Guidance Notes for Grid Forming Plant

EU Code Users - Issue 1

September 2023

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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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 Droop Power	The Active Control Based Power output supplied by a Grid Forming Plant through controlled means (be it manual or automatic). For GBGF-I this is equivalent to a Synchronous Generating Unit with a traditional governor coupled to its prime mover. Active Control Based Droop Power is used by The Company to control System Frequency changes through the instruction of Primary Response and Secondary Response.
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	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	The injection or absorption of Active Power by a Grid Forming Plant to or from the Total System during a deviation of the System Frequency away from the Target Frequency. For a GBGF-I 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 this can rapidly inject or absorb Active Power in addition to the phase-based Active Inertia Power to provide a system with desirable NFP plot characteristics. Active Frequency Response Power can be produced by any viable control technology.
Active Inertia Power or Inertia Power	The injection or absorption of Active Power by a Grid Forming Plant to or from the Total System during a System Frequency change.

	Definitions
	The transient injection or absorption of Active Power from a Grid Forming Plant to the Total System as a result of the ROCOF value at the Grid Entry Point or User System Entry Point. This requires a sufficient energy storage capacity of the Grid Forming Plant to meet the Grid Forming Capability requirements specified in ECC.6.3.19. For the avoidance of doubt, this includes the rotational inertial energy of the complete drive train of a Synchronous Generating 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 Phase Jump Power	The transient injection or absorption of Active Power 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 (within 5ms) inject or absorb Active Phase Jump Power to the Total System as a result of the phase angle change. For GBGF-I 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 5 ms and can have frequency components of over 1000 Hz.
Control Based Reactive Power	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 Figure PC.A.5.8.1(a) and PCA.5.8.1(b) in Grid Code.
Grid Forming Capability	Is (but not limited to) the capability 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. As a consequence, Plant and Apparatus which has a Grid Forming Capability has a frequency of rotation of the Internal Voltage Source which is the same as the System Frequency for normal operation, with only the Load

	Definitions
	Angle defining the relative position between the two. In the case of a GBGF-I, a Grid Forming Unit forming part of a GBGF-I 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 GBGF-I, 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 requirement are only allowed during transients caused by System faults, voltage dips/surges and/or 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 Fast Fault Current Injection	The ability of a Grid Forming Plant to supply reactive current, that starts to be delivered into the Total System in less than 5ms when the voltage falls below 90% of its nominal value at the Grid Entry Point or User System Entry Point.
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
Inertia Constant H	For a GBGF-S the Inertia Constant H is measured in MWsec/MVA.
Inertia Constant He	For a GBGF- I Electronic Power Converter the Inertia Constant He, is measured in MWsec/MVA and produced by the Active ROCOF Response Power.
Internal Voltage Source or IVS	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 (which is often referred to as the Electro Motive Force (EMF)) in the stationary generator winding that has a real 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 there must be an impedance with only real physical values, 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

	Definitions
	GBGF-I.
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.
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.
Peak Current Rating	For a GBGF-I this is the larger of either the: - • The registered maximum steady-state current plus the maximum additional current to supply the Active ROCOF Response Power plus the Defined Active Damping Power; or. • The registered maximum steady-state current plus the maximum additional current to supply the Phase Jump Angle limit power, or. This is the maximum short term total current as declared by the Grid Forming Plant Owner in accordance with PC.A.5.8.1.
Phase Jump Angle	The difference in the measured phase angle of the voltage at the Grid Entry Point or User System Entry Point 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 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 change when applied to a GBGF-I which will result in the GBGF-I 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.
Voltage Jump Reactive Power	The transient Reactive Power injected or absorbed from a Grid Forming Plant to the Total System as a result of either a step or ramp change in the difference between the voltage magnitude and/or phase of the voltage of the Internal Voltage Source of the Grid Forming Plant and Grid Entry Point or User System Entry Point.

	Definitions
	In the event of a voltage magnitude and phase change at the Grid Entry Point or User System Entry Point, a Grid Forming Plant will instantaneously (within 5ms) supply Voltage Jump Reactive Power to the Total System as a result of the voltage magnitude change.
RoCoF	Rate of Change of System Frequency.

Introduction

This document is produced by Electricity System Operator (ESO) and provides additional details 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 were covered by other published Guidance Documents.

The aim of this GB Grid Forming Guide is to provide the necessary guidance on the Compliance Process of Grid Forming technology following 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. In addition, further guidance is available in the Grid Forming Best Practice Guide which is available from https://www.nationalgrideso.com/document/278491/download.

A Grid Forming plant could be included within (but 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). Irrespective of which type of plant is installed with a Grid Forming capability, the key characteristic is that the 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. 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 out of service, the other controllers' performance are not expected to be impacted. Such a capability is 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 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 Electricity Storage Modules and HVDC systems, the simulation and tests need to cover both export and import mode.

Point of Compliance

In concept, Grid Forming defines the boundary at which compliance is demonstrated at the Grid Entry Point or User System Entry Point. This is the ownership boundary between the Grid Forming Plant and transmission system. This is often the termination point in compact switchgear owned by a network licence and a short cable owned by the Grid Forming Plant. In practical terms, if the cable has negligible impact on performance, then metering for Grid Forming Plant and signals for compliance assessment can be at the end of this short cable of 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 dynamic monitoring facility, in accordance with the requirements of ECC.6.6.1.2 or an alternative solution (as agreed with The Company) to accurately record the following parameters at a rate of 10ms:

1). System Frequency using a nominated algorithm as defined by The Company.

2). The ROCOF rate using a nominated algorithm as defined by The Company based on a 500ms rolling average.

3). 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.

Detailed specifications 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 and TS.3.24.70.

Simulation Studies

The simulation studies for Grid Forming Plant 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 for 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:

I. demonstrate an expected performance ahead of connection.
II. demonstrate the model supplied is a true and accurate reflection of the plant, as built.
III. 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 an ION can be issued.

Grid Forming Data Submission

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

a). Each GBGF-I shall be designed so as not to interact with or 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 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.

b). 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) as shown in the Appendix A. When submitting the equivalent linear classical block diagram model (using the Laplace Operator), each User or Non-CUSC Party can use their own design, which may be different to that in Figures PC.A.5.8.1 (a) and PC.A.5.8.1 (b). However, the block diagram should contain all relevant functions in simulation models and other equivalent data and documentation.

c). In order to participate in the Grid Forming Capability market, User and Non-CUSC Parties are required to provide data of their GBGF-I according to Figures PC.A.5.8.1(a) and PC.A.5.8.1(b). Users and Non-CUSC Parties should indicate if the data is submitted on a unit or aggregated basis. Table PC.A.5.8.1(a) as shown in the Appendix A defines the notation used in Figure PC.5.8.1.

d). In order to participate in a Grid Forming Capability market, User and Non-CUSC Parties are also required to provide the data of their GBGF-I according to 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.

Protection Requirements

A 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 withstand without tripping at ROCOF up to and including 2 Hz per second as measured over a rolling 500 milliseconds period.

All other Power Generating Modules when connected and synchronised to the System, shall be able to withstand without tripping at ROCOF up to and including 1 Hz per second as measured over a rolling 500 milliseconds period. Voltage dips may cause localised ROCOF value in excess of 1 Hz per second (or 2Hz/s in the case of Power Park Modules with a Grid Forming Capability) for short period. and in these cases, the requirements under ECC.6.3.15 (fault ride through) supersedes this clause. For the avoidance of doubt, this requirement only relates to the capabilities of Power Generating Modules and does not impose a need of ROCOF protection or 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 for GBGF Plant

a). 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).

b). Each GBGF-I shall comprise an Internal Voltage Source and impedance. For the avoidance of doubt, the impedance between the Internal Voltage Source and Grid Entry Point or User System Entry Point (if Embedded) within the Grid Forming Plant can only be made by a combination of several physical discrete impedances. This could include the impedance of the Synchronous Generating Unit or Power Park Unit or HVDC System or Electricity Storage Unit or Dynamic Reactive Compensation Equipment and the electrical Plant and Apparatus connecting the Synchronous Generating Unit or Power Park Unit or HVDC System or Electricity Storage Unit (such as a transformer) to the Grid Entry Point or User System Entry Point (if Embedded).

(c) In addition to meeting the requirements of 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).

(d) 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.

(e) GBGF plant must satisfy the requirements of ECC.6.3.19.5, referred to as the GBGF Fast Fault Current Injection

(f) GBGF plant must be capable of operating at a minimum Short Circuit level of zero MVA at the Grid Entry Point or User System Entry Point.

(g) GBGF plant must be capable of 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. Such requirements will be pursuant to the terms of the Bilateral Agreement. For the avoidance of doubt, this requirement is in addition to the minimum quality of supply requirements detailed in CC.6.1.5, CC.6.1.6 and CC.6.1.7 (as applicable) or ECC.6.1.5, ECC.6.1.6 and ECC.6.1.7 (as applicable),

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

(a) 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). In satisfying these requirements, User and Non-CUSC Parties should be aware of (but not limited to) the exclusions in CC.6.3.3, CC.6.3.7 and BC3.7.2.1 (as applicable to GB Code Users) or ECC.6.1.2, ECC.6.3.3, ECC.6.3.7 and BC3.7.2.1(b)(i) (as applicable to EU Code Users and Non-CUSC Parties) during System Frequencies between 47Hz – 52Hz, excluding CC.6.1.3 or ECC.6.1,2.1,2 for a Grid Forming Plant with time limited output ratings. For the avoidance of doubt, an asymmetrical response is permissible as agreed with The Company when required to protect Users and Non-CUSC Parties Plant and Apparatus or asymmetry in energy availability.

(b) Operating as a voltage source behind an equivalent impedance.

(c) 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.

(d) Including 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.

(e) Meeting the requirements of ECC.6.3.13 irrespective of being owned or operated by a GB Code User, an EU Code User or a Non-CUSC Party.

(f) 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, referring to Figure ECC.6.3.19.3 in Grid Code. 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.

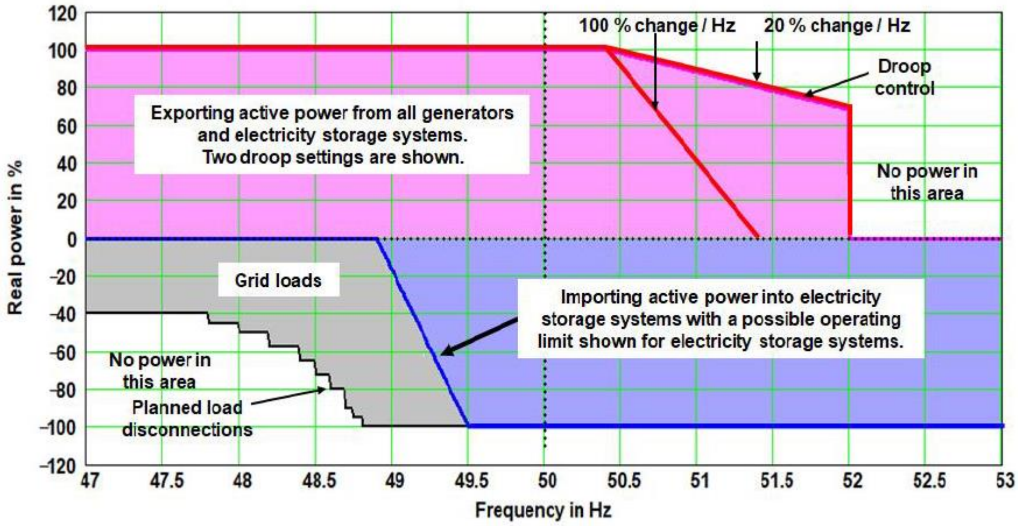


Figure 1: Frequency Response Operating Characteristic

(g) 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 is in line with that of a standard second order system with the same equivalent Damping Factor.

(h) Each GBGF-I shall be designed so as not to interact with or 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 needs to meet the requirements of Fault Ride Through 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 needs to meet the Fast Current Injection requirement referred to ECC.6.3.19.5.

Under 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. 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 Grid Code 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 ECC.16.3.19.5(a). 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.

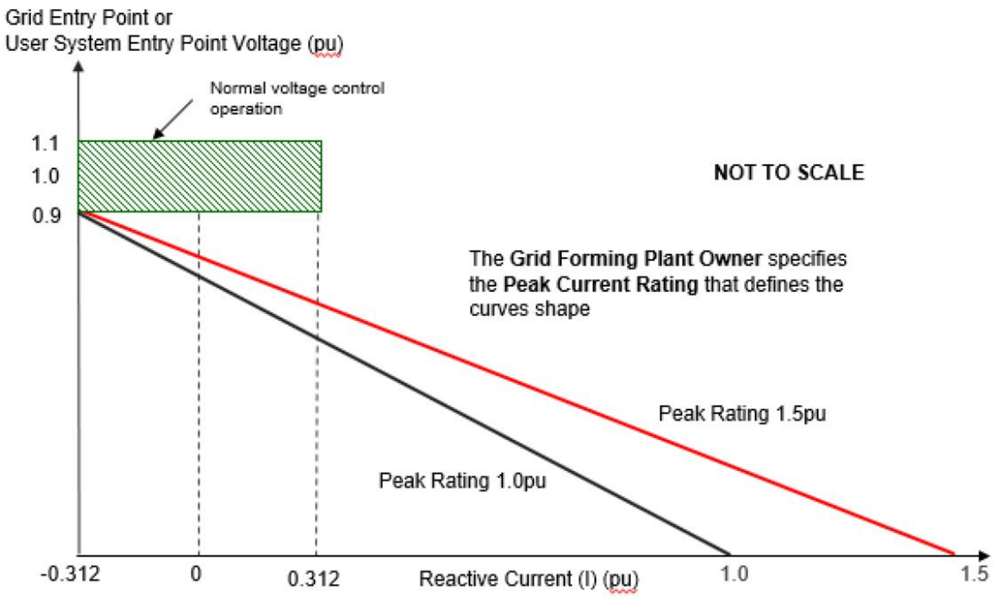


Figure 2: Injected Reactive Current Requirement

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 greater than its pre-fault reactive current and which shall as a minimum, increase each time the voltage at the Grid Entry Point or User System Entry Point (if Embedded) falls below 0.9pu while ensuring the overall rating of the Grid Forming Plant (or constituent element thereof) shall not be exceeded.

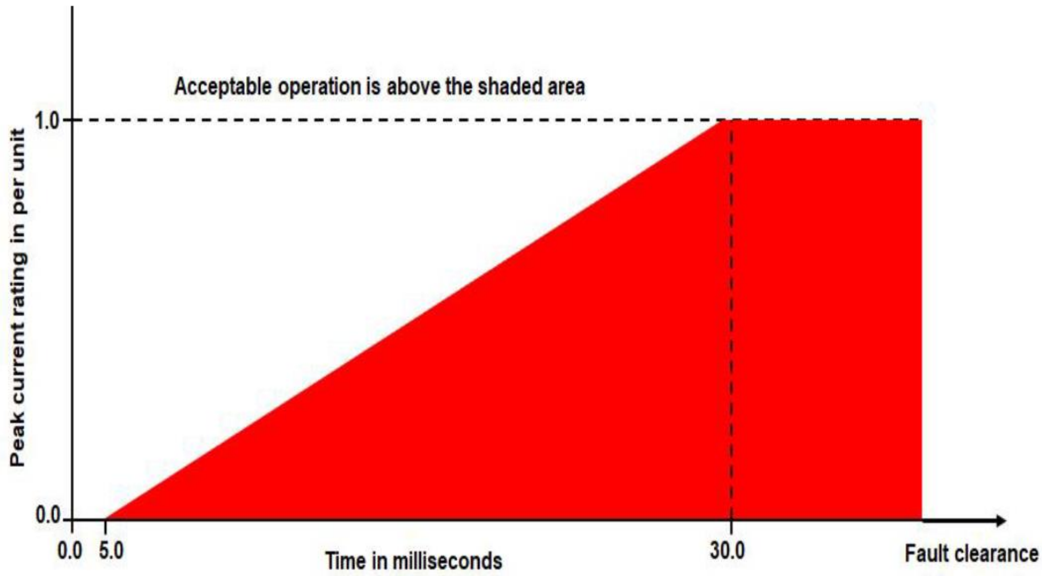


Figure 3: Acceptable Operation of Injected Reactive Current

The injected current shall be above the shaded area shown in Figure 3 referred to ECC.6.3.19.5(b) in Grid Code 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. Under any faulted condition, where the voltage falls outside the limits specified in CC.6.1.4 or ECC.6.1.4 (as applicable), there will be no requirement for each Grid Forming Plant or constituent part to exceed its transient or steady state rating as defined in Table PC.A.5.8.2.

For any planned or switching events (as outlined in CC.6.1.7 or ECC.6.1.7 of the Grid Code) or unplanned events which results in Temporary Power System Over Voltages (TOV's), each Grid Forming Plant will be required to satisfy the transient overvoltage limits specified in the Bilateral Agreement. Therefore, 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.

Each Grid Forming Plant shall be designed to ensure a smooth transition between Voltage Control mode and Fault Ride Through mode to prevent the risk of instability which could arise in the transition between the steady state voltage operating range as defined under CC.6.1.4 or ECC.6.1.4 (as applicable) and abnormal conditions where the retained voltage falls below 90% of nominal voltage. Such a requirement is necessary to ensure adequate performance between the pre-fault operating condition of the Grid Forming Plant and its subsequent behaviour under faulted conditions. Grid Forming Plant Owners are required to both advise and agree with The Company the control strategy employed to mitigate the risk of such instability.

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.

In addition to the requirements of CC.6.3.15 or ECC.6.3.15, 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 each time the voltage at the Grid Entry Point or User System Entry Point falls outside the limits specified in CC.6.1.4 or ECC.6.1.4 (as applicable). Grid Forming Plant Owners should inform The Company of the maximum number of repeated operations that can be performed under such conditions and any limiting factors to repeated operation such as protection or thermal rating.

In the case of a Power Park Module or DC Connected Power Park Module, where it is not practical to demonstrate the compliance requirements of GBGF Fast Fault Current Injection at the Grid Entry Point or User System Entry Point, The Company will accept compliance of the above requirements at the Power Park Unit terminals.

In the case of an unbalanced fault, each Grid Forming Plant, is 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 in the case of an unbalanced fault, the User or Non-CUSC Party shall confirm to The Company their ability to prevent transient over-voltages arising on the remaining healthy phases and the control strategy employed.

Model Validation

Before The Company issues an ION, the User must provide a validated model . Validation can be carried out by cross-checking the test results from other comparable sites, from Factory Acceptance Tests of comparable equipment, or from Type Tests. This is to confirm that the responses shown by the models are representative of the Users Plant and Apparatus.

Factory Acceptance Testing is to be implemented to provide the benchmark data for validating the submitted model. . Tests should generally include steady state Reactive Power capability, Voltage Control, Fault Ride Through and Frequency Response. If any of these tests show discrepancies between the models and the actual Users Plant and Apparatus, the User shall provide updated models, supporting documentation and associated data to prove and ensure the consistency between the models and the actual Users Plant and Apparatus .

In the event that The Company identifies, through lifetime monitoring (OC5), that models are not representative of the User's Plant and Apparatus, The Company shall notify the User. The User shall provide revised models, supporting documentation and associated data whose response is representative of the Users Plant and Apparatus as soon as reasonably practicable, and 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 recognises that it is not possible in most 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 are also expected to be covered. The test results can be used as the benchmark data to validate the model functions. The compliance engineers will advise the extent of the testing to be carried out.

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, the results required, the relevant Grid Code clause(s) and the criteria to be assessed are given in ECP.A.9. The Grid Forming Plant Owner is responsible for drafting test procedures for the Plant as part of the compliance process. These should be submitted for review, prior to an Interim Operational Notification (ION) being issued. 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 shall 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 list of signals generated by the compliance tests is issued to the ESO for review. The scope of signals is set out in ECP.A.4 for EU Code Users.

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

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

(i) 1 Hz for reactive range tests

(ii) 10 Hz for frequency control tests

(iii) 100 Hz for voltage control tests

(iv) 1 kHz for Grid Forming Plant signals including fast fault current measurements.

(v) 100Hz for the other Grid Forming Plant tests carried out in accordance with ECC.6.6.1.9

Co-located Site

n the case of a co-located site, for example Electricity Storage Modules connected within a new or existing Power Station, The Company will accept test results to demonstrate compliance at the Grid Entry Point or User System Entry Point (if Embedded) through a combination of the capabilities of the Power Generating Modules (which could include Grid Forming Plant) and Electricity Storage Modules or Electricity Storage Modules (which could include a Grid Forming Plant) and Generating Units or Power Park Modules. Generators should however be aware that for the purposes of testing, 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. In the case of a Synchronous Electricity Storage Module, The Company would expect the full set of tests to be completed as detailed in ECP.A.5.2 to ECP.A.5.9.

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 the nature of the proposed tests at the earliest stage possible and were possible with 28 days notice. If there is insufficient notice period or information provided by the Grid Forming Plant 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.5.8.1in Grid Code 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.

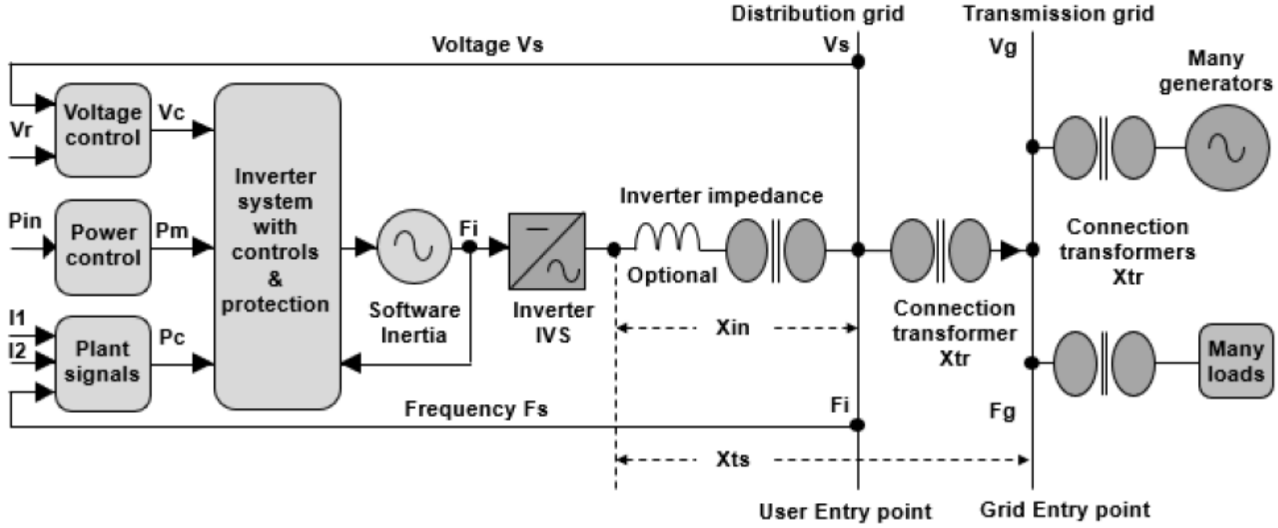


Figure A-1 : Example of Grid Forming Plant

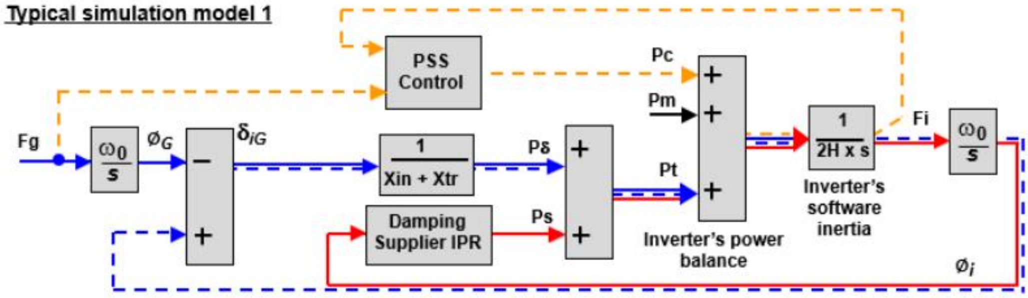


Figure PC.A.5.8.1 (a) Preferred simplified diagram of a **GBGF-I** with a **Power System Stabiliser** "**PSS**" that can add damping to the **GBGF-I**'s closed loop function shown by the solid red line and the dotted blue line.

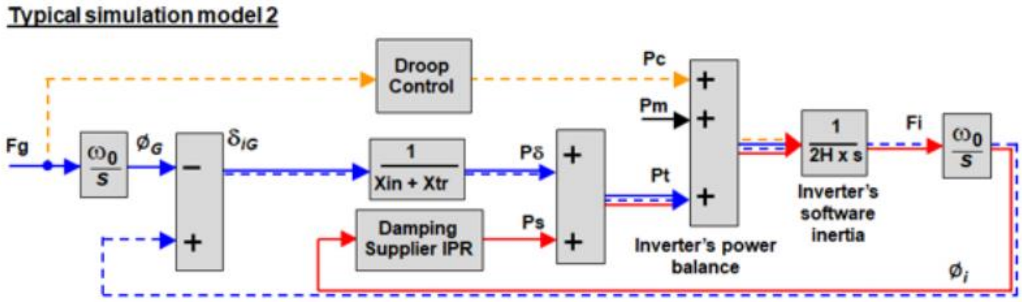


Figure PC.A.5.8.1 (b) – Preferred simplified diagram of a system with a droop control ability that can add **Control-Based Active Droop Power**. This diagram does not add extra closed loop damping to the **GBGF-I's** closed loop function shown by the solid red line and the dotted blue line.

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

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

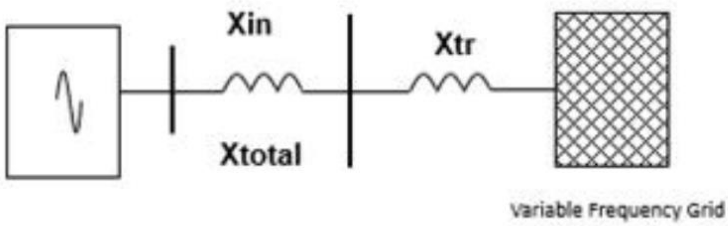
Grid Code ECP.A.3.9.

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.

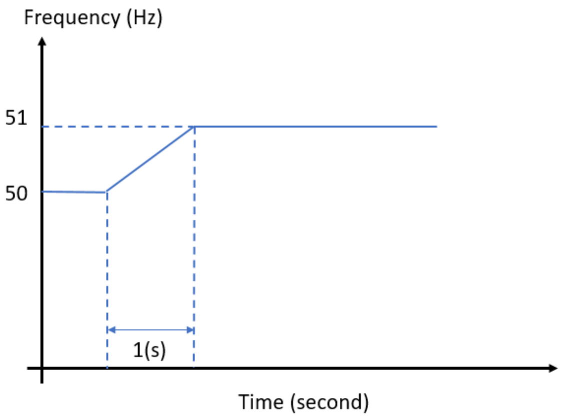
1). A simulation study to the equivalent shown in Appendix B-1 (referred to Figure ECP.A.3.9.4 in GC).



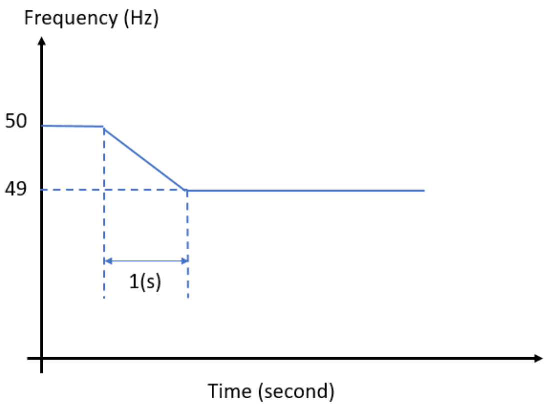
Appendix B-1: Studied Network

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



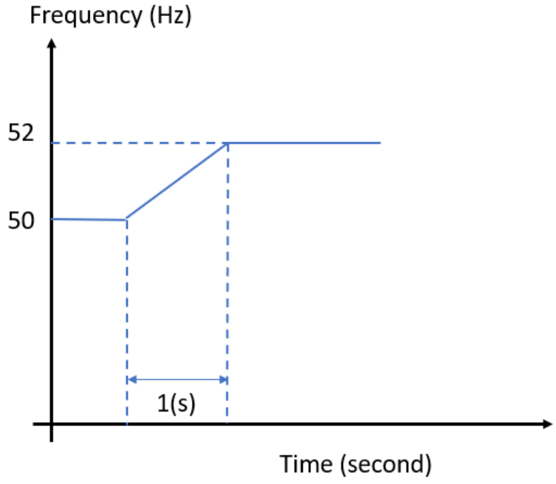
Simulation 1.1



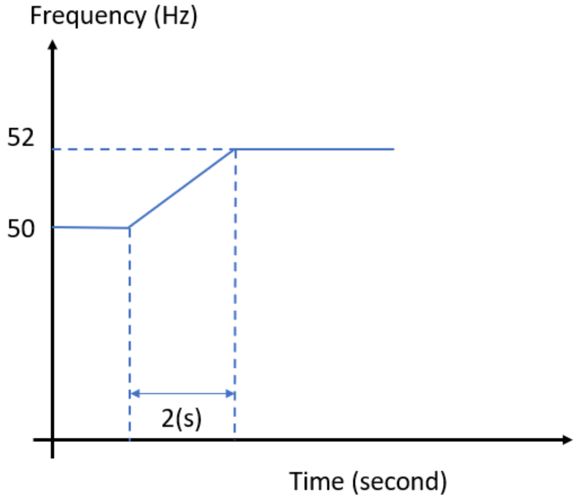
Simulation 1.2

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.

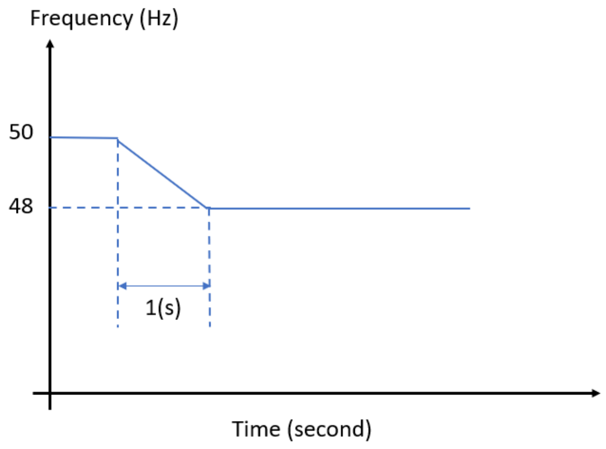
	Initial condition	Voltage Control mode	Frequency control mode	Frequency increase
Simulation 2.1	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 2Hz/s
Simulation 2.2	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 1Hz/s
Simulation 2.3	at full load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



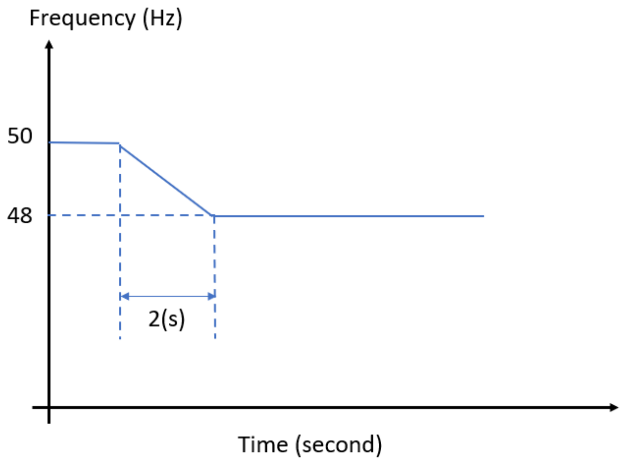
Simulation 2.1



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).

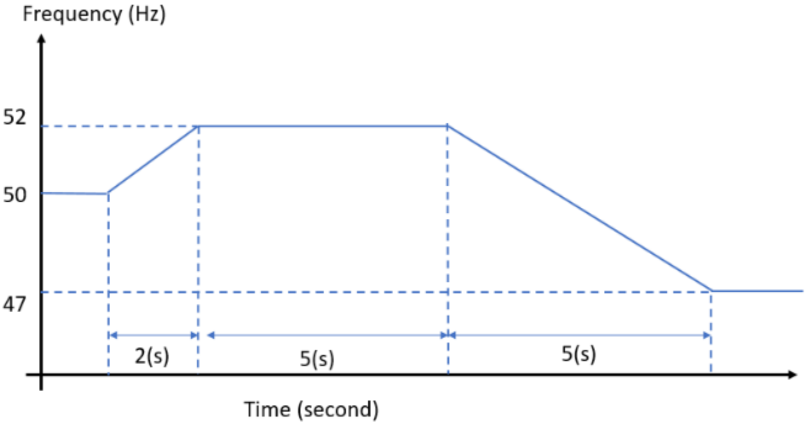
(e) The System Frequency is then decreased from 50Hz to 47Hz at a rate of 1Hz/s over a 3 second period. Allow conditions to stabilise for 5 seconds and then increase the System Frequency from 47Hz to 52Hz at a rate of 1Hz/s over a 5 second period. Allow conditions to stabilise.

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

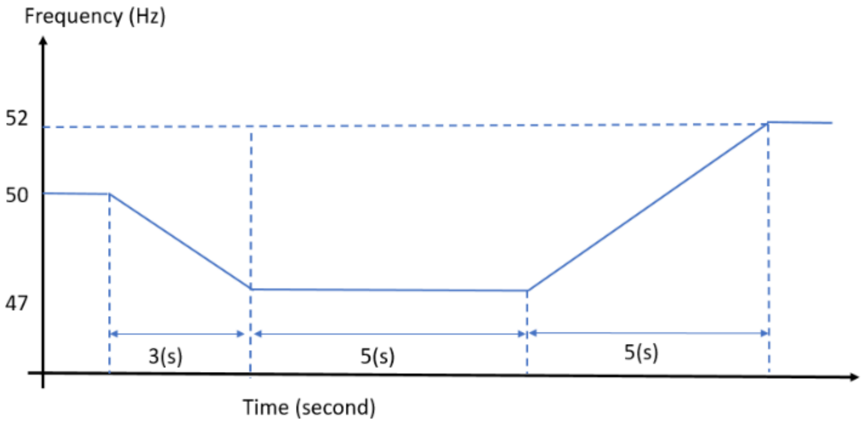
(g) The simulation is required to ensure the Grid Forming Plant can deliver Active ROCOF Response Power without going into saturation and that a behaviour that is equivalent to pole slipping does not occur.

(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 output for both export and import	Disable	Disable both FSM and LFSM	apply a phase jump equivalent to the negative Phase Jump 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).

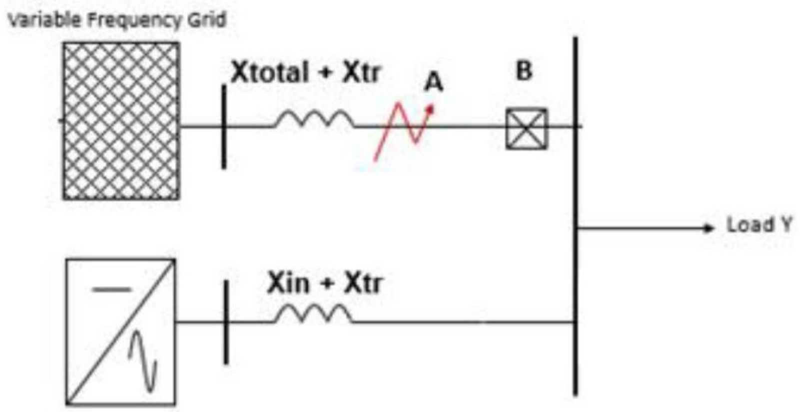


Figure B-2 : a Simulation Network for Simulation 8

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 Non-CUSC 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:

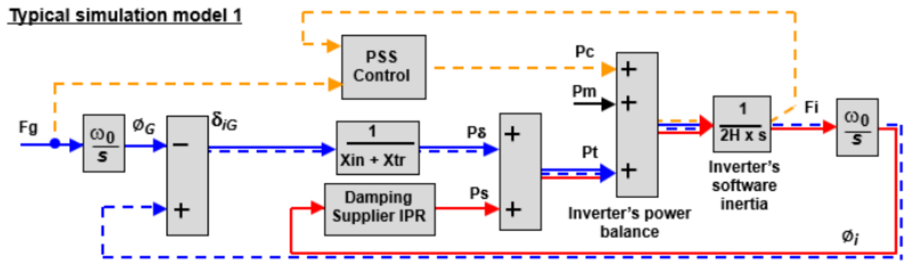


Figure ECP.A.3.9.6(a)

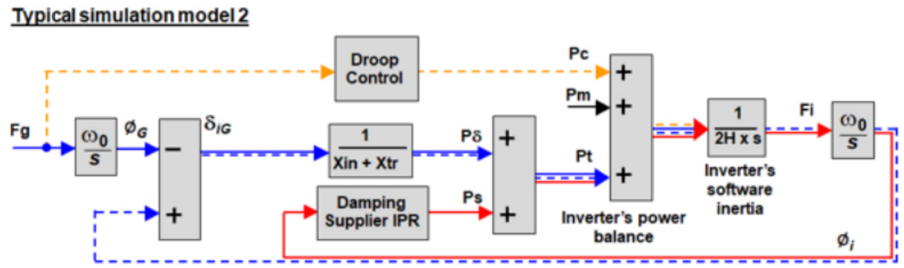


Figure ECP.A.3.9.6(b)

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 the 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.

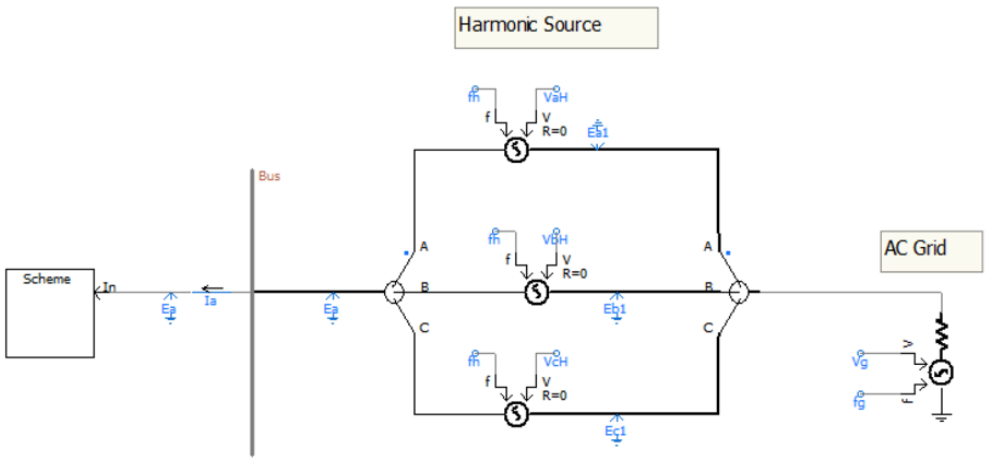


Figure B-4 : Expected study setup for limited time domain study

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:

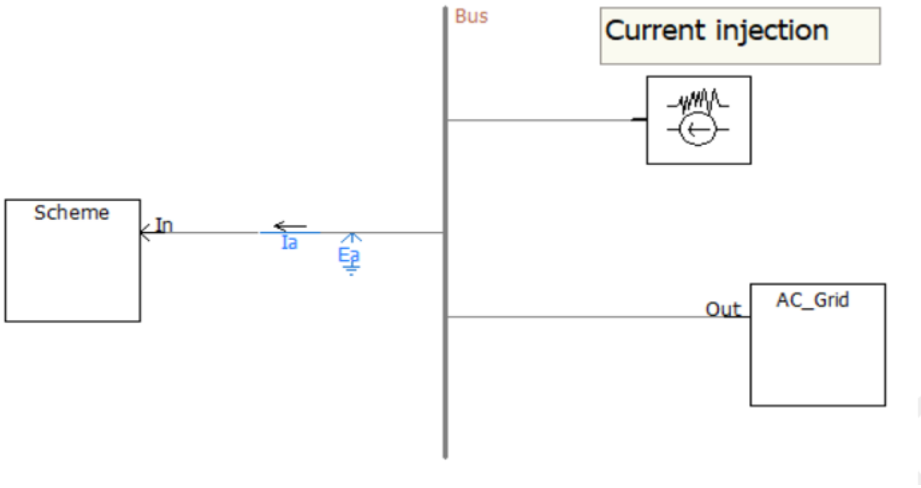


Figure B-5: Typical Model for the Frequency Scan

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

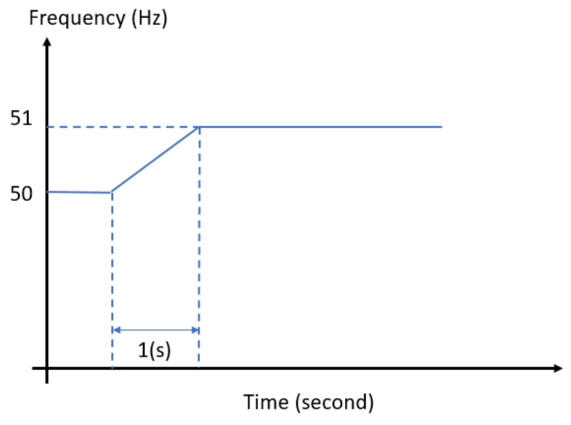
Appendix 9 outlines the general Grid Forming testing requirements for Users or Non-CUSC Parties to demonstrate compliance with the relevant aspects of the Grid Code, Ancillary Services Agreement and Bilateral Agreement.

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).

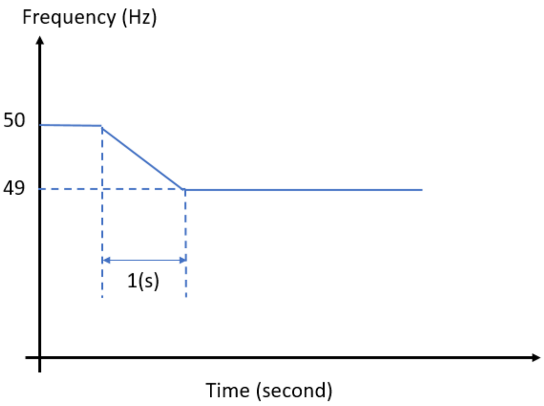
Test 1: Assess Correct Operation of the Grid Forming Plant Without Saturating

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).

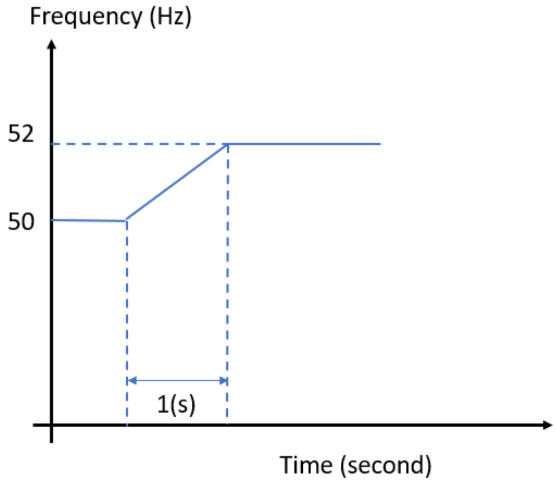
(b) (ii) For a Grid Forming Plant comprising a GBGF-I the frequency of the test network is increased from 50Hz to 52Hz at a rate of 1Hz/s with measurements of the Grid Forming Plant’s Active ROCOF Response Power, System Frequency and time in (ms).

(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).

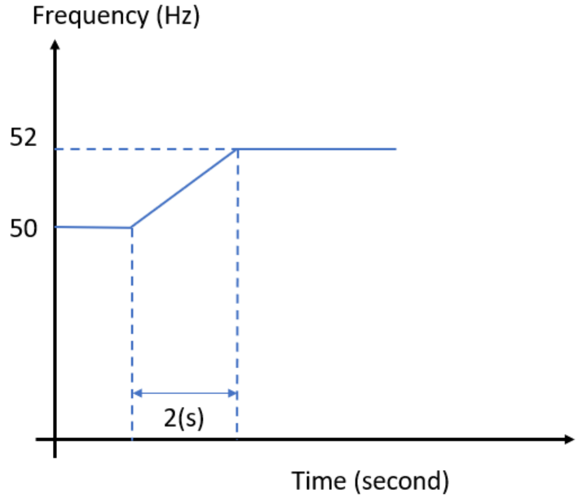
(d) For Grid Forming Plant comprising a GBGF-I the frequency of the test network is decreased from 50Hz to 47 Hz at a rate of 1Hz/s with measurements of the Grid Forming Plant’s Active ROCOF Response Power, System Frequency and time in (ms).

(e)

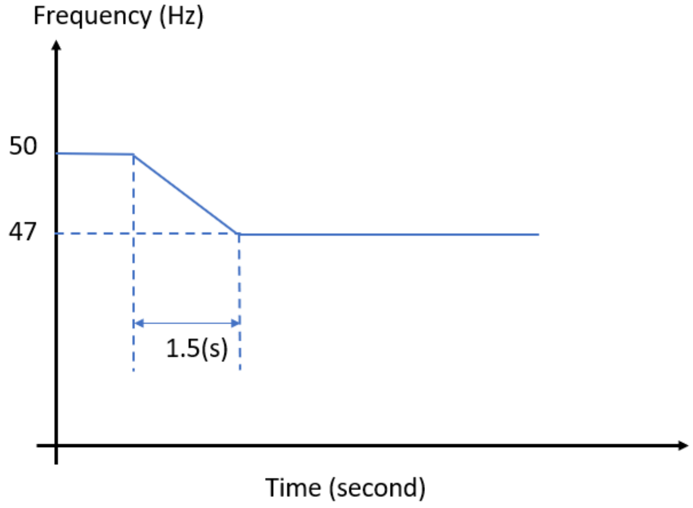
	Initial condition	Voltage Control mode	Frequency control mode	Frequency increase
Test 2.1	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 2Hz/s
Test 2.2	at full load	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 1Hz/s
Test 2.3	at full load	enable	Disable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



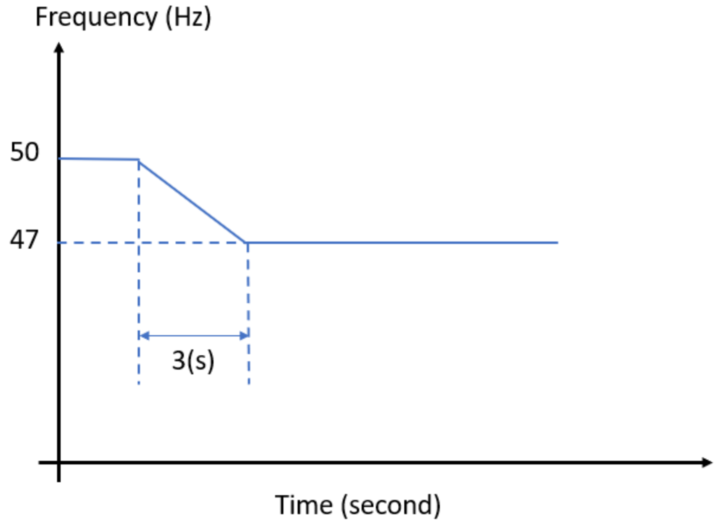
Test 2.1



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.

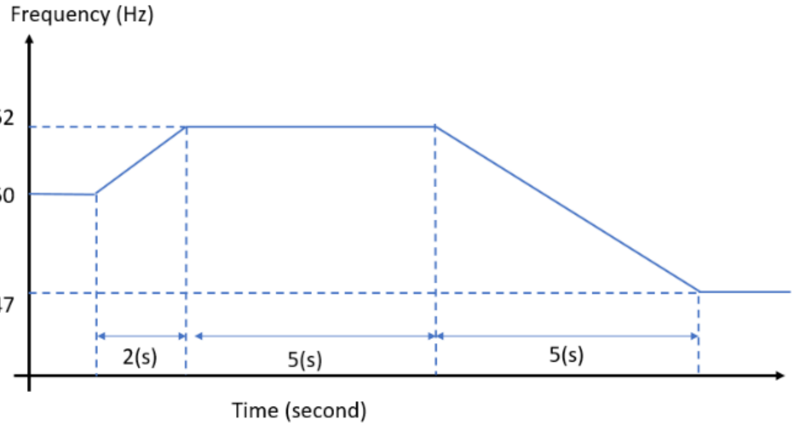
(d) The test now needs to be re-run in the opposite direction. The same initial conditions should be applied as per ECP.A.9.1.9.4(a).

(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.

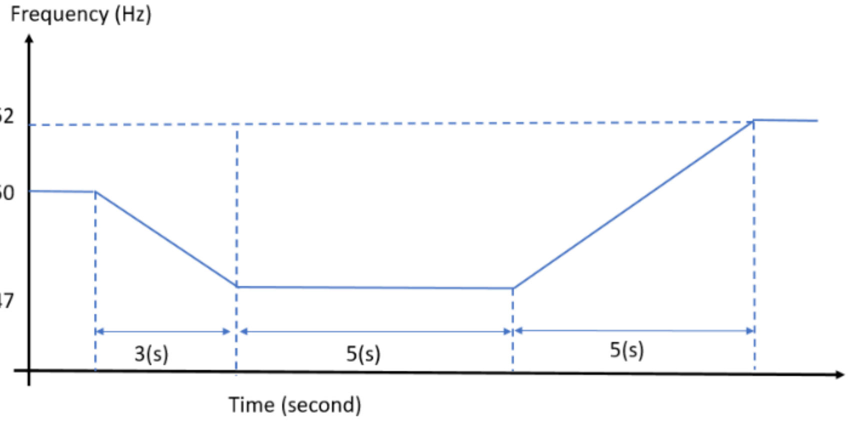
(f) Record results of Active ROCOF Response Power, Reactive Power, voltage and frequency.

(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.

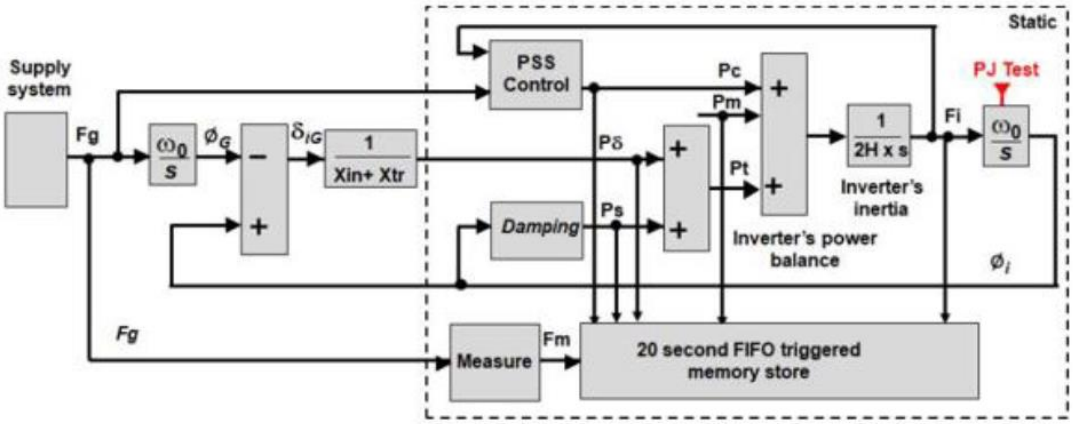


Figure C-1: An Example of Test Model

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 for both export /import mode	Disable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit 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.

(e)

	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 D: Contacting National Grid ESO

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

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

Contact Address:

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

Faraday House, Warwick Technology Park,
Gallows Hill, Warwick, CV346DA
nationalgrideso.com