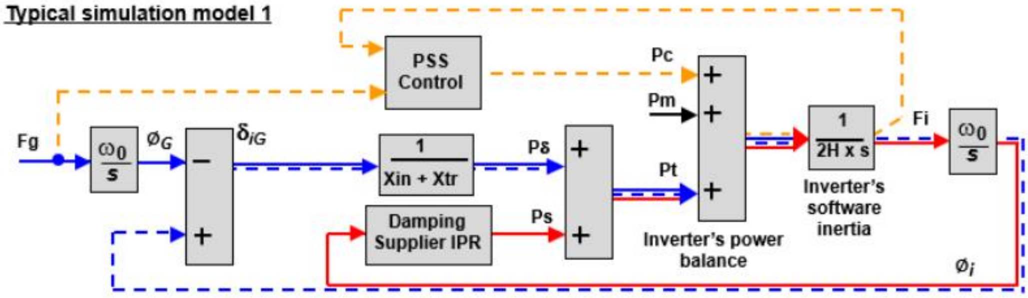


Figure PC.A.5.8.1 (a) Preferred simplified diagram of a **GBGF-I** with a **Power System Stabiliser** "**PSS**" that can add damping to the **GBGF-I**'s closed loop function shown by the solid red line and the dotted blue line.

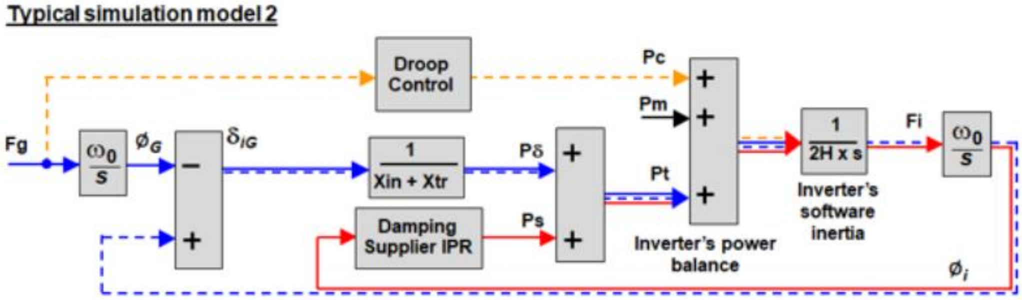


Figure PC.A.5.8.1 (b) – Preferred simplified diagram of a system with a droop control ability that can add **Control-Based Active Droop Power**. This diagram does not add extra closed loop damping to the **GBGF-I's** closed loop function shown by the solid red line and the dotted blue line.

Figure A-2: Simulation model referred to Figure PC.A.5.8.1 (a) and (b) in GC

Table PC.A.5.8.1

Parameter	Symbol	Units
The primary reactance of the **Grid Forming Unit**, in pu.	Xin or Xts	pu on MVA **Rating of Grid Forming Unit**
The additional reactance, in pu, between the terminals of the **Grid Forming Unit** and the **Grid Entry Point** or **User System Entry Point** (if **Embedded**).	X_{tr}	pu on MVA **Rating of Grid Forming Unit**
The rated angle between the **Internal Voltage Source** and the input terminals of the **Grid Forming Unit**.		radians
The rated angle between the **Internal Voltage Source** and **Grid Entry Point** or **User System Entry Point** (if **Embedded**).		radians
The rated voltage and phase of the **Internal Voltage Source** of the **Grid Forming Unit**.		Voltage - pu Phase - radians
The rated electrical angle between current and voltage at the input to the Grid transformer.		radians

Table PC.A.5.8.1

Table PC.A.5.8.2

Quantity	Units	Range (where Applicable)	User Defined Parameter
Type of **Grid Forming Plant** (eg **Generating Unit**, **Electricity Storage Module**, **Dynamic Reactive Compensation Equipment** etc)	N/A		
Maximum Continuous Rating at **Registered Capacity** or **Maximum Capacity**	MVA		
Primary reactance Xin or Xts (see Table PC.A.5.8.1)	pu on MVA		
Additional reactance X_{tr} (See Table PC.A.5.8.1)	pu on MVA		

Maximum Capacity	MW		
Active ROCOF Response Power (MW) injected or absorbed at 1Hz/s **System Frequency** change (which is the maximum frequency change for linear operation of the **Grid Forming Plant**)	MW		
Phase Jump Angle Withstand	degrees		60 degrees specified
Phase Jump Angle limit	degrees		5 degrees recommended
Phase Jump Power (MW) at the rated angle	MW		
Defined Active Damping Power for a **Grid Oscillation Value** of 0.05 Hz peak to peak at 1 Hz	MW		
The cumulative energy delivered for a 1Hz/s **System Frequency** fall from 52 Hz to 47 Hz. This is the total **Active Power** transient output of the **Grid Forming Plant**	MWs or MJ		
Inertia Constant (**H**) using equation 1 or declared in accordance with the simulation results of ECP.A.3.9.4	MWs/MVA		
Inertia Constant (**He**) using equation 2 or declared in accordance with the simulation results of ECP.A.3.9.4	MWs/MVA		
Continuous Overload Capability	% on MVA		
Short Term duration Overload capability			
Duration of Short Term Overload Capability	s		
Peak Current Rating	Pu		
Nominal **Grid Entry Point** or **User System Entry Point** voltage	kV		
Grid Entry Point or **User System Entry Point**	- Location		
Continuous or defined time duration MVA Rating	MVA		
Continuous or defined time duration MW Rating	MW		

For a **GBGF-I** the inverters maximum **Internal Voltage Source** (**IVS**) for the worst case condition – for example operation at maximum exporting **Reactive Power** at the maximum AC **System** voltage	pu		
Maximum Three Phase Short Circuit Infeed at **Grid Entry Point** or **User System Entry Point**	kA		
Maximum Single Phase Short Circuit Infeed at **Grid Entry Point** or **User System Entry Point**	kA		
Will the **Grid Forming Plant** contribute to any other form of commercial service – for example Dynamic Containment, Firm Frequency Response,	Details to be provided		
Equivalent Damping Factor.	Z		0.2 to 5.0 allowed

Table PC.A.5.8.2

H = Installed MWs / Rated installed MVA (equation 1)
He = (Active ROCOF Response Power at 1 Hz / s x System Frequency) / (Installed MVA x 2) (equation 2)

Appendix B Simulation Requirements

Summary of Requirements

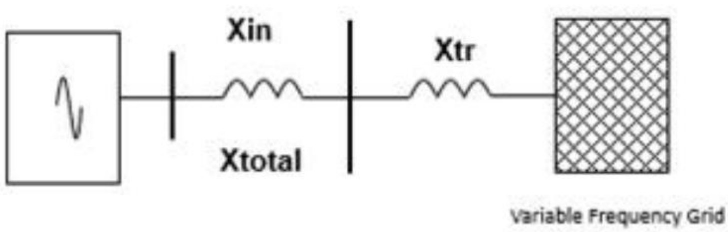
Grid Code ECP.A.3.9.

1. To supply Active ROCOF Response Power
2. To supply Active ROCOF Response Power and asses its withstand capability under extreme System Frequencies
3. To demonstrate the Grid Forming Plant's ability to supply Active ROCOF Response Power over the full System Frequency range.
4. To demonstrate the Grid Forming Plant's ability to supply Active Phase Jump Power under normal operation
5. To demonstrate the Grid Forming Plant's ability to supply Active Phase Jump Power under extreme conditions.
6. To demonstrate the Grid Forming Plant's ability to supply Fault Ride Through and GBGF Fast Fault Current Injection during a faulted condition
7. To demonstrate the GBGF-I model is capable of supplying Active ROCOF Response Power and Active Phase Jump Power, under extreme conditions.
8. To demonstrate the Grid Forming Plant model is capable of contributing to Active Damping Power

Simulation Stages

The simulation study shall comprise of the following stages.

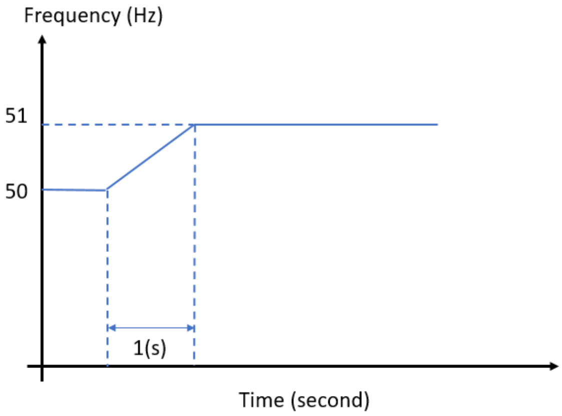
1). A simulation study to the equivalent shown in Appendix B-1 (referred to Figure ECP.A.3.9.4 in GC).



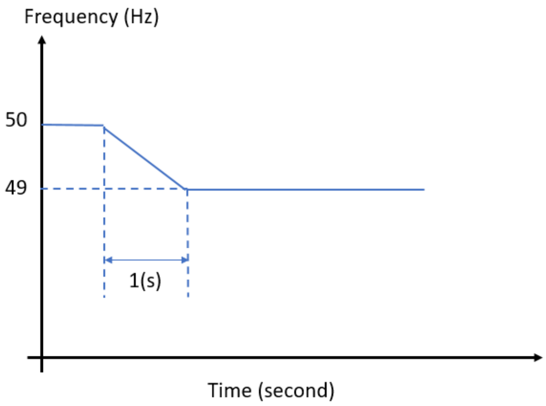
Appendix B-1: Studied Network

2). Supplying Active ROCOF Response Power to the Total System as a result of a System Frequency change. In this simulation, with the Grid Forming Plant initially running at Registered Capacity or Maximum Capacity, the Grid System Frequency is increased from 50Hz to 51Hz at a rate of 1Hz/s with measurements of the Grid Forming Plant's Active ROCOF Response Power, System Frequency and time in (ms). The simulation is required to assess correct operation of the Grid Forming Plant without saturating. Repeat for 50Hz to 49Hz at 1Hz/s.

	Initial condition	Voltage Control mode	Frequency control mode	Frequency increase
Simulation 1.1	Maximum Capacity	Enable	Disable both FSM and LFSM	from 50Hz to 51 Hz at a rate of 1Hz/s
Simulation 1.2	Maximum Capacity	Enable	Disable both FSM and LFSM	50 Hz to 49 Hz at a rate of 1Hz/s



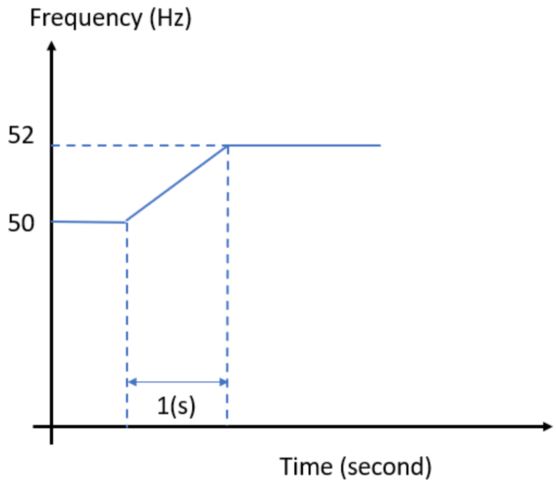
Simulation 1.1



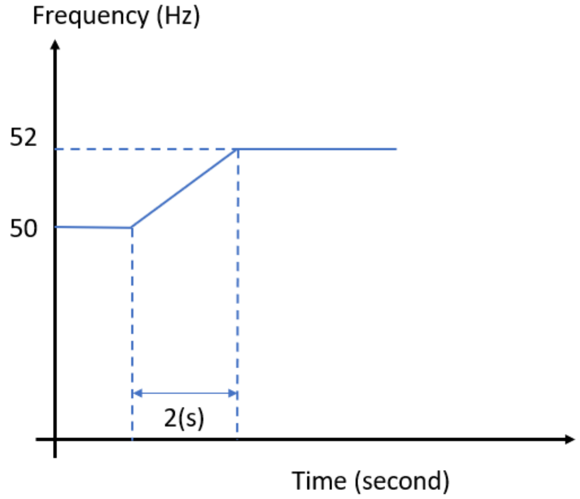
Simulation 1.2

3). The Grid System Frequency is increased from 50Hz to 52Hz at a rate of 1Hz/s with measurements of the Active ROCOF Response Power, System Frequency and time in (ms). This is repeated when the Grid System Frequency is increased from 50Hz to 52Hz at a rate of 2 Hz/s with measurements of the Active ROCOF Response Power, System Frequency and time in (ms). Repeat for 50Hz to 48 Hz at 1 Hz/s and 50Hz to 48 Hz at 2 Hz/s. this simulation is to demonstrate the GBGF-I’s ability to supply Active ROCOF Response Power and assess its withstand capability under extreme System Frequencies.

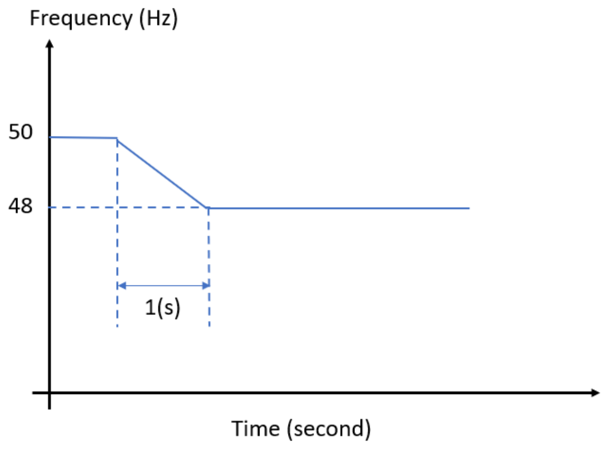
	Initial condition	Voltage Control mode	Frequency control mode	Frequency increase
Simulation 2.1	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 2Hz/s
Simulation 2.2	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 1Hz/s
Simulation 2.3	at full load	enable	Disable both FSM and LFSM	From 50Hz to 48Hz at a rate of 2Hz/s
Simulation 2.4	at full load	enable	Disable both FSM and LFSM	From 50Hz to 48 Hz at a rate of 1Hz/s



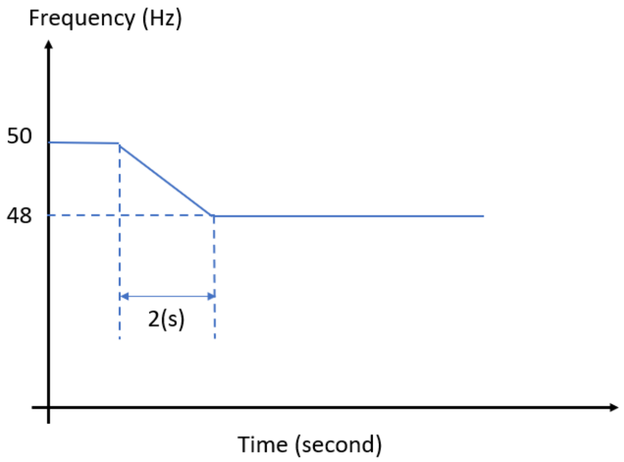
Simulation 2.1



Simulation 2.2



Simulation 2.3



Simulation 2.4

4) demonstrate the Grid Forming Plant's ability to supply Active ROCOF Response Power over the full System Frequency range.

(a) With the System Frequency set to 50Hz, the Grid Forming Plant should be initially running at 75% Maximum Capacity or 75% Registered Capacity, zero MVAr output and both Limited Frequency Sensitive Mode and Frequency Sensitive Mode disabled.

(b) The System Frequency is then increased from 50Hz to 52Hz at a rate of 1Hz/s over a 2 second period. Allow conditions to stabilise for 5 seconds and then decrease the System Frequency from 52Hz to 47Hz at a rate of 1Hz/s over a 5 second period. Allow conditions to stabilise.

(c) Record results of phase based Active ROCOF Response Power, Reactive Power, voltage and System Frequency.

(d) The simulation now needs to be re-run in the opposite direction. The same initial conditions should be applied as per ECP.A.3.9.2iv) (a).

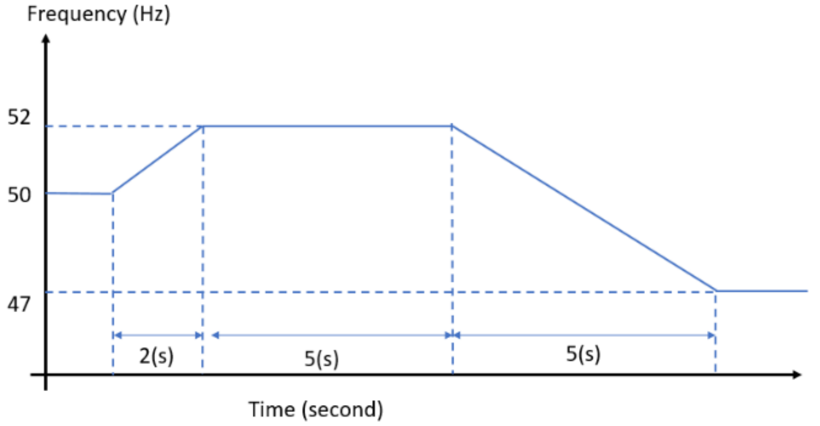
(e) The System Frequency is then decreased from 50Hz to 47Hz at a rate of 1Hz/s over a 3 second period. Allow conditions to stabilise for 5 seconds and then increase the System Frequency from 47Hz to 52Hz at a rate of 1Hz/s over a 5 second period. Allow conditions to stabilise.

(f) Record results of Active ROCOF Response Power, Reactive Power, voltage and System Frequency.

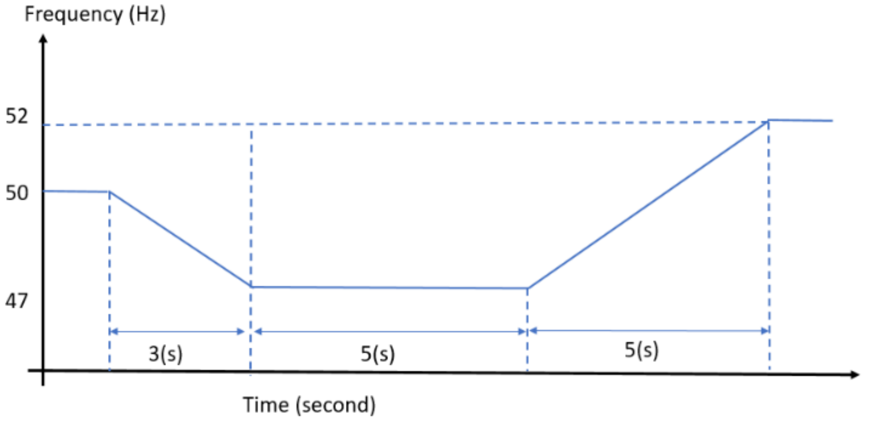
(g) The simulation is required to ensure the Grid Forming Plant can deliver Active ROCOF Response Power without going into saturation and that a behaviour that is equivalent to pole slipping does not occur.

(h)

	Initial condition	Voltage Control mode	Frequency control mode	Frequency Change
Test 3.1	at 75% full load and zero MVAr output	enable	Disable both FSM and LFSM	



	Initial condition	Voltage Control mode	Frequency control mode	Frequency Change
Test 3.2	at 75% full load for both export and import and zero MVAr output	enable	Disable both FSM and LFSM	



5). The fourth simulation is to demonstrate the Grid Forming Plant's ability to supply Active Phase Jump Power under normal operation.

(a) With the System Frequency set to 50Hz, the Grid Forming Plant should initially be running at Maximum Capacity or Registered Capacity or a suitable loading point to demonstrate Grid Forming Capability as agreed with The Company, zero MVAr output and all control actions (e.g. Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control) disabled and keep FRT function is in service.

(b) Apply a positive phase jump of the Phase Jump Angle Limit value at the Grid Entry Point or User System Entry Point.

(c) Record traces of Active Power, Reactive Power, voltage, current and System Frequency for a period of 10 seconds after the step change in phase has been applied. Repeat with a negative phase jump.

	Initial condition	Voltage Control mode	Frequency control mode	Event
Simulation 4.1	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output	Disable	Disable both FSM and LFSM	Apply a positive phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record tracks for 10s
Simulation 4.2	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output for both export /import mode	Disable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record tracks for 10s

6). The fifth simulation is to demonstrate the Grid Forming Plant's ability to supply Active Phase Jump Power under extreme conditions.

(a) With the System Frequency set to 50Hz, the Grid Forming Plant should be initially running at its Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output and all control actions (e.g. Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control) disabled.

(b) Apply a phase jump equivalent to the positive Phase Jump Angle Withstand value at the Grid.

(c) Record traces of Active Power, Reactive Power, voltage, current and System Frequency for a period of 10 seconds after the step change in phase has been applied. Repeat with a negative phase jump.

(d) Repeat steps (a), (b) and (c) of ECP.A.3.9.4(vi) but on this occasion apply a phase jump equivalent to the positive Phase Jump Angle Limit at the Grid.

	Initial condition	Voltage Control mode	Frequency control mode	Event
Simulation 5.1	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output for both export and import	Disable	Disable both FSM and LFSM	Apply positive Phase Jump Angle Withstand value at the connection point of the GBGF-I
Simulation 5.2	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output for both export and import	Disable	Disable both FSM and LFSM	Apply negative Phase Jump Angle Withstand value at the connection point of the GBGF-I
Simulation 5.3	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output for both export and import	Disable	Disable both FSM and LFSM	apply a phase jump equivalent to the positive Phase Jump Angle Limit at the Grid
Simulation 5.4	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr	Disable	Disable both FSM and LFSM	apply a phase jump equivalent to the negative Phase Jump

	output for both export and import			Angle Limit at the Grid

7). The sixth simulation is to demonstrate the Grid Forming Plant's ability to supply Fault Ride Through and GBGF Fast Fault Current Injection during a faulted condition

(a) With the System Frequency set to 50Hz, the Grid Forming Plant should be initially running at its Maximum Capacity or Registered Capacity, zero MVAr output and all control actions (e.g., Limited Frequency Sensitive Mode, Frequency Sensitive Mode, GBGF Fast Fault Current Injection, Fault Ride Through and voltage control other than current limiters) disabled.

(b) Apply a solid three phase short circuit fault at the Grid Entry Point or User System Entry Point for 140ms.

(c) Record traces of Active Power, Reactive Power, voltage, current and System Frequency for a period of 10 seconds after the fault has been applied. The GBGF-I's current limit should be observed to operate.

(d) Repeat steps (a) to (c) but on this occasion with Fault Ride Through, GBGF Fast Fault Current Injection, Limited Frequency Sensitive Mode and voltage control switched into service.

(e) Record traces of Active Power, Reactive Power, voltage, current and System Frequency for a period of 10 seconds after the fault has been applied and confirm correct operation.

	Initial condition	Control mode	Event
Simulation 6.1	Maximum output, zero MVAr output	Limited Frequency Sensitive Mode, Frequency Sensitive Mode, GBGF Fast Fault Current Injection, Fault Ride Through and voltage control other than current limiters disabled	a solid three phase short circuit fault at the connection point for 140ms
Simulation 6.2	Maximum output, zero MVAr output	Fault Ride Through, GBGF Fast Fault Current Injection, Limited Frequency Sensitive Mode and voltage control switched into service	a solid three phase short circuit fault at the connection point for 140ms

8). To demonstrate the GBGF-I model is capable of supplying Active ROCOF Response Power and Active Phase Jump Power, under extreme conditions the Grid Forming Plant Owner shall submit a simulation study representing the response of the Grid Forming Plant. To demonstrate the performance of the Grid Forming Plant under these conditions, the simulation study shall represent the following scenario. The case is for the export mode only.

a) The User or Non-CUSC Party in respect of GBGF-I should supply a simulation study to The Company equivalent to Figure B-2 (referred to ECP.A.3.9.5 in GC).

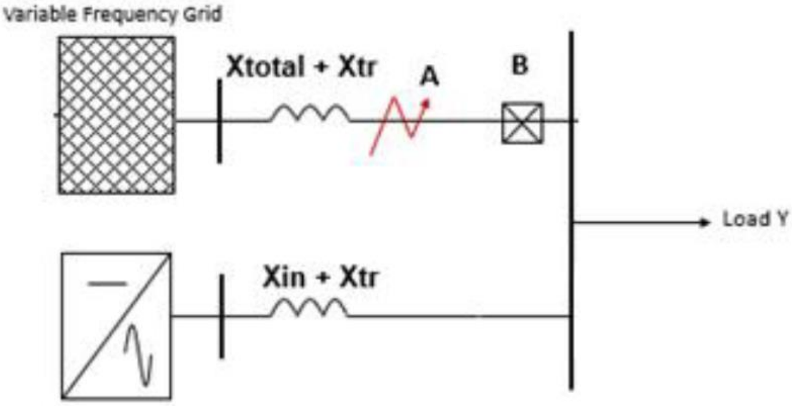


Figure B-2 : a Simulation Network for Simulation 8

b) In this simulation (as shown in Figure ECP.A.3.9.5) the parameters of the variable frequency Grid shall be supplied by The Company. The Load Y is also defined by The Company.

c) With the system running in steady state the GBGF-I and the variable frequency AC Grid should each be running at load Y/2 with the System Frequency of the test network being 50Hz. All control actions (e.g., Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control) should be disabled.

d) With the system in steady state, apply a solid (zero impedance) three phase short circuit fault at point A of Figure ECP.A.3.9.3 and then open circuit breaker B, 140ms after the fault has been applied.

e) Record traces of Active Power, Reactive Power, voltage and System Frequency and record for a period of time after fault inception after allowing conditions to stabilise.

	Initial condition	Control mode		Event
Simulation 7	Y/2 output, zero MVAr output	Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control should be disabled	variable frequency Grid shall be supplied by The Company. The Load Y is also defined by The Company	a solid three phase short circuit fault at the connection point for 140ms, then open circuit breaker B

9) To demonstrate the Grid Forming Plant model is capable of contributing to Active Damping Power, the GBGF-I owner is required to supply a simulation study by injecting a Test Signal in the time domain into the model of the GBGF-I. The GBGF-I model should take the equivalent form shown in either Figure ECP.A.3.9.6(a) or Figure ECP.A.3.9.6(b) as applicable. Each User or NonCUSC Party can use their own design, that may be very different to Figure B-3 (refer to Figures ECP.A.3.9.6(a) or ECP.A.3.9.6 (b) in GC) but should contain all relevant functions. In either case the following tests should be completed, and results supplied to verify the following criteria:

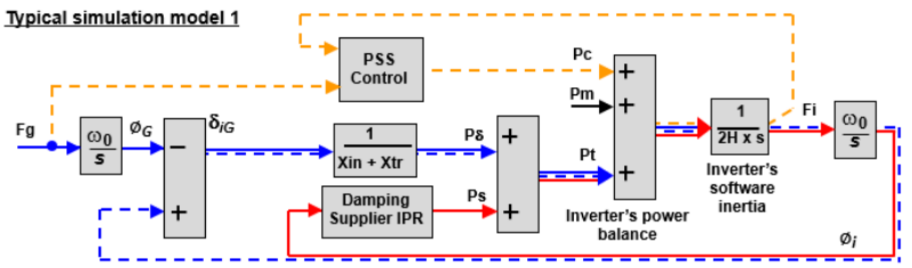


Figure ECP.A.3.9.6(a)

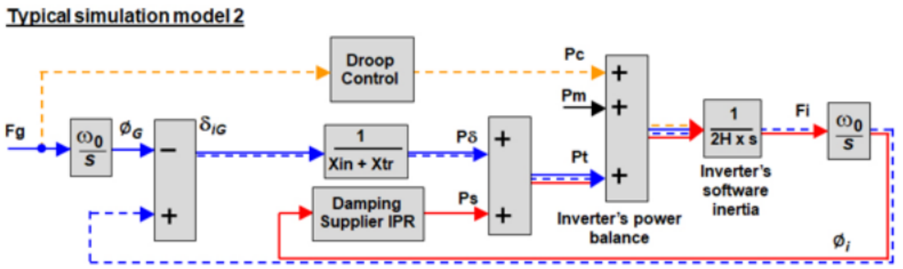


Figure ECP.A.3.9.6(b)

Figure B-3: Typical Simulation Model

a). Demonstration of Damping by injecting a Test Signal in the time domain at the Grid Oscillation Value and frequency into the model of the GBGF-I . An acceptable performance will be judged when the result matches the NFP Plot declared by the Grid Forming Plant Owner as submitted in PC.A.5.8.1(i)

b) Test a) is repeated with variations in the frequency of the Test Signal. An acceptable performance will be judged when the result matches the NFP Plot declared by the Grid Forming Plant Owner as submitted in PC.A.5.8.1(i).

c) Demonstration of phase based Active Control Output Power (or Pc) by injecting a Test Signal into the Grid Forming Plant controller to demonstrate that the Active Control Based Power output is supplied below the 5Hz bandwidth limit. An acceptable performance will be judged where the overshoot and decay matches the Damping Factor declared by the Grid Forming Plant Owner as submitted in PC.A.5.8.1 in addition to assessment against the requirements of CC.A.6.2.6.1 or ECC.A.6.2.6.1 or CC.A.7.2.2.5 or ECC.A.7.2.5.2 as applicable.

	Initial condition	Voltage Control mode	Frequency control mode	Event
Simulation 8.1	at 90% full load for both export and import and zero MVAr output	Disable	Disable both FSM and LFSM	injecting a Test Signal in the time domain at the Grid Oscillation Value and frequency into the model of the GBGF-I
Simulation 8.2	at 90% full load for both export and import and zero MVAr output	Disable	Disable both FSM and LFSM	variations in the frequency of the Test Signal
Simulation 8.3	at 90% full load for both export and import and zero MVAr output	Disable	Disable both FSM and LFSM	injecting a Test Signal into the Grid Forming Plant controller

10). SSCI Simulations

Interaction phenomena in AC grids is becoming more and more common mainly due to conventional synchronous generation being replaced with non-synchronous converter connected generation and consequently not much electrical damping is available in the system, therefore, SSCI simulations may be required to demonstrate the possibility of having controller interactions with a connected AC grid. (SSCI may also expected to be covered by The Factory Acceptance Test (FAT)). In order to find the possibility of interactions among different devices in AC grid, it is suggested to carry out controller interaction study in early phase of the project so that appropriate mitigation measures can be taken in early stages to avoid delays in project execution.

Controller Interactions can occur in frequencies ranging from sub-synchronous (<50Hz) to super synchronous(>50Hz). In literature, controller interactions in sub- synchronous ranges has been named as sub-synchronous controller interactions (SSCI) while interactions that give rise to super synchronous frequencies are called harmonic instability.

There are currently many different screening methods and full-scale study techniques that can be used to identify any potential for controller interactions in an AC grid. Those techniques use time domain and frequency domain studies to conclude the possibility of controller interactions.

There are many techniques that can be used to investigate the possibility of interactions, for example:

- • Limited time domain simulations
- • Active frequency scans

• • Eigen value method (optional)

Simulation 9.1 Limited time domain simulations

EMT time domain simulations are the best way to explore any possibility of interaction that may exist between different devices in AC grid. However, full scale EMT study with detailed modelling of AC grid is not available, therefore, limited time domain simulation study should be run to investigate if scheme has any possibility to interact with connected AC grid.

For purpose of limited time domain study, AC grid is represented as Thevenin equivalent. Frequencies in SSCI range are injected in an AC grid to see the behaviour of a scheme under study. Ideally the scheme under study should provide positive damping to frequency of oscillation.

A simple example of such a representation in PSCAD is shown in diagram below.

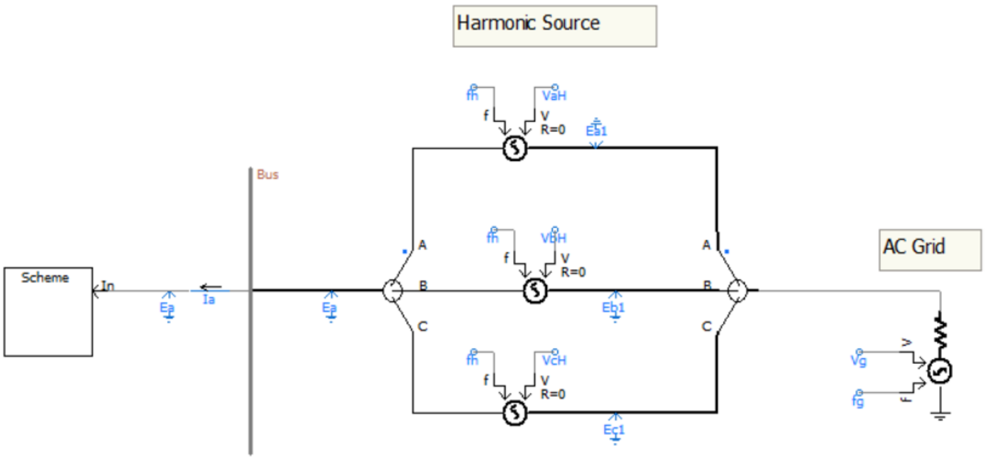


Figure B-4 : Expected study setup for limited time domain study

Test Parameters:
1. Frequencies ranging from 1Hz to 49Hz shall be injected with difference of not more than 1Hz between them. For example frequency injection signal can be set up as 1Hz, 2Hz, 3Hz….
2. Amplitude of injected signal is 1% of nominal voltage.

Test Scenarios:
3. As a minimum, the test cases should be done with both minimum and maximum SCL conditions.
4. Test should cover all different configuration of the scheme.
5. Test should be performed for all control modes of scheme under study i.e. voltage control, reactive power control and power factor control
6. Test should be run at 10%, 50% and 100% power levels.

Report
7. Simulation study results include Vac, f, Qac, Pac, Iac magnitude and phase plots at point of common coupling. Simulations should be run until no further change in output is observed.
8. Summary and observation on results

Simulation 9.2 Active Frequency Scans

It is understood that full scale time domain simulation of an AC grid with accurate representation of all generators with actual control system is not available to study at this stage. Moreover, it is not practical to study all scenarios in small time step. Therefore, to support the limited time domain interaction study active network frequency scans are used.

In order to do this study, scheme under study are represented as EMT model while AC grid is represented a Thevenin equivalent. A small harmonic current of frequencies of interest are injected in the scheme under study. The impedance of the scheme under study are measured by performing Fourier transform on Voltage (V) and current (I) signal.

Typical expected study setup is shown below:

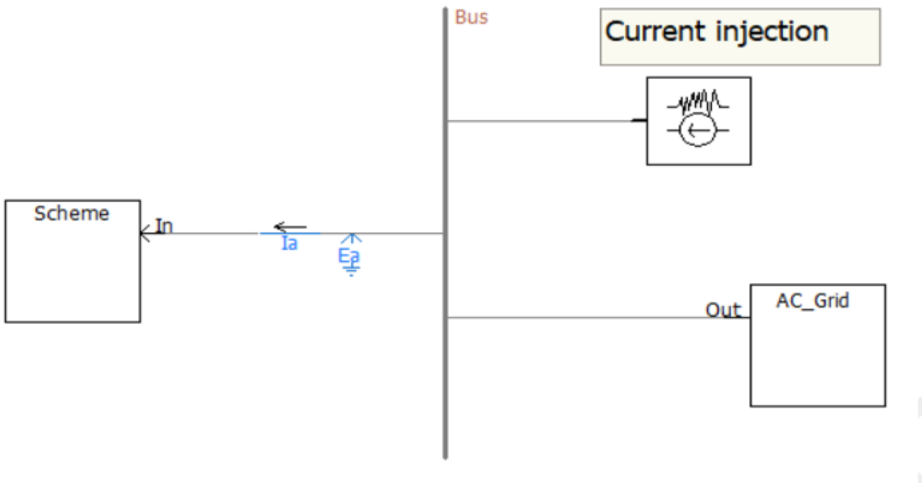


Figure B-5: Typical Model for the Frequency Scan

After obtaining the frequency scans of the scheme under study the stability of the AC network and the scheme can be analysed.

Test Parameter:

1. Injected current amplitude should not be small enough to be lost in noise and should not be large enough to cause any non- linear effects.
2. Frequency increment should be reasonable so that no impedance vs frequency information is lost.

Test Scenarios:

3. It is recommended that such frequency scan should be done for frequency ranges from 0 to 2.5kHz or for the frequency range of interest with reasonable current magnitude and frequency increment.
4. As a minimum, the test cases should be performed with both minimum and maximum SCL conditions.
5. Test should cover all different configuration of the scheme.
6. Test should be performed for all control modes of scheme under study i.e. voltage control, reactive power control and power factor control
7. Test should be run at 10%, 50% and 100% power levels.

Report:

8. Scheme impedance (R&X vs F plot)
9. Summary and observation on results

Simulation 9.3 Eigenvalue Method

Eigenvalue method is another approach of calculating the oscillation modes, frequency of oscillation and damping co-efficient. It is becoming one of the main approaches for the investigating interaction phenomena and apply mitigation measures.

This is a frequency domain study, but still full-scale model representation is required for scheme under study. In this methodology state space representation of system under study and connected AC grid represented as Thevenin equivalent are used to determine the Eigenvalues of the full system.

In past it has been considered as complicated method to estimate state space representation and the finding an eigenvalues but nowadays this functionality has been included in power system tools which solves state space solution and provides oscillation modes, frequency of oscillation and damping co-efficient very quickly.

In order to validate the studies, it is recommended that frequency of oscillations obtained from Eigenvalue method should be compared with frequency of oscillations observed in study methods described earlier or vice versa.

Test Scenarios:

1. As a minimum, the test cases should be done with both minimum and maximum SCL conditions.
2. Test should cover all different configuration of the scheme.
3. Test should be performed for all control modes of scheme under study i.e. voltage control, reactive power control and power factor control.
4. Test should be run at 10%, 50% and 100% power levels.

Report:

5. Oscillation frequencies of the scheme under study.
6. Eigenvalue results comparison with frequency scan and limited time domain study.
7. Summary and observation on results.

Appendix C Test Requirements

Summary of Requirements

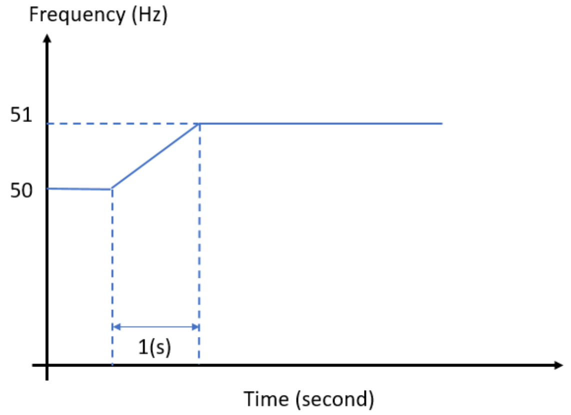
Appendix 9 outlines the general Grid Forming testing requirements for Users or Non-CUSC Parties to demonstrate compliance with the relevant aspects of the Grid Code, Ancillary Services Agreement and Bilateral Agreement.

This section details the procedure for demonstrating Active ROCOF Response Power. Ideally if the test is being completed as part of a type test on an isolated network and it is possible to change the frequency of the isolated network then the tests should be completed using a variable network Frequency. The Company recognise that it is not possible in a large number of cases to adjust the network frequency of the network to which the Grid Forming Plant is connected. If a suitable test network is not available, performance of the GBGF-I will need to be demonstrated through online monitoring as detailed in CC.6.6 or ECC.6.6 and simulation studies as required under ECP.A.3.9.4 will be required during the Interim Operational Notification Process as provided for under CP.6 or ECP.6 (as applicable).

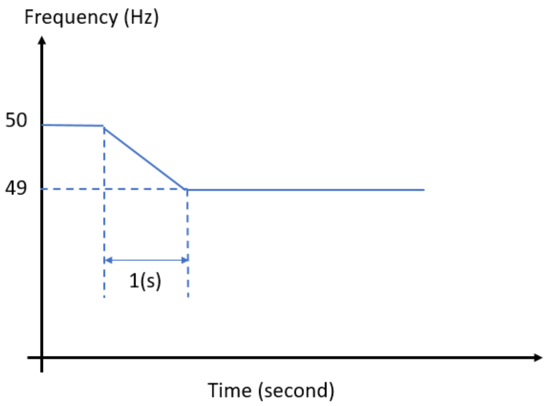
Test 1: Assess Correct Operation of the Grid Forming Plant Without Saturating

In this test, with the Grid Forming Plant initially running at full load, the test network frequency is ideally increased from 50Hz to 51 Hz at a rate of 1Hz/s with measurements of the Grid Forming Plant's Active ROCOF Response Power, System Frequency and time in (ms). The test is required to assess correct operation of the Grid Forming Plant without saturating. This test is then repeated for a 50 Hz to 49 Hz at a rate of 1Hz/s

	Initial condition	Voltage Control mode	Frequency control mode	Frequency increase
Test 1.1	at full load	Enable	Disable both FSM and LFSM	from 50Hz to 51 Hz at a rate of 1Hz/s
Test 1.2	at full load	Enable	Disable both FSM and LFSM	50 Hz to 49 Hz at a rate of 1Hz/s



Test 1.1



Test 1.2

Test 2 : Assess the Grid Forming Plant's Withstand Capabilities under Extreme System Frequencies

These tests are required to assess the Grid Forming Plant's **withstand capabilities** under extreme System Frequencies.

(a) For Grid Forming Plant comprising a GBGF-I the frequency of the test network is increased from 50Hz to 52Hz at a rate of 2Hz/s with measurements of the Grid Forming Plant's Active ROCOF Response Power, System Frequency and time in (ms).

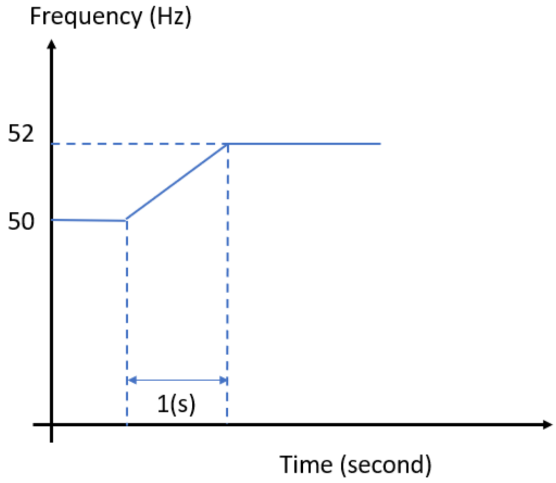
(b) (ii) For a Grid Forming Plant comprising a GBGF-I the frequency of the test network is increased from 50Hz to 52Hz at a rate of 1Hz/s with measurements of the Grid Forming Plant's Active ROCOF Response Power, System Frequency and time in (ms).

(c) For Grid Forming Plant comprising a GBGF-I the frequency of the test network is decreased from 50Hz to 47 Hz at a rate of 2Hz/s with measurements of the Grid Forming Plant's Active ROCOF Response Power, System Frequency and time in (ms).

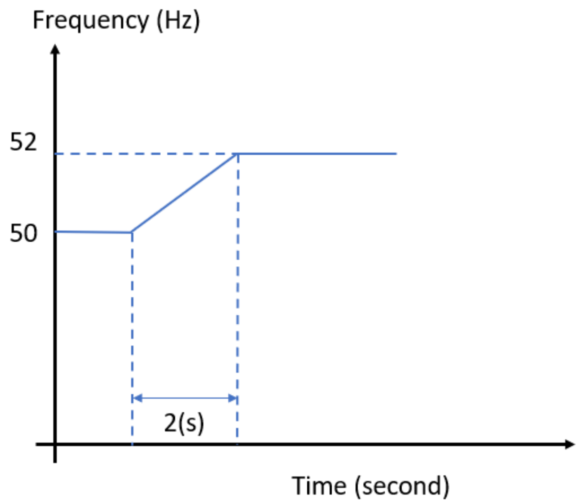
(d) For Grid Forming Plant comprising a GBGF-I the frequency of the test network is decreased from 50Hz to 47 Hz at a rate of 1Hz/s with measurements of the Grid Forming Plant's Active ROCOF Response Power, System Frequency and time in (ms).

(e)

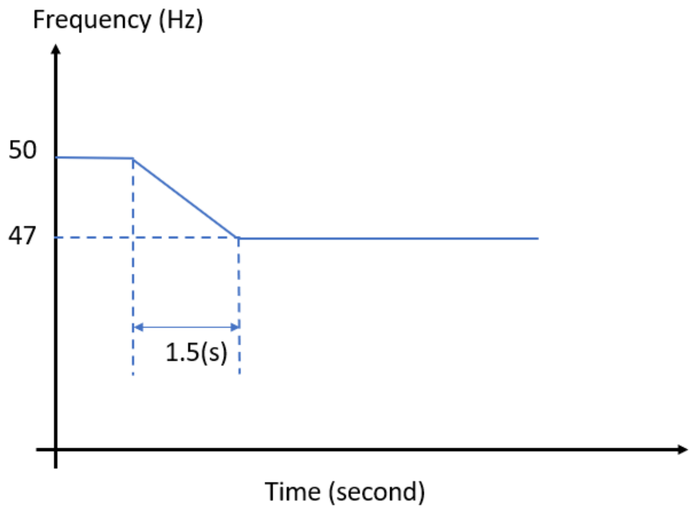
	Initial condition	Voltage Control mode	Frequency control mode	Frequency increase
Test 2.1	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 2Hz/s
Test 2.2	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 1Hz/s
Test 2.3	at full load	enable	Disable both FSM and LFSM	From 50Hz to 47 Hz at a rate of 2Hz/s
Test 2.4	at full load	enable	Disable both FSM and LFSM	From 50Hz to 47 Hz at a rate of 1Hz/s



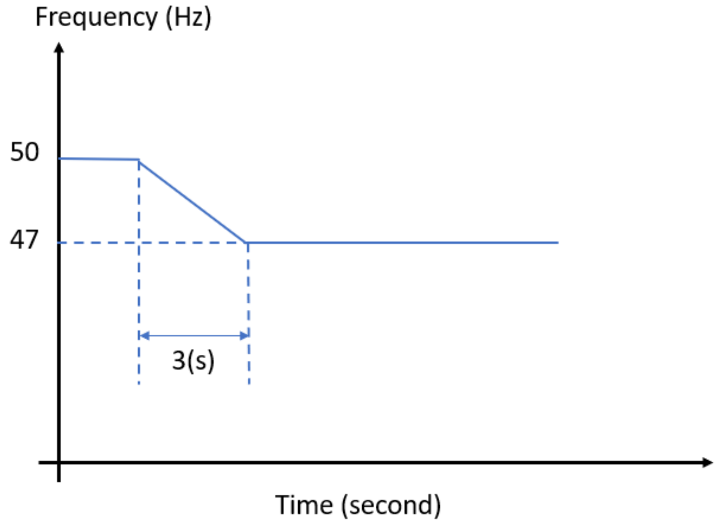
Test 2.1



Test 2.2



Test 2.3



Test 2.4

Test 3 : Assess the Grid Forming Plant's Ability to Supply Active ROCOF Response Power Over the Full System Frequency range.

This test is to demonstrate the Grid Forming Plant's ability to supply Active ROCOF Response Power over the full System Frequency range.

(a) With the frequency of the test network set to 50Hz, the GBGF-I should be initially running at 75% Maximum Capacity or Registered Capacity, zero MVAr output and both Limited Frequency Sensitive Mode and Frequency Sensitive Mode disabled. FRT are in service.

(b) The frequency is then increased from 50Hz to 52Hz at a rate of 1Hz/s over a 2 second period. Allow conditions to stabilise for 5 seconds and then decrease the frequency from 52Hz to 47Hz at a rate of 1Hz/s over a 5 second period. Allow conditions to stabilise.

(c) Record results of Active ROCOF Response Power, Reactive Power, voltage and frequency.

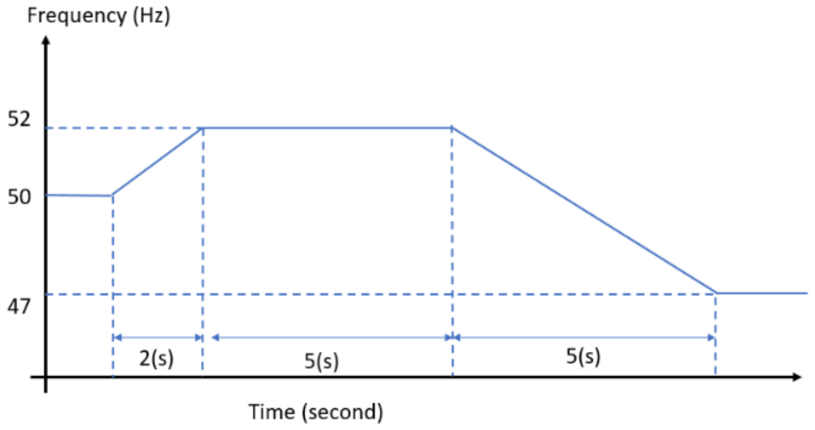
(d) The test now needs to be re-run in the opposite direction. The same initial conditions should be applied as per ECP.A.9.1.9.4(a).

(e) The frequency is then decreased from 50Hz to 47Hz at a rate of 1Hz/s over a 3 second period. Allow conditions to stabilise for 5 seconds and then increase the frequency from 47Hz to 52Hz at a rate of 1Hz/s over a 5 second period. Allow conditions to stabilise.

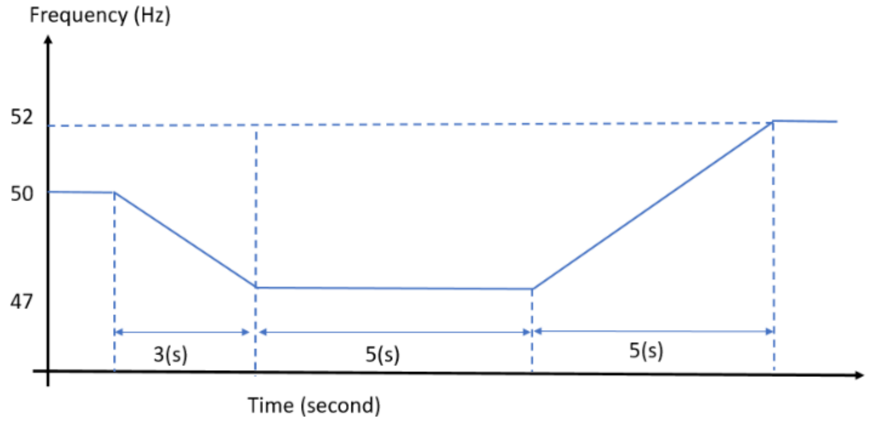
(f) Record results of Active ROCOF Response Power, Reactive Power, voltage and frequency.

(g)

	Initial condition	Voltage Control mode	Frequency control mode	Frequency Change
Test 3.1	at 75% full load for both export and import and zero MVAr output	enable	Disable both FSM and LFSM	



	Initial condition	Voltage Control mode	Frequency control mode	Frequency Change
Test 3.2	at 75% full load for both export and import and zero MVAr output	enable	Disable both FSM and LFSM	



Test 4: Assess the Grid Forming Plant's Ability to Supply Active Phase Jump Power under normal operation

This test is to demonstrate the Grid Forming Plant's ability to supply **Active Phase Jump Power under normal operation**.

(a) With the frequency of the test network set to 50Hz, the GBGF-I should be initially running at Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output and all control actions (e.g. Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control) disabled. FRT are in service.

(b) Apply a positive phase jump of up to the Phase Jump Angle Limit (5 degree as recommended) at the Grid Entry Point or User System Entry Point (if Embedded).

(c) This test can then be repeated by injecting the same angle into the Grid Forming Plant's control system as shown in the "PJ test" point (as indicatively shown in Figure C-1 referred to (Figure ECP.A.9.1.9.5 in GC)). This specific test can be repeated on site as required for a routine performance evaluation test. It should be noted that Figure ECP.A.9.1.9.5 is a simplified representation. Each Grid Forming Plant Owner can use their own design, that may be very different to Figure ECP.A.9.1.9.5 but should contain all relevant functions that can include test points and other equivalent data and documentation. Any additional signals, measurements, parameters and tests shall be agreed between the Grid Forming Plant Owner and The Company.

(d) Repeat tests (b) and (c) with a negative injection up to the Phase Jump Angle Limit.

(e) Record traces of Active Power, Reactive Power, voltage, current and frequency for a period of 10 seconds after the step change in phase has been applied.

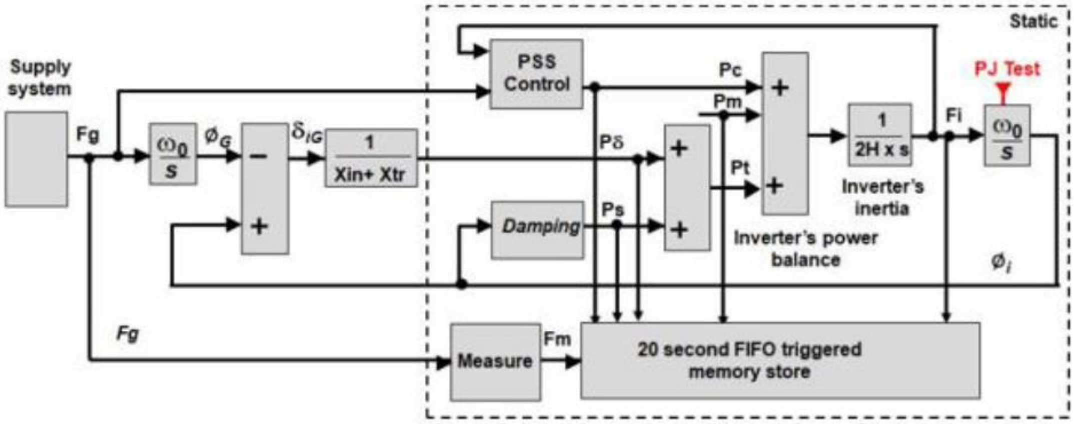


Figure C-1: An Example of Test Model

As part of these tests, the corresponding Active Power change resulting from a phase shift will be a function of the local reactance and the location of where the phase shift is applied in addition to any additional upstream impedance between the GBGF-I and phase step location.

	Initial condition	Voltage Control mode	Frequency control mode	Event
Test 4.1	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output for both export /import mode	Disable	Disable both FSM and LFSM	Apply a positive phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record tracks for 10s
Test 4.2	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output for both export /import mode	Disable	Disable both FSM and LFSM	Apply a positive phase jump of up to the Phase Jump Angle Limit into the Grid Forming Plant's control system and record tracks for 10s
Test 4.1	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output for both export /import mode	Disable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record tracks for 10s
Test 4.2	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output	Disable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit

	for both export /import mode			into the Grid Forming Plant's control system and record tracks for 10s

Test 5 : Assess the Grid Forming Plant's Ability to Supply Active Phase Jump Power under extreme conditions

This test is to demonstrate the Grid Forming Plant's ability to supply Active Phase Jump Power under extreme conditions. Where it is not possible to undertake this test as part of a type test, The Company will accept demonstration through a combination of simulation studies as required under ECP.A.3.9.4(vi) and online monitoring as required under ECC.6.6.1.9.

(a) With the frequency of the test network set to 50Hz, the Grid Forming Plant should be initially running at its Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output and all control actions (e.g., Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control) disabled. FRT is in service.

(b) Apply a phase jump of 60 degrees at the connection point (or PJ-test Point) of the GBGF-I or into the Grid Forming Plant's control system as shown in Figure ECP.A.9.1.9.5.

(c) Record traces of Active Power, Reactive Power, voltage, current and frequency for a period of 10 seconds after the step change in phase has been applied.

(d) Repeat steps (a), (b) and (c) of ECP.A.9.1.9.6 but on this occasion apply a phase jump equivalent to the positive Phase Jump Angle Limit (5 degree as recommended)at the Grid.

	Initial condition	Voltage Control mode	Frequency control mode	Event
Test 5.1	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output	Disable	Disable both FSM and LFSM	Apply a phase jump of 60 degrees at the connection point of the GBGF-I
Test 5.2	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output	Disable	Disable both FSM and LFSM	apply a phase jump equivalent to the positive Phase Jump Angle Limit at the Grid.

Test 6 : Assess the Grid Forming Plant's Ability to Supply Active Phase Jump Power, Fault Ride Through and GBGF Fast Fault Current Injection during a faulted condition

This test is to demonstrate the GBGF-Is ability to supply Active Phase Jump Power, Fault Ride Through and GBGF Fast Fault Current Injection during a faulted condition. Where it is not possible to undertake this test as part of a type test, The Company will accept demonstration through a combination of simulation studies as required under ECP.A.3.9.4(vii) and online monitoring as required under CC.6.6 and ECC.6.6.1.9.

(a) With the frequency set to 50Hz, the Grid Forming Plant should be initially running at its Maximum Capacity or Registered Capacity or at an alternative loading point as agreed with The Company, zero MVAr output and all control actions (e.g., Limited Frequency Sensitive Mode, Frequency Sensitive Mode and voltage control including FRT) disabled. Fault ride through, GBGF Fast Fault Current Injection should be disabled.

(b) Apply a solid three phase short circuit fault at the connection point in the test network forming part of the type test for 140ms or alternatively the equivalent of a zero retained voltage for 140ms.

(c) Record traces of Active Power, Reactive Power, voltage, current and frequency for a period of 10 seconds after the fault has been applied.

(d) Repeat steps (a) to (c) but on this occasion with fault ride through, GBGF Fast Fault Current Injection Limited Frequency Sensitive Mode and voltage control switched into service.

(e) Record traces of Active Power, Reactive Power, voltage, current and frequency for a period of 10 seconds after the step change in phase has been applied and confirm correct operation. ECP.A.9.1.9.8

	Initial condition	Voltage Control mode	Frequency control mode	Event
Test 6.1	Maximum output, zero MVAr output for both export and import	Disable	Disable both FSM and LFSM	a solid three phase short circuit fault at the connection point for 140ms
Test 6.2	Maximum output, zero MVAr output for both export and import	Enable	Disable FSM only	a solid three phase short circuit fault at the connection point for 140ms

Test 7 : Assess the Grid Forming Plant's Ability to contribute Active Damping Power

The final test required is to demonstrate the GBGF-I is capable of contributing to Active Damping Power. The Grid Forming Plant Owner should configure their Grid Forming Plant in form or equivalent (as agreed with The Company) as shown in Figure ECP.A.3.9.6(a) or Figure ECP.A.3.9.6(b) as applicable. Each Grid Forming Plant Owner can use their own design, that may be very different to Figures ECP.A.3.9.6(a) or ECP.A.3.9.6 (b) but should contain all relevant functions. As part of this test, the Grid Forming Plant Owner is required to inject a signal into the Grid Forming Plant controller. The results supplied need to verify the following criteria:-

Inject a Test Signal into the Grid Forming Plant controller to demonstrate the Active Control Based Power output is supplied below the 5Hz bandwidth limit An acceptable performance will be judged where the overshoot or decay matches the Damping Factor declared by the Grid Forming Plant Owner as submitted in PC.A.5.8.1 in addition to assessment against the requirements of CC.A.6.2.6.1 or ECC.A.6.2.6.1 or CC.A.7.2.2.5 or ECC.A.7.2.5.2 as applicable.

	Initial condition	Voltage Control mode	Frequency control mode	Event
Test 7.1	at 90% load and zero MVAr output with minimum fault level	Disable	Disable both FSM and LFSM	Inject a Test Signal into the Grid Forming Plant controller

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
nationalgrideso.com

nationalgridESO