Grid Forming Guidance Note

Issue 4

NESO
National Energy System Operator

Contents

Introduction

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

This Guidance Note is based on the Grid Code, Issue 6, Revision 36, 12 December 2025. It reflects the major changes brought about by Grid Code modification GC0137 as approved by the regulator in February 2022 and the removal of the Virtual Impedance restriction through Grid Code modification GC0163 as approved in July 2024.

The major changes relative to Issue 3 are outlined in the table below and the update is flagged by a "V4" indicator.

	Major Changes made in V4
1	A new section for the Compliance Process for Commercial Services who hold Commercial Service Contracts.
2	Corrections have been made to drawing errors in Figure 3: Acceptable Operation of Injected Apparent Current.
3	Clarify additional simulation requirements to define the Peak Current Rating value
4	Clarify the system initial conditions for ROCOF simulations and tests
5	Clarify the pass criteria for ROCOF simulations and tests
6	Clarify the system initial conditions for Phase Jump Angle simulations and tests
7	Clarify the pass criteria for Phase Jump Angle simulations and tests
8	Clarify the system initial conditions for FRT simulations and tests
9	Simplify the required data in DRC 20

An Expert Working Group is currently formulating recommendations in preparation for a formal Grid Code Modification. The objective of this Expert Group is to modify and clarify various clauses, tests, and definitions, drawing on insights gained from practical experience. Among the topics under discussion are the clarification and simplification of definitions such as Active ROCOF Response Power, Active Control Based Droop Power, and Active Control Based Power; simplifying

Schedule 20 of the Data Registration Code; and refining the technical requirements relating to Fast Fault Current Injection and Peak Current Rating.

This guidance document can therefore be treated as the interim document before further updates are developed to the Grid Code.

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

The provision of a Grid Forming Service is not a mandatory requirement but one which will be delivered through market arrangements, the details of which shall be published on The Company's Website[1]. 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.

All the Grid Forming Plants are expected to demonstrate the appropriate damping performance against potential system oscillations to ensure the safe operation and stability of the transmission system. Additional details can be found in the following document: Guidance on Oscillation Assessment for Inverter Based Resources (IBRs) Version 2[2] .

General 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). Compliance with supplementary technical requirements outlined in the Commercial Contract or Bilateral Agreement must be demonstrated for Pathfinder Projects which is introduced in the "Compliance Process for the Commercial Service" Section.

The process for Grid Forming Plant 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 Plant should carry out (ECP.A.3.9) and the details of compliance tests applicable to Grid Forming Plant (ECP.A.9.1). For Electricity Storage Modules and HVDC systems, the simulation and tests need to cover both export and import modes.

[1] https://www.neso.energy/industry-information/balancing-services/network-services/stability-network-services.
[2] https://www.neso.energy/document/368341/download.

To ensure clarity, any Grid Forming connection not involved in a commercial contract may be permitted to operate in Grid Forming Mode if all technical requirements are satisfied. However, connections capable of both Grid Forming and Grid Following modes must not switch between these modes unless approval has been granted by NESO. Additional simulations will be required for the Grid Forming plant which is subject to a commercial contract to provide system inertia and short-circuit currents.

V4 Compliance Process for the Commercial Services

NESO must ensure that the system is operated in accordance with the relevant license conditions and as part of this, NESO may procure system services, of which a subset must be provided by Grid Forming Plant- for example Stability Services or Primary Restoration Services.

These are paid-for services awarded on a competitive basis per tender event, under the Network Services umbrella. A condition of award of a commercial service contract through these events may be additional compliance requirements that must be demonstrated by successful completion and demonstration of Grid Code and Contract Service terms prior to service go live.

These additional compliance requirements may be above the minimum requirements set out in the Grid Code. These compliance requirements would be specific to the commercial service for which the plant owner holds the contract, for example specific demonstration of the contracted stability service provision.

Figure 1 is a simplified explanation of how a provider would demonstrate compliance for their service up to go live. For the service to go live, the provider would be required to complete compliance with Grid Code[3] and the terms of the commercial service contract.

[3] The required compliance that must be achieved with the Grid Code will be specified in each individual Network Services contract.

For the service to go live, the provider would have to complete compliance against both the Grid Code and the commercial requirements within the contract. The specific requirements of each contract can be found in the relevant Network Services tender documents.

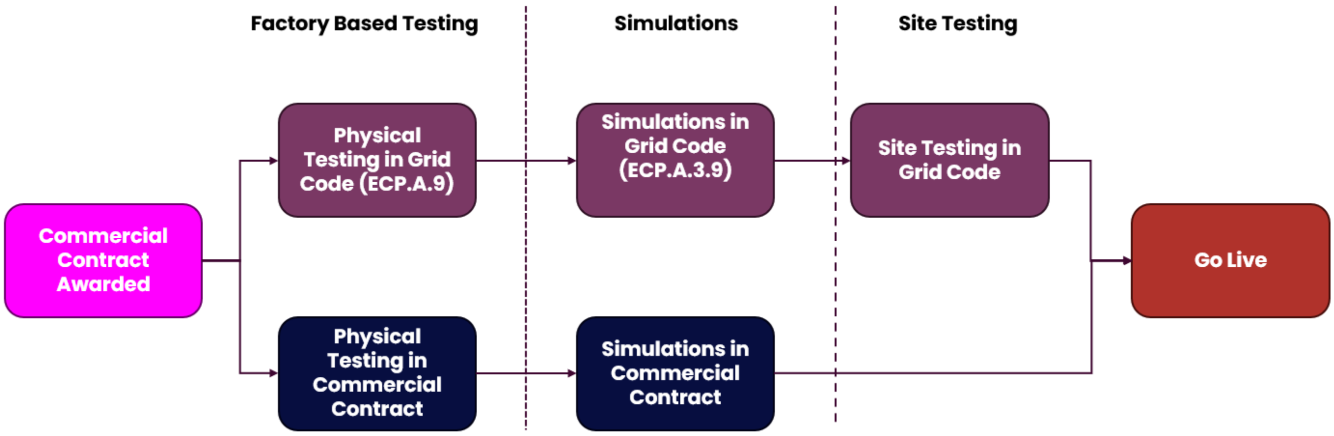

Figure 1: A simplified explanation of the compliance process for commercial services

Point of Compliance

The Grid Entry Point or User System Entry Point (as defined in the Grid Code) defines the boundary at which compliance is demonstrated at the point of connection. This is the ownership boundary between the Grid Forming Plant and the transmission system or the distribution system. This could be the termination point in the Gas Insulated Substation (GIS) owned by a network licensee or a short cable owned by the Grid Forming Plant owner, or in the case of an air insulated substation at the busbar clamps. In practical terms, if the cable has a negligible impact on performance, then metering for Grid Forming Connection systems and signals for compliance assessment can be at the end of the short cable of the Grid Forming Connection. If the cable is considered as having a material effect on performance, then control and signal metering need 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. Where long cables are involved, additional reactive compensation may be required to ensure Grid Code requirements are met in accordance with ECC.6.3.2.3.1.

System Monitoring

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

- System Frequency using a nominated algorithm as defined by The Company
- The ROCOF rate using a nominated algorithm as defined by The Company based on a 500ms rolling average.

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

This requirement only relates to monitoring the performance of the Grid Forming Plant and not the technical capability of the Plant itself. As noted, this is a complex area as measuring phase jumps requires high sampling rates. The Grid Forming Expert Group still needs to do some work on this area but in the absence of a more detailed specification we would require all customers to install a dynamic system monitor in accordance with the requirements of TS.3.24.70[4] unless they decided to develop their own algorithm which would need to be agreed with NESO.

Simulation Studies

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

In general, simulation studies are required to:

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

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

Grid Forming Data Submission

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

- Each User shall be required to submit a Network Frequency Perturbation Plot and Nichols Chart (or equivalent as agreed with The Company) which shall be assessed in accordance with the requirements of ECP.A.3.9.3.

[4] https://www.neso.energy/document/244026/download.

- Each User or Non-CUSC Party is required to supply a high-level equivalent architecture diagram of their Grid Forming Plant as shown in Figure PC.A.5.8.1 together with the equivalent linear classical block diagram model (using the Laplace Operator) of their Grid Forming Plant which should preferably be in the general form shown in Figure PC.A.5.8.1 (a) or Figure PC.A.5.8.1 (b). When submitting either Figure PC.A.5.8.1 (a) or Figure PC.A.5.8.1 (b), each User or Non-CUSC Party can use their own design, that may be very different to Figures PC.A.5.8.1 (a) or PC.A.5.8.1 (b), but should contain all relevant functions that can include simulation models and other equivalent data and documentation.

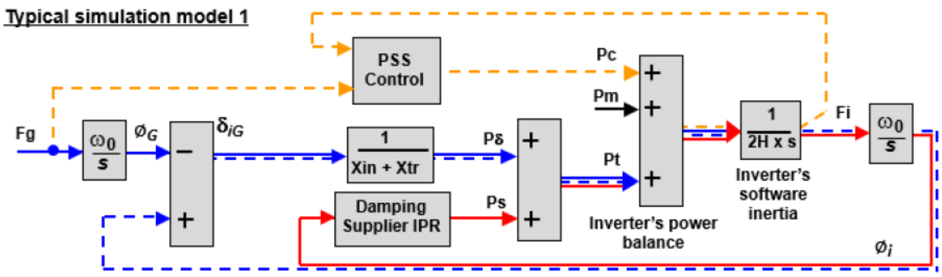

Figure PC.A.5.8.1 (a) Preferred simplified diagram of a **GBGF-I** with a **Power System Stabiliser** "**PSS**" that can add damping to the **GBGF-I**'s closed loop function shown by the solid red line and the dotted blue line.

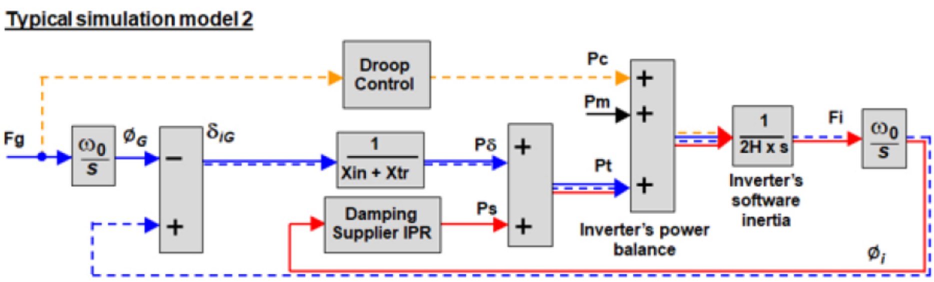

Figure PC.A.5.8.1 (b) – Preferred simplified diagram of a system with a droop control ability that can add **Control-Based Active Droop Power**. This diagram does not add extra closed loop damping to the **GBGF-I's** closed loop function shown by the solid red line and the dotted blue line.

Figure 2: Simplified controller diagrams of GBGF-I referred to Figure PC.A.5.8.1 (a) and Figure PC.A.5.8.1 (b) in the Grid Code

- To participate in the Grid Forming Capability market, Users and Non-CUSC Parties are required to provide data of their GBGF-I in accordance with Figures PC.A.5.8.1(a) and PC.A.5.8.1(b). Users and Non-CUSC Parties in respect of Grid Forming Plants should indicate if the data is submitted on a unit or aggregated basis. Table PC.A.5.8.1(a) defines the notation used in Figure PC.5.8.1

- To participate in a Grid Forming Capability market, Users and Non-CUSC Parties are also required to provide the data of their GBGF-I in accordance with Table PC.A.5.8.1.2 to The

Company. The details and arrangements for Users and Non-CUSC Parties participating in this market shall be published on The Company's Website.

The required data format is referred to the DRC 20 and was shown in the Appendix A.

Protection Requirements

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

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

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

Technical Requirements of GBGF

Each GBGF shall be capable of:

1) In addition to meeting the fault ride through requirements referred to in ECC.6.3.15, each Grid Forming Plant is required to remain in synchronism with the Total System and maintain a Load Angle whose value can vary between 0 and 90 degrees (π/2 radians). When subject to a fault or disturbance, or System Frequency change, each Grid Forming Plant shall be capable of supplying Active ROCOF Response Power, Active Phase Jump Power, Active Damping Power, Active Control Based Power, Control Based Reactive Power, Voltage Jump Reactive Power and GBGF Fast Fault Current Injection.
2) For GB Grid Forming – Synchronous or GBGF-S, the FFCI requirements are not appliable; for the GB Grid Forming - Inverter or GBGF-I, the modified requirements of FFCI are detailed in the "**V4** Fault Ride Through (FRT) and Fast Fault Current Injection (FFCI) Requirement section of this document.
3) Operating at a minimum short circuit level of zero MVA at the Grid Entry Point or User System Entry Point.

4) Providing any additional quality of supply requirements, including but not limited to reductions in the permitted frequency of Temporary Power System Over-voltage events (TOV's) and System Frequency bandwidth limitations, as agreed with The Company.

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

1) 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).
2) Operating as a voltage source behind an impedance
3) 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.
4) Include an Active Control Based Power part of the control system that can respond to changes in the Grid Forming Plant or external signals from the Total System available at the Grid Entry Point or User System Entry Point but with a bandwidth below 5 Hz to avoid AC System resonance problems.
5) Meeting the requirements of frequency, rate of change of frequency and voltage protection settings referred to in ECC.6.3.13 irrespective of being owned or operated by a GB Code User, EU Code User or Non-CUSC Party.
6) 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 3 (referred to in Figure ECC.6.3.19.3 of the Grid Code European Connection Conditions). 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.

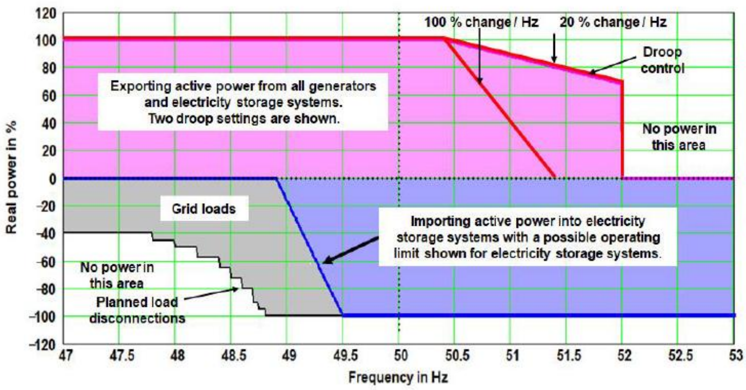

Figure ECC.6.3.19.3

Figure 3: Frequency Response Operating Characteristic referred to Grid Code Figure ECC.6.3.13.3

7) Each User or Non-CUSC Party shall design their GBGF-I system with an equivalent Damping Factor of between 0.2 and 5.0. It is down to the User or Non-CUSC Party to determine the Damping Factor, whose value shall be agreed with The Company. It is typical for the Damping Factor to be less than 1.0, though this will be dependent upon the parameters of the Grid Forming Plant and the equivalent System impedance at the Grid Entry Point or User System Entry Point. The output of the Grid Forming Plant shall be designed such that following a disturbance on the System, the Active Power output and Reactive Power output shall be adequately damped. The damping shall be judged to be adequate if the corresponding Active Power response to a disturbance decay with a response that is in line with the response of second order system that has the same equivalent Damping Factor.

8) Each GBGF-I shall be designed so as not to interact and affect the operation, performance, safety or capability of other User's Plant and Apparatus connected to the Total System. To achieve this requirement, each User and Non-CUSC Party shall be required to submit the data required in PC.A.5.8.

V4 Active ROCOF Power

According to the Grid Code definition, Active ROCOF Power is the Active Inertia Power developed from a Grid Forming Plant plus the Active Frequency Response Power that can be supplied by a Grid Forming Plant when subject to a rate of change of the System Frequency.

The simulation and testing specifications for ROCOF power are outlined in Appendix C and Appendix D.

The following criteria constitute the passing requirements:

1) Provide inherent capability of a Grid Forming Plant to respond naturally within 5ms following changes in the System Frequency.
2) Providing a symmetrical ability for importing and exporting Active ROCOF Response Power, under both rising and falling System Frequency conditions.
3) System oscillation should not occur.
4) An increase in frequency must result in a decrease in active power response and active power should change with the Rate of Change of Frequency.

V4 Active Phase Jump Power

According to the Grid Code definition, Active Phase Jump Power is 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.

The Grid Code outlines two important concepts: the Phase Jump Angle Limit and the Phase Jump Angle Withstand.

The Phase Jump Angle Limit is the angle up to which the GBGF-I plant will result in a linear controlled response such that any further increase in the Phase Angle (beyond the Phase Jump Angle Limit) would activate the current limiting functions of the Grid Forming controller.

The Phase Jump Angle Withstand is the angle beyond which the plant is no longer able to remain connected to the system as any further angle increase is too large for the plant to remain connected.

The simulation and testing specifications for Active Phase Jump Power are outlined in Appendix C and Appendix D. The following criteria constitute the passing requirements for the linear and non-linear responses of Grid Forming Connection.

Requirements on linear response:

1) At the immediate instant of the phase jump, both the instantaneous active power and the positive sequence active current from the plant shall exhibit an inversely directed response with respect to the direction of the phase jump itself. Specifically, both quantities increase in magnitude when the phase jump is negative and decrease when the phase jump is positive.
2) Grid Forming Plant shall provide an inherent active power capability that starts to respond naturally, within 5ms following a phase jump event.
3) Following the phase jump, the plant's responses shall be well-damped, without sustained or significant oscillations, and shall return stably to their respective pre-disturbance operating points shortly after. The responses include:
   - power responses, including both active and reactive power; and
   - current responses, including all current components (active and reactive, and both positive- and negative-sequence components).

Requirements on non-linear response:

1) At the immediate instant following the phase jump, the positive sequence active current from the plant shall exhibit an inversely directed response with respect to the direction of the phase jump itself, before reaching any current limit. Specifically, the positive sequence active current increases in magnitude when the phase jump is negative and decreases when the phase jump is positive.
2) The Grid Forming Plant shall provide an inherent active power capability that starts to respond naturally, within 5ms following a phase jump event.
3) Following the phase jump, the plant shall be capable of stable, uninterrupted continuous operation, including controlled and stable entry into and exiting from the current limitation state.
4) Following the phase jump, the plant's responses shall be well-damped, without sustained or significant oscillations, and shall shortly afterwards return to their respective pre-disturbance operating points in a stable manner. The responses include:

- power responses, including both active and reactive power; and
- current responses, including all current components (active and reactive, and both positive- and negative-sequence components).

5) A full explanation of the current limiting function shall be provided, including but not limited to:
   - Current limiting method, such as virtual impedance; and
   - Current limiting activation conditions; and
   - Control target in the current limiting process; and
   - Current limiting deactivation conditions.

Peak Current Rating

From the definition of Peak Current Rating in the Grid Code, 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.

When an event occurs within the system, the change in frequency is not instantaneous due to the system's inertia. Consequently, the Rate of Change of Frequency (ROCOF) and Damping Power are provided over time during the frequency event, rather than instantaneously. This means that these currents are not instantaneous and, therefore, are not suitable for defining the plant's Peak Current Rating. As a result, the Peak Current Rating should be assessed using the Phase Jump Angle Limit Power. For clarity, the Peak Current Rating must be recorded at the Point of Connection (POC).

The Peak Current Rating should be established according to the maximum leading Q conditions at the minimum short circuit level, considering injection up to the Negative Phase Jump Angle Limit. For BESS and Interconnector systems, it is essential to also factor in the maximum import during maximum leading conditions at the minimum short circuit level, with injection applied up to the Positive Phase Jump Angle Limit.

V4 Fault Ride Through (FRT) and Fast Fault Current Injection (FFCI) 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 which is operating in a Grid Forming Capability mode needs to meet the fault ride through requirements referred to CC.6.3.15 or ECC.6.3.15 and 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 the FRT requirements, the Grid Forming Plant must also comply with the Fast Fault Current Injection criteria. The original standards are detailed in ECC.6.3.19. However, interim requirements will be applied to GBGF-I based plants prior to the formal introduction of a Grid Forming Grid Code modification, which is anticipated to be proposed in late 2026.

For any balanced fault which results in the positive 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 an Apparent Current of at least their Peak Current Rating when the voltage at the Grid Entry Point or User System Entry Point drops to zero as shown in the Figure 4.

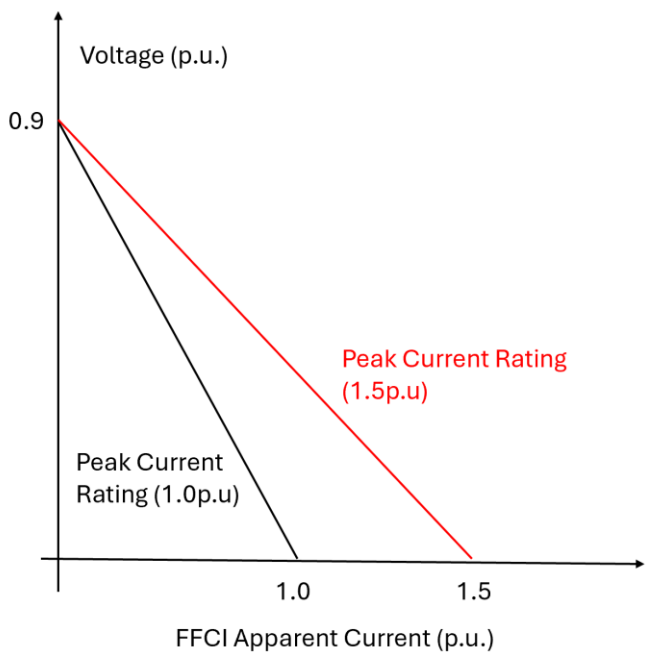

Figure 2: Injected Apparent Current Requirement During Fault Conditions

For intermediate retained voltages at the Grid Entry Point or User System Entry Point, the injected Apparent Current shall be on or above the line drawn. Typical examples of limit lines are shown in Figure 4 for a Peak Current Rating of 1.0pu where the injected Apparent Current must be above the black line and a Peak Current Rating of 1.5pu where the injected Apparent Current must be above the red line. For the purposes of this requirement, the Peak Current Rating value need to be declared by the Grid Forming Plant Owner in accordance with Table PC.A.5.8.2.

Figure 5 outlines the FFCI required to be delivered during fault conditions, which is determined by both the pre-fault operating state and the retained voltage at either the Grid Entry Point or User

System Entry Point. Each Grid Forming Plant, including its constituent elements, must inject an Apparent Current that is no less than its pre-fault value. The injected FFCI must remain above the threshold indicated by the red line in Figure 5 throughout the fault clearance period; for faults on the Transmission System cleared through Main Protection with a nominal voltage of 400kV, this duration may extend up to 140ms. The Grid Forming Plant must respond by injecting Apparent Current within 5ms following the onset of the fault.

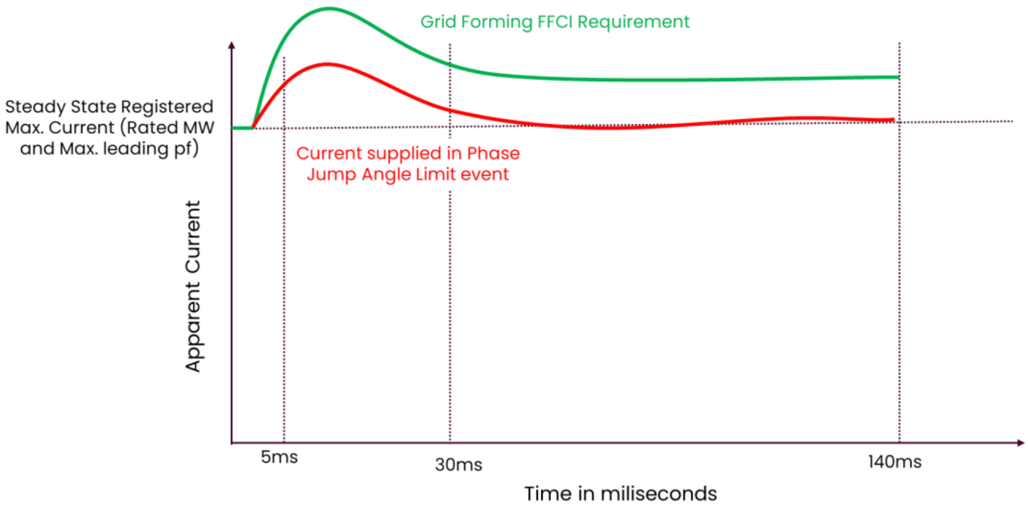

Figure 3: Acceptable Operation of Injected Apparent Current

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.

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

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

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

The subsequent sections will provide an assessment of FFCI, based on the Peak Current Rating value.

For example, the following Table 1 shows a 200MW Grid Forming Plant connecting to the 275kV Transmission system:

Table 1: 200MW Grid Forming Plant Example

MW	MVAr	MVA	Power Factor	Point of Connection Voltage (kV)	Continuous Rating Current (kA)
200	66	210.609	0.95	275	0.442

The Fault Ride Through study should be assessed from the initial operating condition of Active Power= 200MW and Reactive Power = -66 MVAr, under the minimum short circuit level conditions in accordance with ECP.A.3.5. Shown below in Table 2 are the Phase Jump Angle Limit simulation results based on this operational condition.

Table 2: 200MW Grid Forming Plant Fault Ride Through Example

Case No	Initial Condition	Phase Jump Angle Limit (degree)	Maximum Peak Current (kA)
1	200MW/ -66 MVAr	-20	0.8

Therefore, from this example, the steady state value of the FFCI should be equal to or greater than 0.442kA, as this is the plant continuous rating.

The transient peak value of the FFCI, should be greater than or equal to 0.8kA as this is the Peak Current Rating of the plant, before stabilising at its steady state value. In this example the maximum additional current to supply the Phase Jump Angle Limit Power can be valued as 0.8kA – 0.442kA = 0.358kA

Model Requirements

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

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

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

For the avoidance of doubt, the user is also reasonably required to comply with any additional modelling requirements that may be included in the BCA.

For detailed recommendations and advice on the model(s) submission aimed at complying with PC.A.9 of the Grid Code, please refer to "Guidance Notes on Modelling Requirements – GC0141 Grid Code Modification[5] , Frequently Asked Questions on Root Mean Square (RMS)[6] and Guidance for EMT Models V2.0 Sep 2025[7]

It is recommended that the Grid Forming simulation be conducted using the EMT model. Additionally, it is expected that the current limiting function will be explained within the EMT Model Guidance Document, noting that the impedance between the Grid Forming Plant and Grid Entry Point or User System Entry Point, could be real, virtual or a combination of the two.

Model Validation

Prior to the Company issuing an ION, models must be validated. Validation may be conducted using test results from other comparable sites, Factory Acceptance Tests, or type test results to demonstrate that the model responses accurately reflect those of the User's Plant and Apparatus.

If Factory Acceptance Testing (FAT) is carried out, test process should cover steady-state reactive power capability, voltage control, fault ride through, and frequency response. For GBGF-I plant, users are expected to validate their RMS and EMT models using Rate of Change of Frequency (ROCOF) and Phase Jump Events as well.

In the ION stage, the model validation should follow requirements specified in the ECP.A.3.7.

If testing shows the models do not accurately represent the User's Plant and Apparatus, the User must provide updated models, documentation, and data to ensure the model's results match actual test responses.

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

Compliance Tests

The tests specified in ECP.A.9 of the Grid Code are intended to demonstrate compliance with the relevant provisions of both the Grid Code and the Bilateral Agreement, wherever feasible. Should the test requirements outlined in ECP.A.9 differ from those in the Bilateral Agreement or prove

[5] https://www.neso.energy/document/316631/download.
[6] https://www.neso.energy/document/377131/download
[7] https://www.neso.energy/document/275661/download

irrelevant to the plant type, the Grid Forming provider is encouraged to consult with NESO to discuss and establish an alternative test programme and success criteria.

In addition to the dynamic signals provided under ECP.A.4, the User or Non-CUSC Party must inform The Company of the following information prior to the commencement of testing—and communicate any changes to these items should values alter during testing: (i) all applicable transformer tap numbers, if utilised; (ii) the number of Grid Forming Units in operation.

For each test performed, ECP.A.9 provides the description and purpose, expected results, relevant Grid Code clauses, and assessment criteria. The Grid Forming Plant owner is responsible for drafting test procedures as part of the compliance process prior to issuance of the Interim Operational Notification (ION). ECP.A.9 and its appendices supply outline test schedules to assist the Grid Forming Plant owner in this task.

NESO may request additional compliance tests or supporting evidence to verify site-specific technical requirements according to the Bilateral Agreement or to resolve specific compliance concerns. Such further tests will be identified subsequent to NESO's review of the User's Data File Structure (UDFS).

Testing is managed by the Grid Forming Plant or their designated agent. The Company recognise that it is not possible in a large number of cases to adjust the network frequency or phase angle or set up a short circuit fault at 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 will be required during the Interim Operational Notification Process as provided for under CP.6 or ECP.6 (as applicable). FAT conducted in accordance with ECP.A.9.1 requirements is also capable of demonstrating Grid Forming Performance.

The Grid Forming Plant is also required to supply appropriate digital monitoring equipment to record all pertinent test signals necessary for verifying performance, working alongside NESO's recording equipment.

Compliance Test Signals

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

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

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

- 1 Hz for reactive range tests
- 10 Hz for frequency control tests
- 100 Hz for voltage control tests
- 1 kHz for Grid Forming Plant signals including fast fault current measurements

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

Co-located Site

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

Test Notification to Control Room

The Grid Forming Plant Owner is responsible for notifying the 'NESO 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 'NESO 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 NESO's Website in the Grid Code, Associated Documents section.

The Grid Forming Plant Owner should be aware that this interface with NESO transmission planning will normally be available in weekday working hours only. As best practice, the Grid Forming Plant Owner should advise the 'NESO Control Centre' and in Scotland the relevant Transmission Owner, or Distribution Network Operator (if embedded) of the times and nature of the proposed tests at the earliest stage possible and were possible with 28 days' notice. If there is insufficient notice or information provided by the HVDC Owner, then the proposed testing may not be allowed to be proceed.

V4 Appendix A DRC 20

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

1) The representation of their Grid Forming Plant in a format should either be the same as Figure A-1 (referred to Figure PC.A.5.8.1 in GC) of PC.A.5.8.1 or in an equivalent format.
2) The data associated with their Grid Forming Plant as required in PC.A.5.8.1
3) 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.
4) A Network Frequency Perturbation Plot with a Nichols Chart demonstrating the equivalent Damping Factor.
5) For the items a) to d), the User or Non-CUSC Party can submit the data in any equivalent format as agreed with The Company.

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

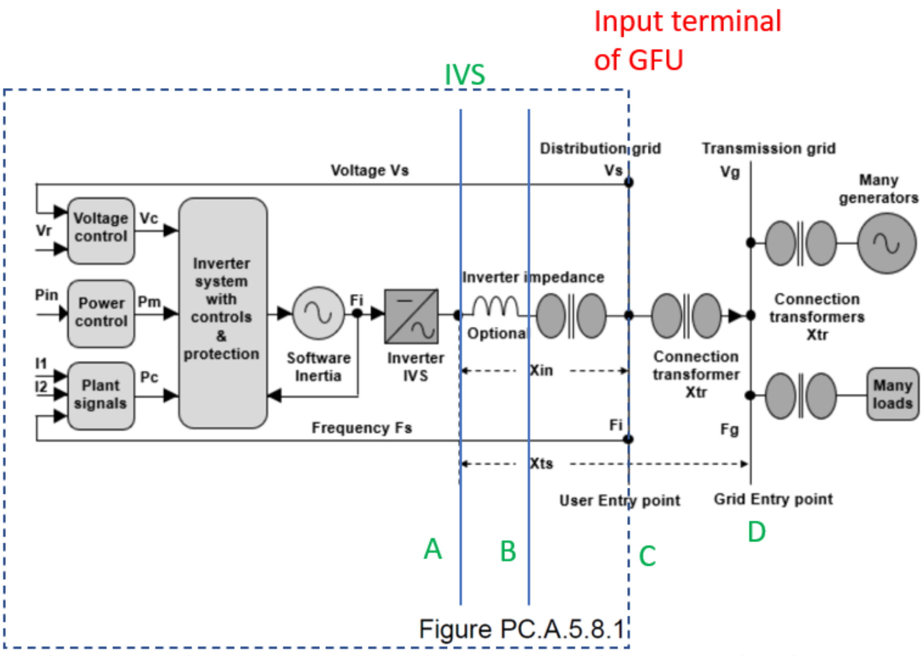

Figure A 1: Example of Grid Forming Plant

With reference to Figure A 1 the following must be noted:

1) The IVS voltage must not change in either magnitude or phase at the instant when a Phase Jump Angle occurs in the Grid's AC voltage when the plant has a linear response.
2) The impedance Xin will always have a transformer. The inductor is marked as optional as it is not needed by certain designs of GBGF inverters.

3) The GBGF inverter's IVS is always the inverter's output voltage which located at the point "A"
4) The design of the GFU shown by the dash black box

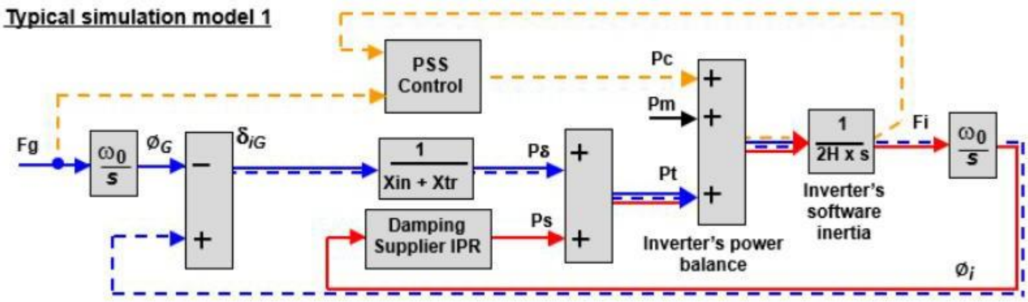

Figure PC.A.5.8.1 (a) Preferred simplified diagram of a **GBGF-I** with a **Power System Stabiliser** "**PSS**" that can add damping to the **GBGF-I**'s closed loop function shown by the solid red line and the dotted blue line.

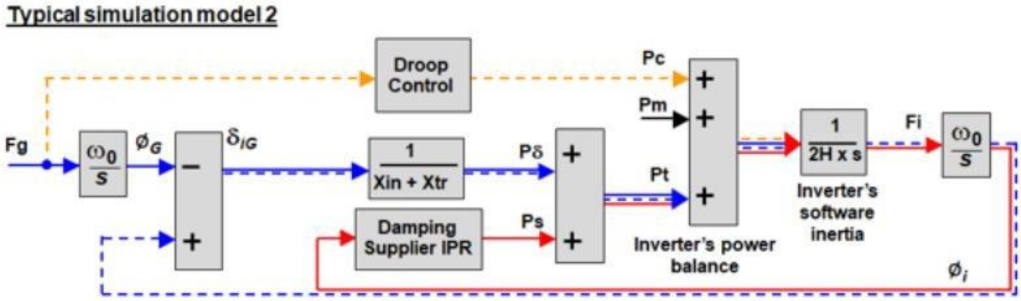

Figure PC.A.5.8.1 (b) – Preferred simplified diagram of a system with a droop control ability that can add **Control-Based Active Droop Power**. This diagram does not add extra closed loop damping to the **GBGF-I's** closed loop function shown by the solid red line and the dotted blue line.

Figure A 2: Simulation Model referred to Figure PC.A.5.8.1 (a) and (b)

Table A 1: DRC Schedule 20

Data Description	Data Format	Grid Forming Plant Data
Submission of **Network Frequency Perturbation Plot** and **Nichols Chart** for each **GBGF-I** (PC.A.5.8.1)	Graphs	
High level equivalent architecture diagram of Grid Forming Plant (PC.A.5.8.1)	Diagram	
GBGF-I Grid Forming Plant Block Diagram (Laplace Operator) in the general form shown in Figure PC.A.5.8.1 or as agreed with **The Company**. When submitting either Figure PC.A.5.8.1 (a) or Figure PC.A.5.8.1 (b), each **User** or **Non- CUSC Party** can use their own design, that may be very different to Figures PC.A.5.8.1 (a) or PC.A.5.8.1 (b), but should contain all relevant functions that can include simulation models and other equivalent data and documentation	Block Diagram (Laplace Operator)	
Each **User** or **Non-CUSC Party** shall provide a model of their **Grid forming Plant** which provides a true and accurate reflection of its **Grid Forming Capability**	Model and Documentation format to be agreed with **The Company**	

In order to participate in the **Grid Forming Capability** market, **User's** and **Non-CUSC Parties** are required to provide data of their **GBGF-I** in accordance with Figures PC.A.5.8.1(a) and PC.A.5.8.1(b). **Users** and **Non- CUSC** Parties in respect of **Grid Forming Plants** should indicate if the data is submitted on a unit or aggregated basis. Table 1 below defines the notation used in Figure PC.5.8.1.

V4 Table A 2: Schedule 20 Table 1 continued

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)**.	Xtr	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 angle in radians between voltage of point A and D or C (for embedded))
~~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~~

***Note 1**: Only the Rated Angle between the Internal Voltage Source and Grid Entry Point or User System Entry Point (if Embedded) is required

***Note 2**: the Rated Angle Means the load angle, which is the relative position between the internal voltage source and the system voltage. This is the maximum rated MW value at which instantaneous power will be delivered by the Grid Forming Converter to the system for a maximum angle change.

The angle associated with the maximum instantaneous power in a linear performance determines the Grid Forming Plant's capacity prior to transitioning into non-linear performance For instance, if the rated angle is 20 degrees, the plant may supply up to additional 10 MW at this threshold; increasing the angle difference to 21 degrees does not result in further power output—the maximum remains at 10 MW. Additionally, when the angle exceeds 20 degrees, the virtual impedance is activated to restrict current injection.

Table A 3: Schedule 20 Table 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		

To participate in a Grid Forming Capability market, User's and Non-CUSC Parties are also required to provide the data of their GBGF-I in accordance with the Table below 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.

Table A 4: Schedule 20 Table 2 Continued

Additional reactance X_{tr} (See Table 1)	pu on MVA		
Maximum Capacity	MW		
Active ROCOF Response Power (MW) supplied 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 (The Phase jump angle withstand must be at least 60 degrees)
Phase Jump Angle limit *	degrees		5 degrees (5 degrees is the recommended value, however, the phase jump angle limit value can be smaller or larger than 5 degrees as agreed with The Company)
Phase Jump Power (MW) at the rated angle **	MW		The maximum instantaneous power to the system in the linear mode before the Grid Forming Plant starts to operate in the nonlinear mode.

***Note 1: Phase Jump Angle limit** is expected to be provided based on different operational scenarios. The following operational scenarios detailed in Table 1 are expected to be covered.

** **Note 2: Phase Jump Power** should be the instantaneous power value and is expected to be provided based on injecting the Phase Jump Angle Limit value.

Table A 5: Phase Jump Angle Limit Required Simulations

Case No.	Initial Condition	Phase Jump Angle limit (degree)	Maximum peak current (kA)	Phase Jump Power (MW)
1	Maximum P Export / Q (0.95 leading)	Negative Phase Jump angle injection		
2	Maximum P Import/ Q (0.95 leading) for BESS / Interconnector connection only	Positive Phase Jump angle injection		

Table A 6: Schedule 20 Table 2 Continued

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 *	kA		
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		
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.	ζ		0.2 to 5.0 allowed

H = Installed MWs / Rated installed MVA (equation 1)

He = (Active ROCOF Response Power at 1 Hz / s x System Frequency) / (Installed MVA x 2)

Appendix B Grid Forming Factory Acceptance Testing (FAT) Expectation

The objective of this Appendix is to produce guidance on the physical testing of the Grid-Forming Plant In this Appendix there is a summary of the main technical specifications applied to the demonstrator and verified during the FAT. They are based on current Grid Code requirements for the connection of Grid Forming and Commercial requirements as part of the Stability Pathfinder Project.

Required data / documentation before scheduling FAT

Before witnessing / approving FAT tests, the following information is expected to be provided by the User

1) The representation of their Grid Forming Plant in a format either the same as Figure PC.A.5.8.1 of PC.A.5.8.1 or in an equivalent format.
2) The data associated with their Grid Forming Plant as required in PC.A.5.8.1
3) 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.
4) A Network Frequency Perturbation Plot with a Nichols Chart demonstrating the equivalent Damping Factor.
5) For the items a) to c) the User or Non-CUSC Party can submit the data in any equivalent format as agreed with The Company.
6) DRC data 20
7) the Grid Forming Test procedures
8) The system settings in the FAT including
    a. The Minimum / Maximum short circuit level conditions
    b. MV and HV transformer parameters along with any assumptions made if using a lumped impedance model.
    c. Inertia Constant (H)
    d. Damping Factor (D)
    e. Droop setting of FSM and LFSM
    f. POD settings (if Applicable)
    g. Droop setting of the Voltage control

Compliance Monitoring

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

Signal Provision for Witnessing Tests

In the case of a GBGF-I system, the following signals shall be supplied to The Company by the Grid Forming Plant Owner in accordance with ECC.6.6.3. For the avoidance of doubt, User's and Non-CUSC Parties will also be required to undertake the necessary testing of their Plant in accordance with the requirements of ECC.A.4 and OC5 as applicable.

Table B 1: Required Data For Grid Forming Test

ECP.A.4.3.6(a) Real Time Downloadable	Signals required shall be agreed with The Company in accordance with ECC.6.6.3.2(iv) and ECC.6.6.3.2(v)
	Record traces of Grid Forming Plant's Active ROCOF Response Power, Grid Forming Plant's Active Phase Jump Response Power, Phase Jump Angle, Active Power, Reactive Power, Voltage, Current (including FFCI) and Frequency

Voltage and Frequency Regulation

Site level of Voltage regulation and Frequency regulation are expected to be provided.

The tested system should include a voltage reference Uref with a settable reactive power droop such that:

$$(U_{ref} – U_{Poc}) / U_{base} = (Q_{Poc} / Q_{base}) \times droop,$$

Where:

- **UPoc** is the voltage at the connection point
- **QPoc** is the injected reactive power.
- **Uref** is the voltage reference value
- **Droop** is the Voltage control Droop setting

The tested system should be able to achieve a compliant Frequency control including the Primary Frequency Response, Secondary Frequency Response and High Frequency Response with a settable Frequency droop:

FInjected /Fbase = (Pchange/Pbase) x droop ,

Where:

- **Finjected** is the injected F signal
- **Pchange** is the recorded P change in the Connection Point.
- **Droop** is the Frequency control droop Setting

Demonstrator description

Factory Acceptance Testing (FAT) generally encompasses both a single-unit physical testing and plant-level Control Hardware-in-the-Loop (CHiL) testing. The plant-level CHiL test should accurately simulate the entire plant's behaviour. Any Grid Forming Tests specified in ECP.A.9 that cannot be conducted using CHiL testing may be demonstrated through single-unit physical testing, subject to agreement with The Company.

1) Single-unit physical testing
    a) The test system should include a physical Inverter Module, an Inverter Controller and /or a DC source for the BESS / PV connection and/or the PPC controller.
    b) The Inverter controller includes the Grid Forming control and FRT function.
    c) PPC controller includes the frequency control (FSM, LFSM and Deload (for BESS)) and voltage control.

2) CHiL testing

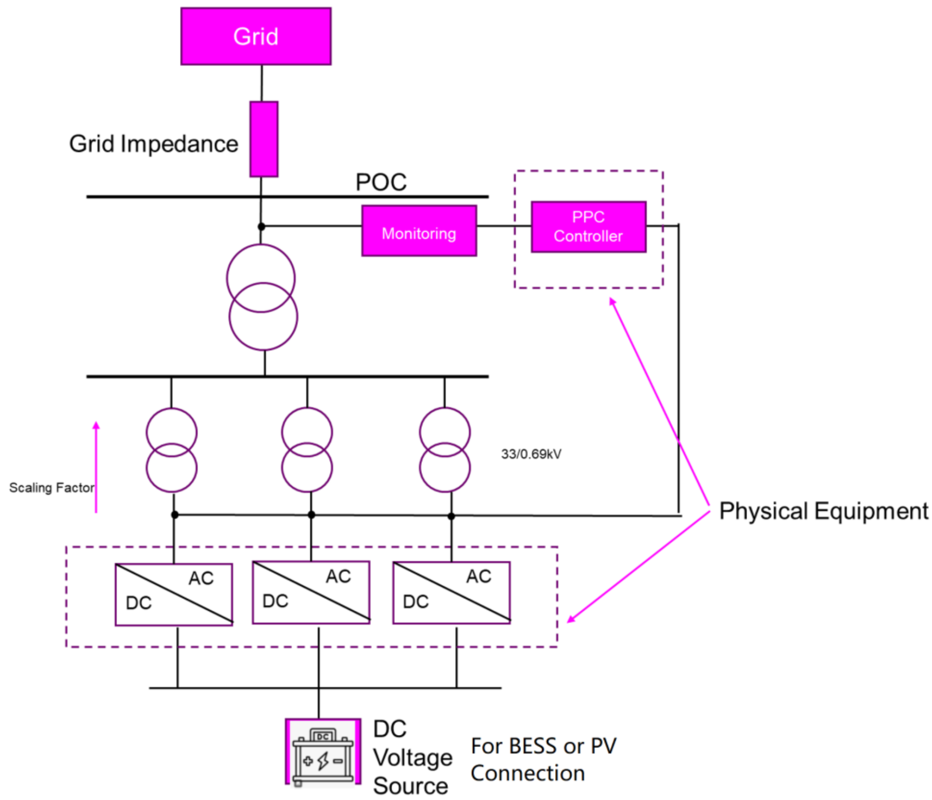

Figure B 1: The System Setup for CHiL Test

a) In instances where physical constraints prevent the Grid Forming Plant owner from conducting onsite tests as outlined in Appendix ECP.A.9, NESO intends to utilize Factory Acceptance Test (FAT) results to verify Grid Forming performance at the site level. During the FAT, NESO may integrate these results into the testing protocol and proactively identify any potential issues, which will subsequently be addressed with the developer through root cause analysis. If no instability is detected, the developer is expected to submit the test data via the UDFS process, following which NESO will issue final confirmation.

b) The test system must include, at a minimum, Inverter Controllers and/or two physical Inverter Modules, as well as the PPC controller. If the OEM indicates that DC voltage source performance may affect the plant's transient response, then a physical battery unit or PV should be incorporated into the test setup to accurately evaluate plant performance. It is recommended to scale the output from the 33/0.69 HV side of the transformer terminal to align with the TEC capacity at the Point of Connection (POC). If output scaling is not feasible, comprehensive simulations should be conducted to demonstrate the transformers' impact on Grid Forming capability.

c) The Inverter controller includes Grid Forming control and the FRT function.

d) The PPC controller includes the frequency control (FSM, LFSM, De-load), voltage control and POD function if applicable.

e) Site base test results are used to check the Grid Forming performance against the requirements of PC.A.5.8, ECC.6.3.19, ECC.6.6.3, ECP.A.3.9 and ECP.A.9.1.

f) When tests are conducted by the provider in a FAT environment, NESO approval of these test results is required prior to undertaking and submitting any simulation studies for approval. This process ensures that the parameters established during the final, accepted FAT tests are accurately represented in subsequent simulations. Additionally, all reports generated from the FAT process must be of sufficient quality to facilitate thorough review. This includes, but is not limited to, presenting time series plots with clear markers and data points (capturing data before, during, and after the simulation event) that are easily legible within the report. Furthermore, these time-series plots must possess adequate resolution to allow for comprehensive performance assessment.

g) Please note that the HVDC and Windfarm developer may adopt alternative approaches to demonstrate the Grid Forming Function, subject to agreement with The Company.

Appendix C 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.
9) The simulation needs to cover both export and import mode for the BESS and interconnector.

Simulation Stages

The simulation study shall comprise of the following stages.

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

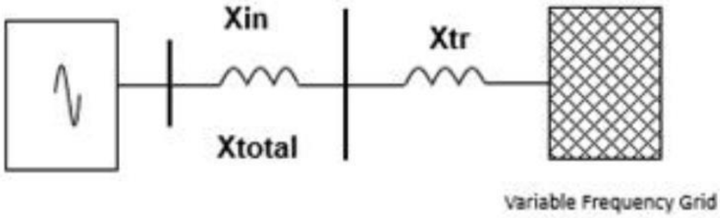

Figure C 1: Studied Network

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.

Table C 1: Active ROCOF Response Power Simulation 1

	V4 **Initial condition**	V4 **Voltage Control mode**	V4 **Frequency control mode**	**Frequency Event**
Simulation 1.1	Maximum Capacity zero MVAr output	Enable	Disable both FSM and LFSM	from 50Hz to 51 Hz at a rate of 1Hz/s
Simulation 1.2	Maximum Capacity zero MVAr output	Enable	Disable both FSM and LFSM	50 Hz to 49 Hz at a rate of 1Hz/s

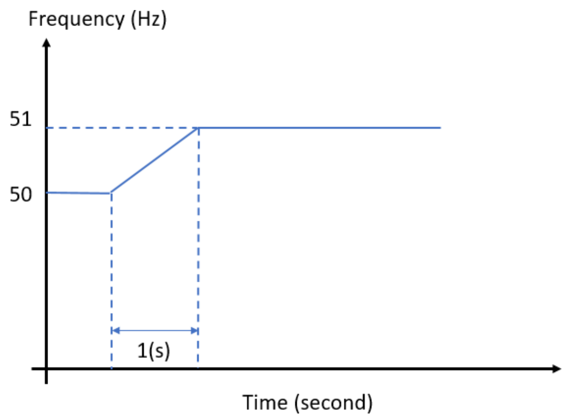

Figure C 2: Simulation 1.1

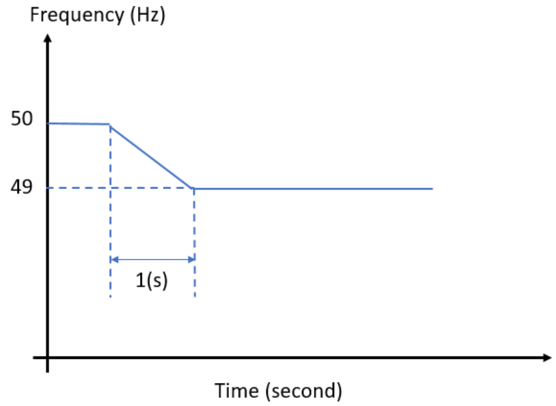

Figure C 3: Simulation 1.2

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.

Table C 2: Active ROCOF Response Power Simulation 2

	V4 **Initial condition**	V4 **Voltage Control mode**	**Frequency control mode**	**Frequency Event**
Simulation 2.1	Maximum Capacity zero MVAr output	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 2Hz/s
Simulation 2.2	Maximum Capacity zero MVAr output	enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 1Hz/s
Simulation 2.3	Maximum Capacity zero MVAr output	enable	Disable both FSM and LFSM	From 50Hz to 48Hz at a rate of 2Hz/s
Simulation 2.4	Maximum Capacity zero MVAr output	enable	Disable both FSM and LFSM	From 50Hz to 48 Hz at a rate of 1Hz/s

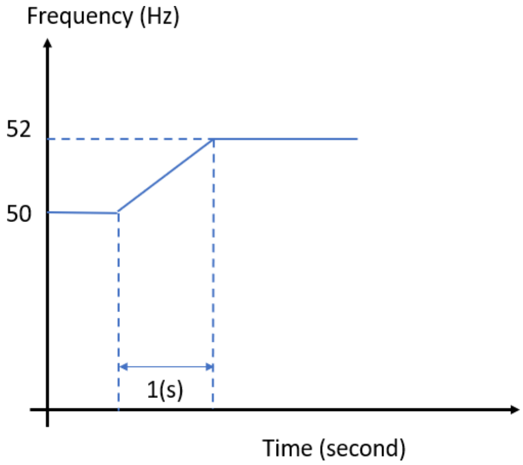

Figure C 4: Simulation 2.1

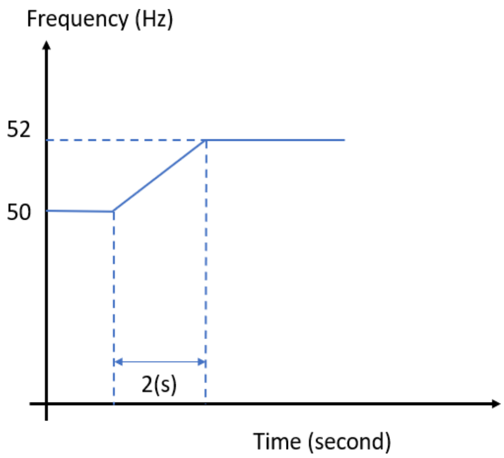

Figure C 5: Simulation 2.2

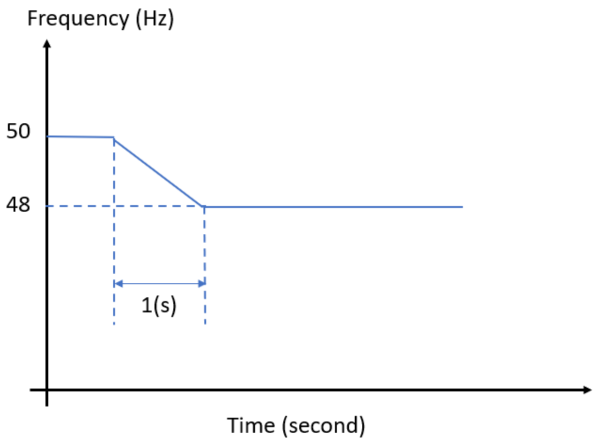

Figure C 6: Simulation 2.3

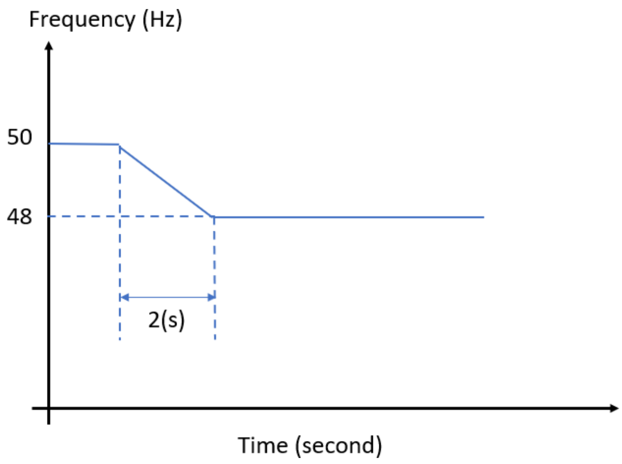

Figure C 7: Simulation 2.4

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.

Table C 3: Active ROCOF Response Power Simulation for the Full Frequency Range 1

	Initial condition	Voltage Control mode	Frequency control mode	Frequency Change
Simulation 3.1	at 75% full load and zero MVAr output	enable	Disable both FSM and LFSM	50Hz to 52Hz to 47Hz

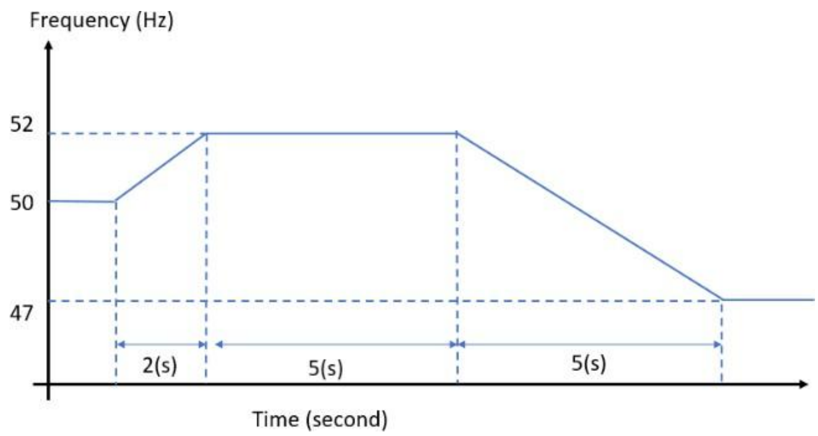

Figure C 8: Simulation 3.1

Table C 4: Active ROCOF Response Power Simulation for the Full Frequency Range

	Initial condition	Voltage Control mode	Frequency control mode	Frequency Change
Simulation3.2	at 75% full load for both export and import and zero MVAr output	enable	Disable both FSM and LFSM	50Hz to 47Hz to 52Hz

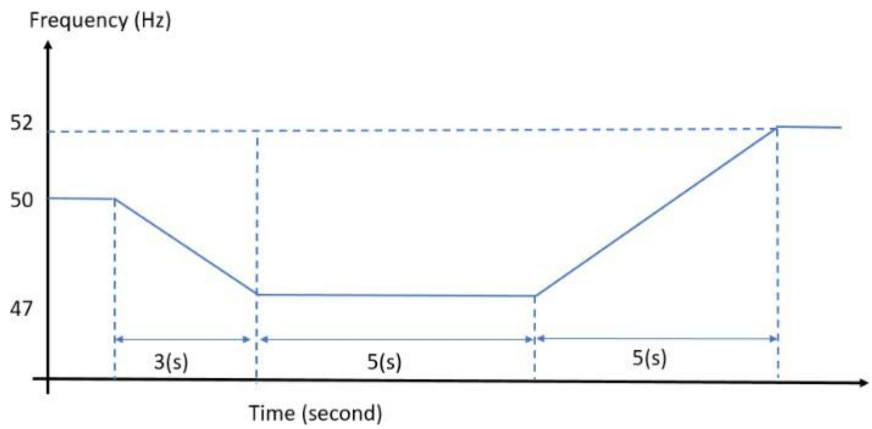

Figure C 9: Simulation 3.2

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 the 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.

Table C 5: Grid Forming Plant's ability to supply Active Phase Jump Power under normal operation

	V4 **Initial condition**	V4 **Voltage Control mode**	**Frequency control mode**	**Event**
Simulation 4.1	Maximum Capacity or Registered Capacity or at its agreed de-loaded 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 traces for 10s
Simulation 4.2	Maximum Capacity or Registered Capacity or at its agreed de-loaded point, zero MVAr output	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 traces for 10s
Simulation 4.3	Maximum Capacity or Registered Capacity or at its agreed de-loaded point, Maximum Leading MVAr output	Enable	Disable both FSM and LFSM	Apply a positive phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record traces for 10s
Simulation 4.4	Maximum Capacity or Registered Capacity or at its agreed de-loaded point, Maximum Leading MVAr output	Enable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record traces for 10s

Please note V4:

- The Phase Jump Angle Limit value should remain consistent with DRC Schedule 20 and which may be different to 5 degrees.
- The Phase Jump Angle Limit value may be different under different system initial conditions
- The Negative Phase Jump Angle limit apply to the export active power, and the positive Phase Jump angle limit apply to the import active power for the BESS and Interconnector.

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.

Table C 6: Grid Forming Plant's ability to supply Active Phase Jump Power under extreme conditions

	V4 **Initial condition**	**Voltage Control mode**	**Frequency control mode**	V4 **Event**
Simulation 5.1	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output	Disable	Disable both FSM and LFSM	Apply positive Phase Jump Angle Withstand value at the Grid
Simulation 5.2	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr output	Disable	Disable both FSM and LFSM	Apply negative Phase Jump Angle Withstand value at Grid
~~**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 for both export and import~~	~~Disable~~	~~Disable both FSM and LFSM~~	~~Apply a phase jump equivalent to the negative Phase Jump angle limit at Grid~~

***Note:** V4 Simulation 5.3 and 5.4 will become optional once approved by the Company.

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.

Table C 7 :Grid Forming Plant's ability to supply Fault Ride Through and FFCI

	V4 **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
Simulation 6.3	Maximum output, Maximum MVAr leading 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

***Note**: The Fast Current Injection and Fault Ride Through controller may remain enabled if approval is granted by the Company.

****Note**: Simulation 6.2 will become optional once approved by the Company.

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).

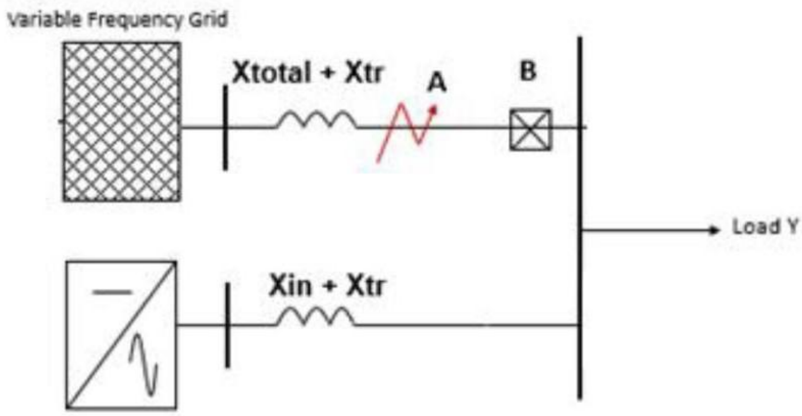

Figure C 10: Simulation network for Simulation 8

    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. After agreement by The Company, the variable frequency Grid can be replaced by an infinite busbar system with the minimum short circuit level.

    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.

Table C 8: Grid Forming Plant's ability to supply Active ROCOF Response Power and Active Phase Jump Power, under extreme conditions

	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	A solid three phase short circuit fault at the connection point for 140ms, then open circuit breaker B

***Note 1:** The default Y value should be the TEC of the connection. For example, if the TEC of the connection is 200MW, the initial condition for the connection will be 100MW and the Y should be 200MW, therefore the Grid will supply the other 100MW of load when operating under initial conditions.

***Note 2:** The load Y can be fixed with P and Q.

***Note 3:** The variable frequency grid shall be provided by the Company, or an infinite busbar system may be implemented upon agreement with the Company.

9) To demonstrate the Grid Forming Plant model can contribute to Active Damping Power, the GBGF- I is 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:

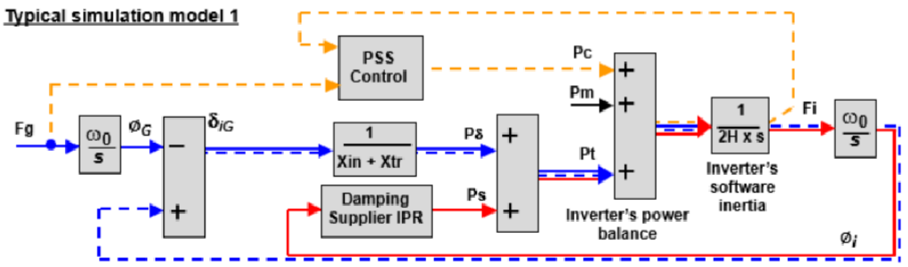

Figure ECP.A.3.9.6(a)

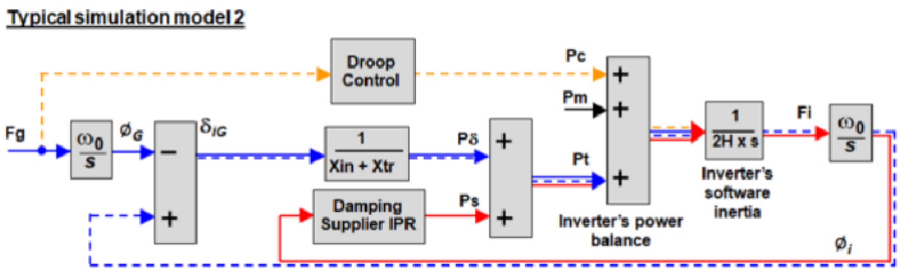

Figure ECP.A.3.9.6(b)

Figure C 11: 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.

Table C 9: Grid Forming Plant's ability to supply Active Damping Power

	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

Appendix D Test Requirements

Summary of Requirements

Appendix 9 of the Grid Code European Compliance Processes (ECP.A.9) sets out Grid Forming testing requirements for Users or Non-CUSC Parties to show compliance with the Grid Code, Ancillary Services Agreement, and Bilateral Agreement.

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.

Table D 1: Active ROCOF Response Power Without Saturating

	V4 **Initial condition**	V4 **Voltage Control mode**	**Frequency control mode**	**Frequency increase**
Test 1.1	At full load, zero Reactive power exchange at POC	Enable	Disable both FSM and LFSM	From 50Hz to 51 Hz at a rate of 1Hz/s
Test 1.2	At full load, zero Reactive power exchange at POC	Enable	Disable both FSM and LFSM	50 Hz to 49 Hz at a rate of 1Hz/s

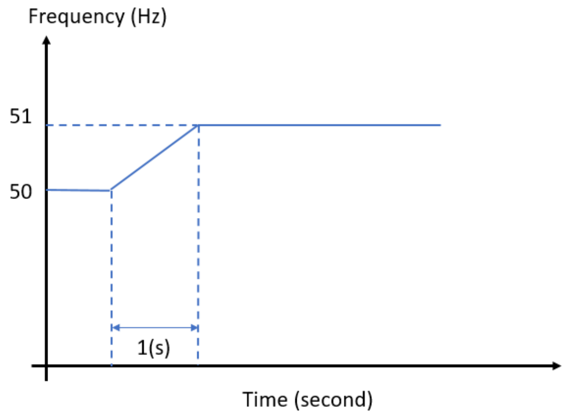

Figure D 1: Test 1.1 Grid Forming Plant without Saturating

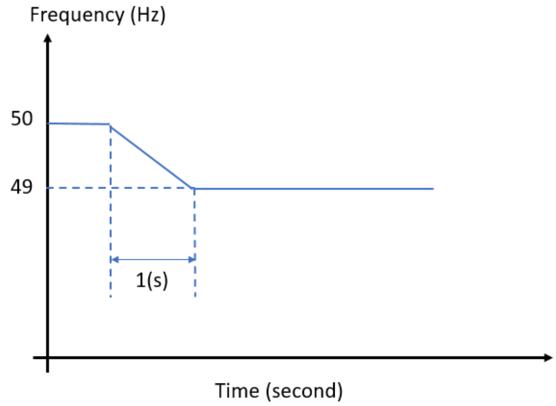

Figure D 2: Test 1.2 Grid Forming Plant without Saturating

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) 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).

Table D 2: Assess the Grid Forming Plant's withstand capabilities under extreme System Frequencies

	V4 **Initial condition**	V4 **Voltage Control mode**	**Frequency control mode**	**Frequency increase**
Test 2.1	At full load, zero Reactive power exchange at POC	Enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 2Hz/s
Test 2.2	At full load, zero Reactive power exchange at POC	Enable	Disable both FSM and LFSM	From 50Hz to 52Hz at a rate of 1Hz/s
Test 2.3	At full load, zero Reactive power exchange at POC	Enable	Disable both FSM and LFSM	From 50Hz to 47 Hz at a rate of 2Hz/s
Test 2.4	At full load, zero Reactive power exchange at POC	Enable	Disable both FSM and LFSM	From 50Hz to 47 Hz at a rate of 1Hz/s

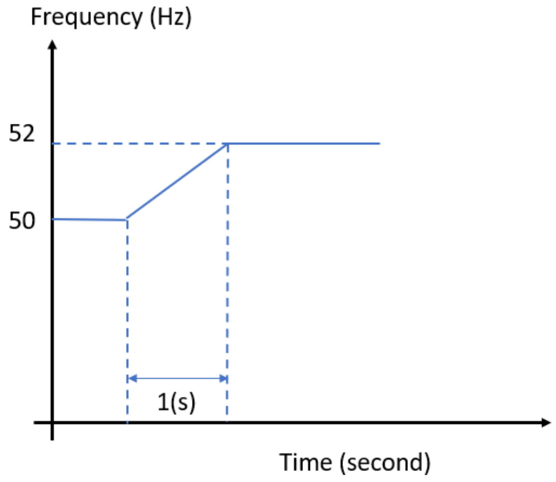

Figure D 3: Test 2.1 Assess the Grid Forming Plant's withstand capabilities under extreme System Frequencies

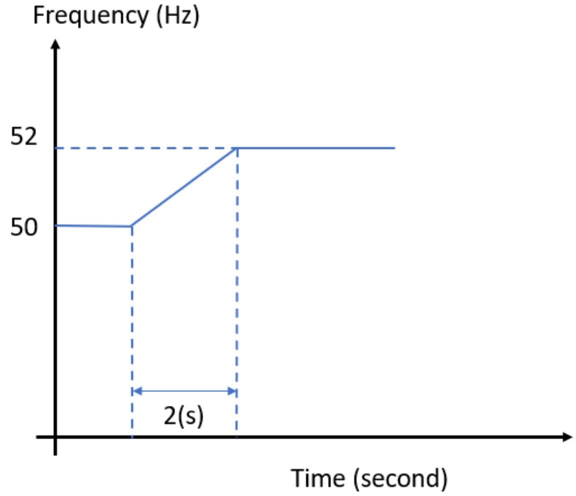

Figure D 4: Test 2.2 Assess the Grid Forming Plant's withstand capabilities under extreme System Frequencies

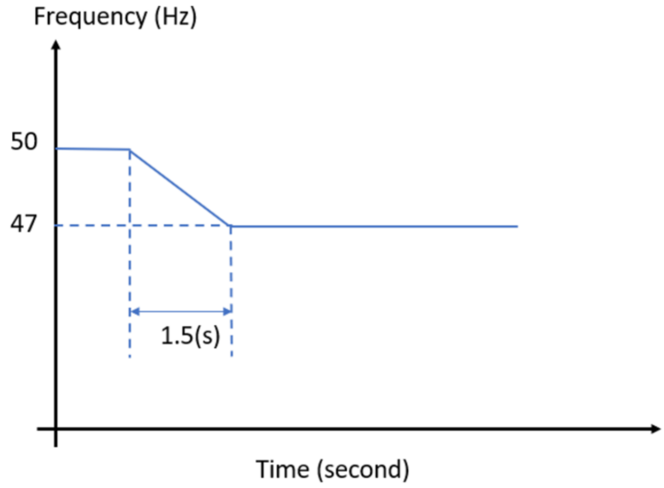

Figure D 5: Test 2.3 Assess the Grid forming Plant's withstand capability under extreme System Frequencies

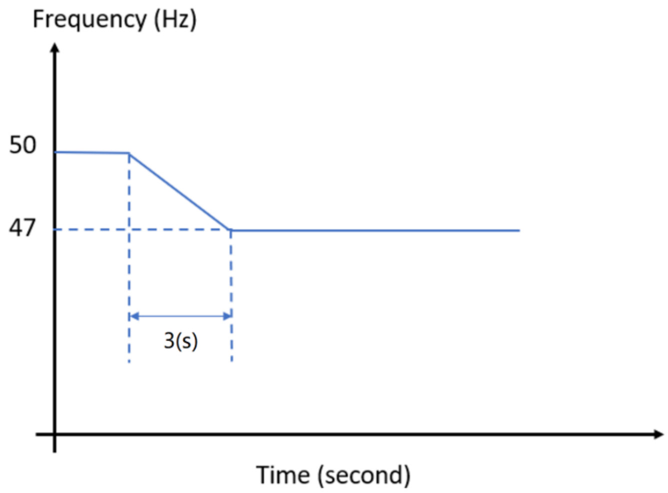

Figure D 6:Test 2.4 Assess the Grid Forming Plant's withstand capabilities under extreme System Frequencies

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

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% of 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.

Table D 3: Assess the Grid Forming Plant's Ability to Supply Active ROCOF Response Power when Frequency is increased

	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	50 Hz to 52 Hz to 47 Hz

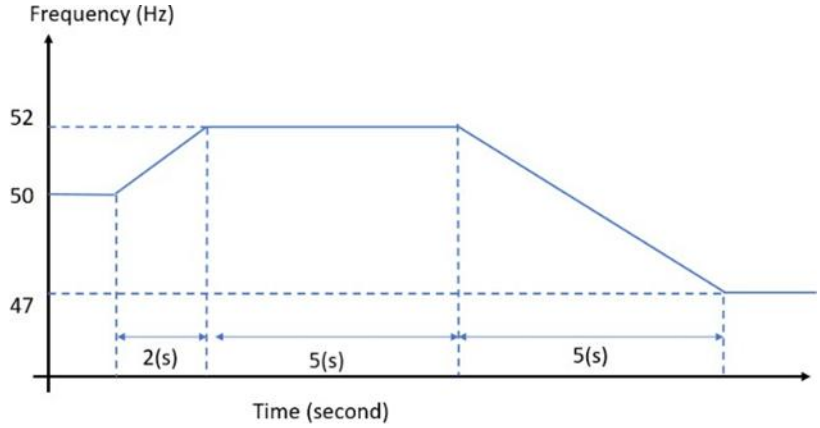

Figure D 7: Test 3.1 Assess the Grid Forming Plant's Ability to Supply Active ROCOF Response Power when Frequency is increased

Table D 4: Assess the Grid Forming Plant's Ability to Supply Active ROCOF Response Power when Frequency is reduced

	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	50 Hz to 47 Hz to 52Hz

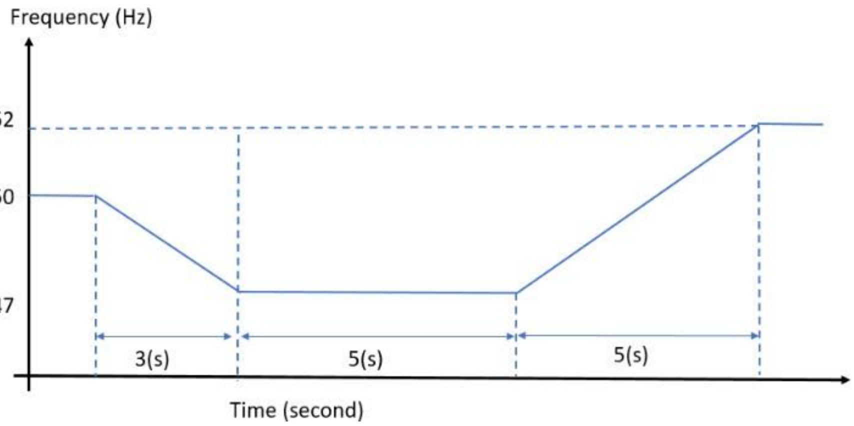

Figure D 8: Assess the Grid Forming Plant's Ability to Supply Active ROCOF Response Power when Frequency is reduced.

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

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 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.

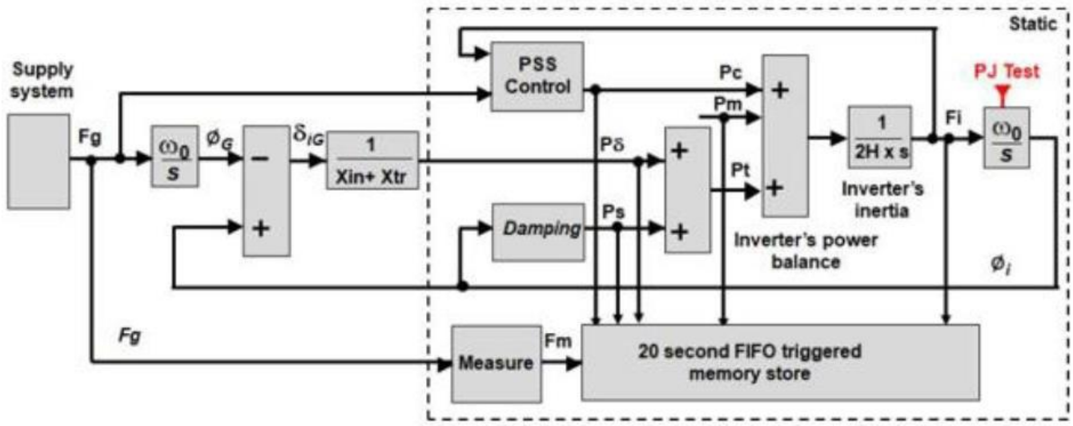

Figure D 9: An Example of a Test Network

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.

Table D 5: Assess the Grid Forming Plant's Ability to Supply Active Phase Jump Power under normal operation

	V4 **Initial condition**	**V4 Voltage Control mode**	**Frequency control mode**	V4 **Event**
Test 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 traces for 10s
Test 4.2	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output	Disable	Disable both FSM and LFSM	Apply a positive phase jump of up to the Phase Jump Angle Limit into the Grid Forming Plant's control system and record traces for 10s

Test 4.3	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output	Disable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record traces for 10s
Test 4.4	Maximum Capacity or Registered Capacity or at its agreed deloaded point, zero MVAr output	Disable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit into the Grid Forming Plant's control system and record traces for 10s
Test 4.5	Maximum Capacity or Registered Capacity or at its agreed de-loaded point, Maximum Leading MVAr output	Enable	Disable both FSM and LFSM	Apply a positive phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record traces for 10s
Test 4.6	Maximum Capacity or Registered Capacity or at its agreed de-loaded point, Maximum Leading MVAr output	Enable	Disable both FSM and LFSM	Apply a negative phase jump of up to the Phase Jump Angle Limit to Grid Entry Point and record traces for 10s

V4 **Please note:**

1) The Phase Jump Angle Limit should stay aligned with DRC Schedule 20, and it may differ from 5 degrees.
2) The Phase Jump Angle Limit can vary depending on the system's initial conditions.
3) Tests 4.2 and 4.4 may be considered optional if the Grid Forming Plant Owner or OEM can prove that implementation is not feasible due to design constraints.
4) Test 4.5 and Test 4.5 are required to verify the Peaking Current Rating value.

5) For the BESS and Interconnector, the negative Phase Jump Angle limit applies when exporting active power, while the positive Phase Jump Angle limit applies when importing active power.

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).

Table D 6: Assess the Grid Forming Plant's Ability to Supply Active Phase Jump Power under extreme conditions

	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 positive phase jump of 60 degrees at the connection point of the GBGF-I or into the Grid Forming Plant's control system
~~**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 5.3	Minimum Stable Operating Level or Minimum Stable Generation, zero MVAr Output	Disable	Disable both FSM and LFSM	Apply a negative phase jump of 60 degrees at the connection point of the GBGF-I or into the Grid Forming Plant's control system

<u>**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</u>

a) This test is to demonstrate the GBGF-I plants 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 may 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.

b) 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. Please Note, FRT function may able to in active after agreeing with Company.

c) 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.

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

f) 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

Table D 7: Assess the Grid Forming Plant's Ability during a faulted condition

	V4 **Initial condition**	**Voltage Control mode**	**Frequency control mode**	**Event**
Test 6.1	Maximum Capacity or Registered Capacity or at an alternative loading point as agreed with The Company, zero MVAr output	Disable	Disable both FSM and LFSM	A solid three phase short circuit fault at the connection point for 140ms
Test 6.2 *	Maximum Capacity or Registered Capacity or at an alternative loading point as agreed with The Company, zero MVAr output	Enable	Disable FSM only	A solid three phase short circuit fault at the connection point for 140ms
Test 6.3	Maximum Capacity or Registered Capacity or at an alternative loading point as agreed with The Company, Maximum leading MVAr output	Enable	Disable FSM only	A solid three phase short circuit fault at the connection point for 140ms

***Note 1:** Test 6.2 may be considered optional with Company approval

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.

Table D 8: Assess the Grid Forming Plant's Ability during a faulted condition

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