NOA Stability Pathfinder Phase 3

Technical Performance Requirements

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Version Control

Version number	Date	Notes
1.0	10/09/2021	Initial version
2.0	20/12/2021	1. Reactive power requirements and steady state voltage range in Part B is revisited. 2. Updated Fast Fault Current Injection requirement in Section 1.9. 3. Updated Inertia equations in Section 2.2. 4. Repeated inertial response requirement from GBGF-I plants is added in Section 2.5. 5. Clarified that fault current that will be considered is the reactive component. 6. Part E compliance requirements added 7. Minor editorial changes.
3.0	20/04/2022	Updated Fast Fault Current Injection requirement in Section 1.9.

Introduction

This document presents the technical requirements which solutions will need to meet in order to participate in the Network Options Assessment (NOA) Stability Phase 3 Tender. This technical specification is based on the latest draft version (September 2021) of GC0137- Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability, which is currently going through the Grid Code Modification Process, as well as the Technical requirements developed for the NOA Stability Phase 2 tender. The document has also been updated to reflect some of the feedback that has been received as part of the consultation window.

Definitions

Active Control Based Power	If applicable , is the **Active Power** output supplied by a **Grid Forming Plant** through controlled means (be it manual or automatic) of the positive phase sequence Root Mean Square **Active Power** produced at fundamental **System Frequency** by the control system of a **Grid Forming Unit.** For **GBGF-I Plant,** this is equivalent to a **Synchronous Generating Unit** with a traditional governor coupled to its prime mover. **Active Control Based Power** includes **Active Power** changes that results from a change to the **Grid Forming Plant Owners** available set points that have a 5 Hz limit on the bandwidth of the provided response. **Active Control Based Power** also includes **Active Power** components produced by the normal operation of a **Grid Forming Plant** that comply with the **Engineering Recommendation** P28 limits. These **Active Power** components do not have a 5 Hz limit on the bandwidth of the provided response. **Active Control Based Power** does not include **Active Power** components proportional to **System Frequency**, slip or deviation that provide damping power to emulate the natural damping function provided by a real **Synchronous Generating Unit**.
Active Control Based Droop Power	If applicable, **The Active Control Based Power** output supplied by a **Grid Forming Plant** through controlled means (be it manual or automatic). For **GBGF-I Plant, this** is equivalent to a **Synchronous Generating Unit** with a traditional governor coupled to its prime mover. **Active Control Based Droop Power** is used by **The Company** to control **System Frequency** changes through the instruction of **Primary Response** and **Secondary Response**.
Active Damping Power	The **Active Power** naturally injected or absorbed by a **Grid Forming Plant** to reduce **Active Power** oscillations in the **Total System**. More specifically, **Active Damping Power** is the damped response of a **Grid Forming Plant** to an oscillation between the voltage at the **Grid Entry Point** and the voltage of the **Internal Voltage Source** of the **Grid Forming Plant**. For the avoidance of doubt, **Active Damping Power** is an inherent capability of a **Grid Forming Plant** that starts to respond naturally, within less than 5ms to low frequency oscillations in the **System Frequency**.

Active Frequency Response Power	The injection or absorption of **Active Power** by a **Grid Forming Plant** to or from the **Total System** during a deviation of the **System Frequency** away from the **Target Frequency**. For a **GBGF-I Plant** this is very similar to **Primary Response** but with a response time to achieve the declared service capability (which could be the **Maximum Capacity** or **Registered Capacity**) within 1 second. For **GBGF-I Plant** this can rapidly inject or absorb **Active Power** in addition to the phase-based **Active Inertia Power** to provide a system with desirable **NFP** plot characteristics. **Active Frequency Response Power** can be produced by any viable control technology.
Active Inertia Power	The injection or absorption of **Active Power** by a **Grid Forming Plant** to and from the **Total System** during a **System Frequency** change. The transient injection or absorption of **Active Power** from a **Grid Forming Plant** to the **Total System** as a result of changes in the **ROCOF** value at the **Grid Entry Point**. This requires a sufficient energy storage capacity of the **Grid Forming Plant** to meet the **Grid Forming Capability** requirements specified in this document. For the avoidance of doubt, this includes the rotational inertial energy of the complete drive train of a **Synchronous Generating Unit**. **Active Inertia Power** is an inherent capability of a **Grid Forming Plant** to respond naturally, within less than 5ms, to changes in the **System Frequency**. For the avoidance of doubt the **Active Inertia Power** has a slower frequency response compared with **Active Phase Jump Power**.
Active Phase Jump Power	The transient injection or absorption of **Active Power** from a **Grid Forming Plant** to the **Total System** as a result of changes in the phase angle between the **Internal Voltage Source** of the **Grid Forming Plant** and the **Grid Entry Point**. In the event of a disturbance or fault on the **Total System**, a **Grid Forming Plant** will instantaneously (within 5ms) inject or absorb **Active Phase Jump Power** to the **Total System** as a result of the phase angle change. For **GBGF-I Plant** as a minimum value this is up to the **Phase Jump Angle Limit Power**. **Active Phase Jump Power** is an inherent capability of a **Grid Forming Plant** that starts to respond naturally, within less than 5ms, and can have frequency components of over 1000 Hz.
Active ROCOF Response Power	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**.
Control Based Reactive Power	The **Reactive Power** supplied by a **Grid Forming Plant** through controlled means based on operator adjustment selectable setpoints (these may be manual or automatic).

Damping Factor (ζ)	The ratio of the actual damping to critical damping. For a **GBGF-I Plant** the open loop phase angle, for an open loop gain of one, is measured from the systems **Nichols Chart.** This angle is used to define the system's equivalent **Damping Factor** that is the same as the **Damping Factor** of a second order system with the same open loop phase angle. Alternatively, the **Damping Factor** refers to the damping of a specific oscillation mode that is associated with the second order system created by the power to angle transfer function as shown in Figures 3 and 4.
Defined Active Damping Power	The **Active Damping Power** supplied by a **GBGF-I Plant** when it is operating at the **Grid Oscillation Value**.
Dynamic Reactive Compensation Equipment	**Plant** capable of injecting or absorbing **Reactive Power** in a controlled manner which could include but is not limited to Synchronous Compensators, Static Var Compensators (SVCs), or STATCOM devices.
Electronic Power Converter	Electrical **Plant** which uses switched solid state power electronic devices to produce a real voltage waveform, that has a fundamental component with harmonics.
Fast Fault Current Injection	The ability of a **Grid Forming Plant** to supply reactive current, that starts to deliver into the **Total System** in less than 5 ms, when the voltage falls below 90% of its nominal value at the **Grid Entry Point**.
GB Grid Forming Inverter or GBGF-I Plant	Any **Power Park Module**, **HVDC System**, **DC Converter**, **OTSDUW Plant and Apparatus**, **Non-Synchronous Electricity Storage Module**, **Dynamic Reactive Compensation Equipment** or any **Plant** and **Apparatus** (including a smart load) which is connected or partly connected to the **Total System** via an **Electronic Power Converter** which has a **Grid Forming Capability (GBGF-I)**.
GB Grid Forming Synchronous Plant or GBGF-S Plant	A **Synchronous Power Generating Module**, **Synchronous Electricity Storage Module** or **Synchronous Generating Unit** with a **Grid Forming Capability**.
Grid Forming Active Power	**Grid Forming Active Power** is the inherent **Active Power** injected or absorbed by **Grid Forming Plant** that includes **Active Inertia Power** plus **Active Phase Jump Power** plus **Active Damping Power**.

Grid Forming Capability	Is (but not limited to) the capability of 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) to supply **Active Power** which is directly proportional to the difference between the magnitude and phase of its **Internal Voltage Source** and the magnitude and phase of the voltage at the **Grid Entry Point** and the sine of the **Load Angle**. As a consequence, a **Plant** which has a **Grid Forming Capability** is one where the frequency of rotation of the **Internal Voltage Source** is the same as the **System Frequency** for normal operation, with only the **Load Angle** defining the relative position between the two. In the case of a **GBGF-I Plant,** a **Grid Forming Unit** forming part of a **GBGF-I Plant** shall be capable of sustaining a voltage at its terminals irrespective of the voltage at the **Grid Entry Point** for normal operating conditions. For **GBGF-I Plant,** the control system, which determines the amplitude and phase of the **Internal Voltage Source**, shall have a response to the voltage and **System Frequency** at the **Grid Entry Point** with a bandwidth that is less than a defined value as shown by the control system's **NFP** Plot. Exceptions to this requirement are only allowed during transients caused by **System** faults, voltage dips/surges and/or a step or ramp changes in the phase angle which are large enough to cause damage to the **Grid Forming Plant** via excessive currents.
Grid Forming Electronic Power Converter	A **Grid Forming Plant** whose output is derived from an **Electronic Power Converter** with a **GBGF-I** capability.
Grid Forming Plant	A **Plant** which is classified as either a **GBGF-S Plant** or a **GBGF-I Plant**.
Grid Forming Plant Owner	The owner or operator of a **Grid Forming Plant**.
Grid Forming Unit	A **Power Park Unit** or **Electricity Storage Unit** or a **Synchronous Power Generating Unit** or individual **Load** with a **Grid Forming Capability**.
Grid Oscillation Value	This is an injected test frequency signal applied at nominal **System Frequency** with a superimposed oscillatory response overlayed onto the nominal **System Frequency** with an amplitude of 0.05 Hz peak to peak at a frequency of 1 Hz and is used for the rating of the **Defined Active Damping Power**.

Internal Voltage Source or **IVS**	For a **GBGF-S Plant** a real magnetic field, that rotates synchronously with the **System Frequency** under normal operating conditions, which as a consequence induces an internal voltage (which is often referred to as the Electro Motive Force (EMF) in the stationary generator winding that has a real impedance. In a **GBGF-I Plant**, switched power electronic devices are used to produce a voltage waveform, with harmonics, that has a fundamental rotational component called the **Internal Voltage Source (IVS)** that rotates synchronously with the **System Frequency** under normal operating conditions. For a **GBGF-I Plant** there must be an impedance with only real physical values, between the **Internal Voltage Source** and the **Grid Entry Point**. For the avoidance of doubt a virtual impedance, is not permitted in **GBGF-I Plant**.
Load Angle	The angle in radians between the voltage of the **Internal Voltage Source** and the voltage at the **Grid Entry Point**.
Network Frequency Perturbation Plot	A form of Bode Plot which plots the amplitude (%) and Phase (degrees) of the resulting output oscillation responding to an applied input oscillation across a frequency base. The plot will be used to assess the capability and performance of a **Grid Forming Plant** and to ensure that it does not pose a risk to other **Plant** and **Apparatus** connected to the **Total System**. For a **GBGF-I Plant**, these are used to provide data to **The Company** which together with the associated **Nichols Chart** (or equivalent) define the effects on a **GBGF-I Plant** for changes in the frequency of the applied input oscillation. The input is the applied input oscillation and the output is the resulting oscillations in the **GBGF-I Plant's Active Power**. For the avoidance of doubt **Generators** in respect of **GBGF-S Plants** can provide their data using the existing formats and do not need to supply **NFP** plots.
Nichols Chart	For a **GBGF-I Plant** a **Nichols Chart** is derived from the open loop Bode Plots that are used to produce an **NFP Plot**. The **Nichols Chart** plots open loop gain versus open loop phase angle. This enables the open loop phase for an open loop gain of 1 to be identified for use in defining the **GBGF-I's** equivalent **Damping Factor.**
Non-CUSC Party	A Party who does not accede to the **Connection and Use of System Code** (**CUSC**).

Peak Current Rating	For a **GBGF-I Plant** this is the larger of either the: - • The registered maximum steady-state current declared by the **Grid Forming Plant Owner** 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 declared by the **Grid Forming Plant Owner**, or. • The maximum short-term total current declared by the **Grid Forming Plant Owner.**
Phase Jump Angle	The difference in the measured phase angle of the voltage at the **Grid Entry Point** in a given mains half cycle compared with the measured phase angle of the voltage at the **Grid Entry Point** in the previous mains half cycle.
Phase Jump Angle Limit	The maximum **Phase Jump Angle** when applied to a **GBGF-I Plant** which will result in a linear response without activating current limiting functions. This is specified for a **Total System** angle near to zero which would be considered to be operating under steady state conditions.
Phase Jump Angle Withstand	The maximum **Phase Jump Angle** change when applied to a **GBGF-I Plant** which will result in the **GBGF-I Plant** remaining in stable operation with current limiting functions activated. This is specified for a **Total System** angle near to zero which would be considered to be operating under steady state conditions.
Power Generating Module Performance Chart	A diagram showing the **Active Power** (MW) and **Reactive Power** (MVAr) capability limits within which a **Synchronous Power Generating Module** or **Power Park Module** at its **Grid Entry Point** will be expected to operate under steady state conditions.
ROCOF	**Rate of Change of Frequency**
Synchronous Generating Unit Performance Chart	A diagram showing the **Active Power** (MW) and **Reactive Power** (MVAr) capability limits within which a **Synchronous Generating Unit** at its stator terminals (which is part of a **Synchronous Power Generating Module**) will be expected to operate under steady state conditions.
Voltage Jump Reactive Power	The transient **Reactive Power** injected or absorbed from a **Grid Forming Plant** to the **Total System** as a result of either a step or ramp change in the difference in voltage magnitude and/or phase between the **Internal Voltage Source** of the **Grid Forming Plant** and **Grid Entry Point**. In the event of a voltage magnitude and phase change at the **Grid Entry Point**, a **Grid Forming Plant** will instantaneously (within 5ms) supply **Voltage Jump Reactive Power** to the **Total System** as a result of the voltage magnitude change.

1. Grid Forming Capability for the NOA Stability Pathfinder Phase 3

1.1 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**).

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

1.3 In addition to meeting the requirements of CC.6.3.15 or ECC.6.3.15, each **Grid Forming Plant** is required to remain in synchronism with the **Total System** and maintain a **Load Angle** whose value can vary between 0 and 90 degrees (π/2 radians).

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

1.5 Each **GBGF-I Plant** shall be capable of:-

1.5.1 providing a symmetrical ability for importing and exporting **Active Inertia Power**, **Active Phase Jump Power**, **Active Damping Power** and **Active Control Based Power** under both rising and falling **System Frequency** conditions. Such requirements would apply over the full **System Frequency** range as detailed in CC.6.1.2 and CC.6.1.3 or ECC.6.1.2 (as applicable). In satisfying these requirements, **User's** and **Non-CUSC Parties** should be aware of (but not limited to) the exclusions in CC.6.3.3, CC.6.3.7 and BC3.7.2.1 (as applicable for **GB Code User's**) or ECC.6.1.2, ECC.6.3.3, ECC.6.3.7 and BC3.7.2.1(b)(i) (as applicable for **EU Code User's** and **Non-CUSC Parties**) during **System Frequencies** between 47Hz – 52Hz, excluding CC.6.1.3 or ECC.6.1,2.1,2 for a **Grid Forming Plant** with time limited output ratings. For the avoidance of doubt, an asymmetrical response is permissible as agreed with **The Company** when required to protect **User's** and **Non CUSC Parties Plant** and **Apparatus** or asymmetry in energy availability.

1.5.2 operating as a voltage source behind a real physical reactance.

1.5.3 being designed to operate with a **Phase Jump Angle Limit** of at least 5 degrees and a **Phase Jump Angle Withstand** of at least 60 degrees.

1.5.4 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**.

1.5.5 including an **Active Control Based Power** part of the control system that can respond to changes in the **Grid Forming Plant** or external signals from the **Total System** available at the **Grid Entry Point** but with a bandwidth below 5 Hz to avoid AC **System** resonance problems.

1.5.6 meeting the requirements of ECC.6.3.13 irrespective of being owned or operated by a **GB Code User**, **EU Code User** or **Non-CUSC Party**. **GBGF-I Plants** connected and synchronised to the **Total System**, are 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 milliseconds period. For the avoidance of doubt, **HVDC Systems** and **Remote End HVDC Converter Stations** will need to meet the requirements of ECC.6.3.13.3.

1.5.7 **GBGF-I Plants** with an importing capability mode of operation such as **DC Converters**, **HVDC Systems** and **Electricity Storage Modules** are required to have a predefined frequency response operating characteristic over the full import and export range which is contained within the envelope defined by the red and blue lines shown in Figure 1. If requested, this characteristic shall be submitted to **The Company**. For the avoidance of doubt, **Grid Forming Plants** which are only capable of exporting **Active Power** to the **Total System** are only required to operate over the exporting power region.

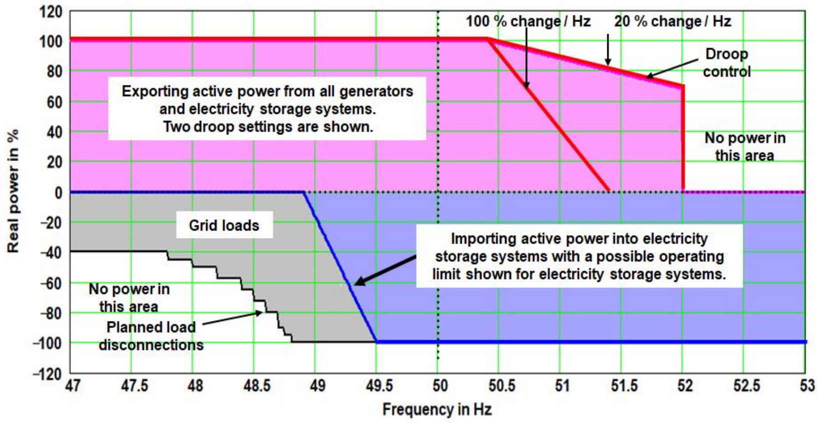

Figure 1 – Frequency response characteristic requirement for **GBGF-I Plants** with importing and exporting modes.

1.6 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 would be dependent upon the parameters of the **Grid Forming Plant** and the equivalent **Total System** impedance at the **Grid Entry Point**.

The output of the **Grid Forming Plant** shall be designed such that following a disturbance on the **Total 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** and/or **Reactive Power** response to a disturbance decays with a response that is in line with the response of second order system that has the same equivalent **Damping Factor**.

1.7 Each **GBGF-I Plant** 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 shall be required to submit a **Network Frequency Perturbation Plot** and **Nichols chart** (or equivalent as agreed with **The Company**) which shall be assessed by **The Company.**

If requested by **The Company**, 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 2 together with the equivalent linear classical block diagram model (in the Laplace domain) of their **Grid Forming Plant** which should preferably be in the general form shown in Figure 3 or Figure 4. When submitting either Figure 3 or Figure 4, each **User** or **Non-CUSC Party** can use their own design, that may be very different to Figures 3 or 4, but should contain all relevant functions that can include simulation models and other equivalent data and documentation.

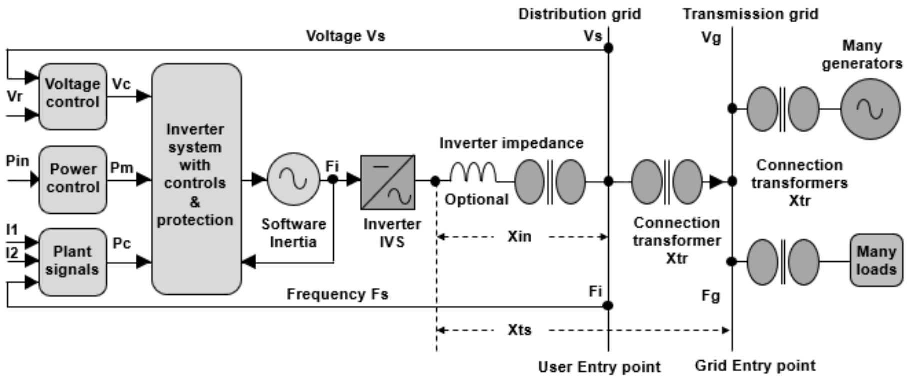

Figure 2-High level equivalent architecture diagram of a **Grid Forming Plant** to be submitted if requested.

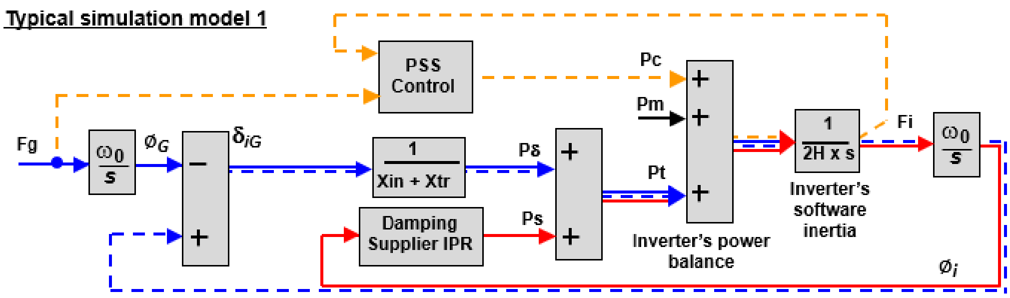

Figure 3-Preferred simplified diagram of a **GBGF-I Plant** with a **Power System Stabiliser** "**PSS**" that can add damping to the **GBGF-I Plant**'s closed loop function shown by the solid red line and the dotted blue line.

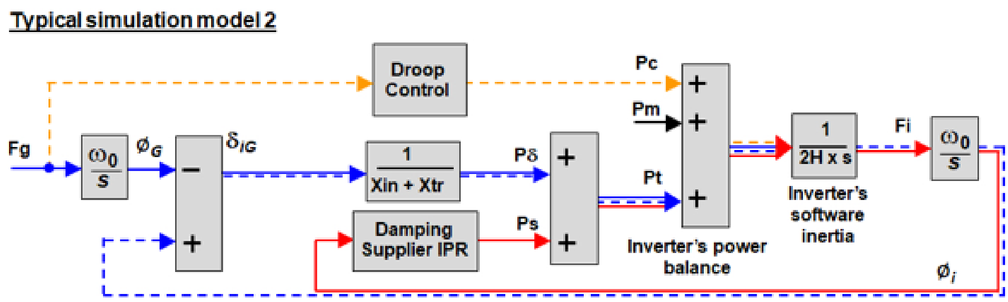

Figure 4 - Preferred simplified diagram of a system with a droop control ability that can add **Control-Based Active Droop Power.** This diagram does not add extra closed loop damping to the **GBGF-I Plant's** closed loop function shown by the solid red line and the dotted blue line.

1.8 Each **Grid Forming Plant** shall also be capable of:-

1.8.1 satisfying the requirements specified in Section 1.9

1.8.2 providing the values set out in in Part A 2.1 and Part A 2.2 and other **Grid Forming Capabilities** irrespective of the short circuit level at the **Grid Entry Point**.

1.8.3 providing any additional quality of supply requirements, including but not limited to Temporary over voltage (TOV) limits and **System Frequency** bandwidth limitations, as agreed with **The Company**. Such requirements would be pursuant to the terms of the **Bilateral Agreement.** For the avoidance of doubt, this requirement is in addition to the minimum quality of supply requirements detailed in CC.6.1.5, CC.6.1.6 and CC.6.1.7 (as applicable) or ECC.6.1.5, ECC.6.1.6 and ECC.6.1.7 (as applicable),

1.9 **GBGF Fast Fault Current Injection**

1.9.1 ***(Updated in V3)*** For **GBGF-I**, any balanced fault which results in the positive phase sequence voltage falling below the voltage levels specified in CC.6.1.4 or ECC.6.1.4 (as applicable) at the **Grid Entry Point**, **a GBGF-I Plant** shall, as a minimum be required to inject a reactive current of at least their **Peak Current Rating** when the voltage at the **Grid Entry Point** drops to zero. For intermediate retained voltages at the **Grid Entry Point**, the injected reactive current shall be on or above the black line drawn from the bottom left hand corner of the normal voltage control operating zone (shown in the rectangular green shaded area of Figure 5) and the specified **Peak Current Rating** at a voltage of zero at the **Grid Entry Point** as shown in Figure 5. The injected reactive current for **GBGF-I Plants**, shall also be on or below the red line drawn from the point equal to a **Grid Entry Point** voltage of 1.1pu on the right corner of the normal voltage control operating zone (shown in the rectangular green shaded area of Figure 5) and the maximum **Peak Current Rating** at a voltage of 0.3pu at the **Grid Entry Point** as shown in Figure 5. For the avoidance of doubt, **the Fast Fault Current Injection** of **GBGF-S plants** should be in line with the behavior of a directly coupled synchronous generator.

When the voltage at the **Grid Entry Point** is below 0.9pu but above 0pu, GBGF-I plants should utilise the rest of the inverter's current capability to inject active fault current with pre-fault active current as a target.

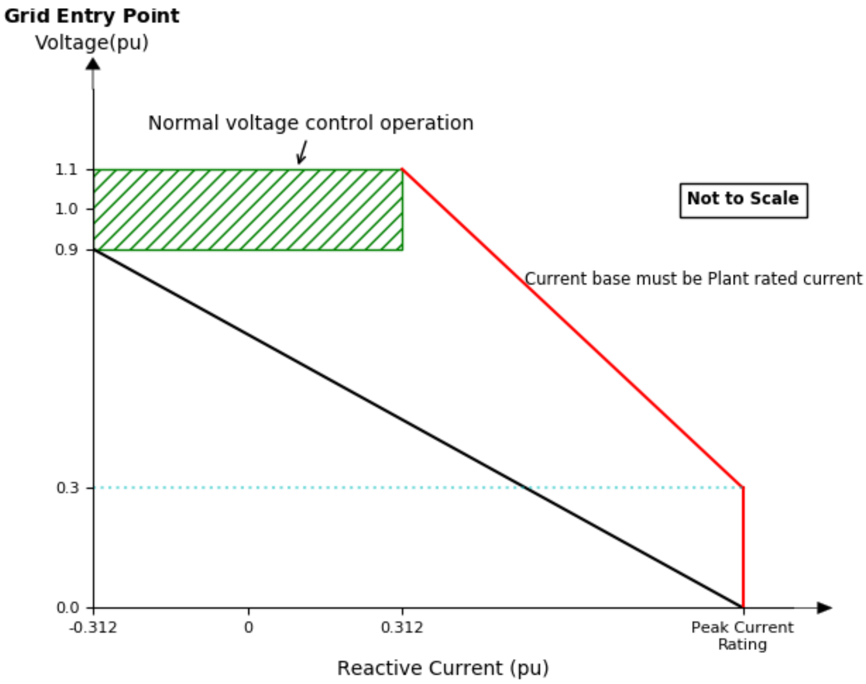

Figure 5 **(Updated in V3)**

1.9.2 Figure 5 defines the reactive current to be supplied under a faulted condition which shall be dependent upon the pre-fault operating condition and the retained voltage at the **Grid Entry Point**. For the avoidance of doubt, each **Grid Forming Plant** (and any constituent element thereof), shall be required to inject a reactive current which shall be not less than its pre-fault reactive current and which shall as a minimum, increase each time the voltage at the **Grid Entry Point** falls below 0.9pu whilst ensuring the overall rating of the **Grid Forming Plant** (or constituent element thereof) shall not be exceeded.

1.9.3 Each **Grid Forming Plant** shall be required to inject reactive current above the shaded area shown in Figure 6 when the retained voltage at the **Grid Entry Point** falls to 0pu. Where the retained voltage at the **Grid Entry Point** is below 0.9pu but above 0pu (for example when significant active current is drawn by loads and/or resistive components arising from both local and remote faults or disturbances from other **Plant** and **Apparatus** connected to the **Total System**) the injected reactive current component shall be in accordance with Figure 5.

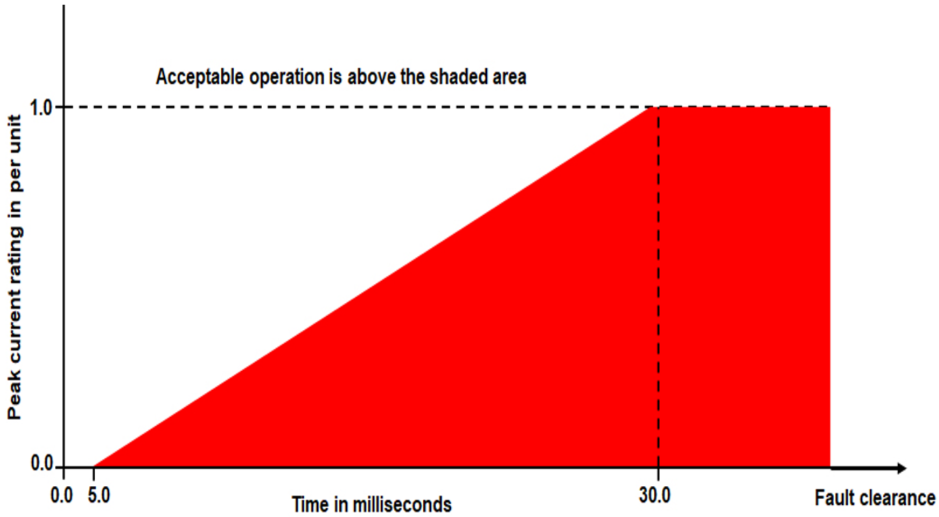

Figure 6

1.9.4 The injected current shall be above the shaded area shown in Figure 6 for the duration of the fault clearance time which for faults on the **Transmission System** cleared in **Main Protection** operating times shall be up to 140ms. Under any faulted condition, where the voltage falls outside the limits specified in CC.6.1.4 or ECC.6.1.4 (as applicable), there would be no requirement for each **Grid Forming Plant** or constituent part to exceed its **Peak Current Rating**.

1.9.5 For any planned or switching events (as outlined in CC.6.1.7 or ECC.6.1.7 of the Grid Code) or unplanned events which results in Temporary Over Voltages (TOV's), each **Grid Forming Plant** will be required to withstand the temporary over voltage limits specified sections 4.1 and 4.2 of TGN(E)288.

1.9.6 Each **Grid Forming Plant** shall be designed to reduce the risk of Temporary Over Voltage levels arising following clearance of the fault and in order to mitigate the risk of any form of instability which could result. The requirements for the maximum temporary overvoltage withstand capability and associated time duration, shall be in accordance with sections 4.1 and 4.2 of TGN(E)288.

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

1.9.8 In addition to the requirements of CC.6.3.15 or ECC.6.3.15, each **Grid Forming Plant Owner** is required to confirm to **The Company**, their repeated ability to supply **GBGF Fast Fault Current Injection** to the **Total System** each time the voltage at the **Grid Entry Point** falls outside the limits specified in CC.6.1.4 or ECC.6.1.4 (as applicable). **Grid Forming Plant Owners** should inform **The Company** of the maximum number of repeated operations that can be performed under such conditions and any limiting factors to repeated operation such as protection or thermal rating.

1.9.9 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).

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

2. Part A -Stability Requirements for the NOA Stability Pathfinder Phase 3

The **Grid Forming Plant Owner** shall:

2.1 ensure that during a fault, the short circuit level contribution from the **Grid Forming Plant/ Facility** will be XX MVA at the **Grid Entry Point**. Short circuit level defined as in Equation 1:

$$\textbf{Short circuit level (MVA)} = \sqrt{\mathbf{3}} * \textbf{Rated voltage (kV)} * \textbf{Fault current(kA)} \qquad \text{Equation 1}$$

Where:

the fault current is defined as the reactive positive sequence RMS fault current seen at 100ms after a 3-phase fault at the **Grid Entry Point** and Rated voltage is defined as the voltage at the **Grid Entry Point.**

Note: Equation 1 gives the reactive short circuit level since the reactive portion of the fault current is to be considered.

2.2 ensure that the **Grid Forming Plant/ Facility** will provide an inertial response with an inertia of XX MW.s or MJ. The inertial response must be provided for frequency changes in both directions.

Inertia shall be defined as in Equation 2:

$$\textbf{Inertia} = \frac{\Delta P\, f_0}{2 \times RoCoF} \qquad \text{Equation 2}$$

Where:

ΔP is the **Active Inertia Power** of the **Grid Forming Plant** for a frequency event of 1Hz/s (MW)

RoCoF is the Rate of Change of **Frequency** (**RoCoF**) in Hz/s

f_0 is the pre-fault **System Frequency** (Hz)

For **GBGF-I Plants,** the inertial response must be such that **Active Inertia Power** is provided without activating current limiting functions for a Rate of Change of System Frequency (**RoCoF**) whose magnitude is of less than or equal to 1Hz/s.

Additional requirements

The **Grid Forming Plant**/ **Facility** must be able to:

2.3 provide the values set out in in Part A 2.1 and Part A 2.2 based on the normal operating mode of the **Facility**. These include, but is not limited to, steady state active and reactive power operating modes, operating modes at all system voltages specified in in CC.6.1.4 or ECC.6.1.4 (as applicable) of the Grid Code, whichever is applicable. For the avoidance of doubt, such operating modes should not limit the ability to provide the capabilities set out in Parts A 2.1 and A 2.2 at any time.

2.4 in the event that the resulting **Active Inertia Power** would have caused the **Facility** to exceed its maximum overload capability or rated capability, a limited **Active Inertia power** can be supplied up to its maximum overload capability providing this value is reflected in Part A 2.2

2.5 Each **Grid Forming Plant Owner** is required to confirm to **The Company**, about their repeated ability to supply **Active Inertia Power** in the event of successive frequency events of either +1Hz/s or -1Hz/s lasting for 1 second each, without the need to charge or discharge in between the events. **Grid Forming Plant Owners** should inform **The Company** of the maximum number of repeated operations that can be performed under such conditions and any limiting factors to repeated operation such as storage capacity available for inertial response.

2.6 provide continuous voltage support through the injection of reactive current during a fault condition as defined in ECC.6.3.15. During a fault or voltage disturbance, priority should be given to the injection of reactive current whilst ensuring that active power recovery satisfies the requirements of ECC.6.3.15 (as applicable), though equally the performance expected from a synchronous machine would also be considered appropriate for this requirement.

2.7 ensure continuous and controllable operation shall be possible at all system voltages specified in CC.6.1.4, ECC.6.1.4.1, ECC.6.1.4.2, ECC.6.1.4.3 of the Grid Code, whichever is applicable.

2.8 ensure continuous and controllable operation shall be possible at all system frequencies specified in ECC.6.1.2.1.2 of the Grid Code.

2.9 ride through voltage depressions at the **Grid Entry Point** down to 0pu for up to 140ms as defined in ECC.6.3.15.

2.10 for the avoidance of doubt, a **Facility**, with an existing connection and meeting the additionality criteria is expected to comply with the specific sections of Grid Code referred to in this contract in addition to its normal Grid Code obligations.

Power Oscillation Damping of System Oscillations

2.11 The **Facility** shall be capable of active and/or reactive power oscillation damping achieved over a duration of 20s. The power oscillation damping shall:

2.11.1 inherently or through a control system contribute to damping sub-synchronous frequency oscillations in the system’s active or reactive power range over a frequency bandwidth of 0.3-2 Hz;

2.11.2 inject active or reactive current adequately in antiphase to achieve a reduction in oscillations (as described in 2.11.1) at the **Grid Entry Point**.

2.11.3 change the amount of active or reactive current injection proportional to the amplitude of the oscillations.

2.11.4 ensure the influence of any subsidiary control functions be no more than 10% of the machine rating.

2.12 If the **Facility** is to operate with a Power System Stabiliser (PSS) capability as specified through its **Bilateral Connection Agreement** and GB Grid Code then this PSS mode shall be used instead of the Power Oscillation damping specified in 2.11. If at any time during the length of the Stability Compensation Service, the **Facility** is not operating with a PSS, then, the **Facility** will need to meet requirements set out in 2.11.

Part B - Continuous Voltage Requirements

General requirement

1. The **Facility** shall, following an **Instruction**, have the capability to provide **Reactive Power** within the range set out in the following table[1].

Purpose	**GEP Voltage (pu)**	**Active Power condition (if applicable)**	**MW at GEP**	**Lead MVAr at GEP (absorption: -ve)**	**Lag MVar at GEP (injection: +ve)**
Required service (for **GBGF- I** and **GBGF-S**)	0.95	Maximum MW export			
		0 MW			
		Maximum MW import			
	1	Maximum MW export			
		0 MW			
		Maximum MW import			
	1.05	Maximum MW export			
		0 MW			
		Maximum MW import			
Required Service for **GBGF-I** only For **GBGF-S** this is only for information	0.9	Maximum MW export			
		0 MW			
		Maximum MW import			
	1.1	Maximum MW export			
		0 MW			

[1] Reactive generation and absorption values to be as specified by the tenderer in their tender submission. Relevant parts of the table to be filled in as required depending on technology type.

		Maximum MW import			

2. The reactive capability of **Grid Forming Plants** should be in accordance with the applicable sections of ECC.6.3.2. For all **Grid Forming Plants** where the voltage at the **Grid Entry Point** is between 0.95pu and 1.05pu inclusive, the values of reactive power injection and absorption at the **Grid Entry Point** should be no less than ±33MVAr or ±33% of the Maximum Active Power Capacity (Pmax) of the **Facility**, whichever is higher[2]. Please note that the minimum reactive power capability requirements should be available irrespective of the MW output of the **Grid Forming Plant**.
3. **GBGF-S Plants** and **GBGF-I Plants** for which there are no explicit reactive power provisions in the Grid Code e.g. the **Grid Forming Plants** that do not export MW (e.g. synchronous condensers) should meet the requirement as defined in Figures 7 and 8 respectively.
4. The reactive capability must be achievable at the **Grid Entry Point** where the voltage at the **Grid Entry Point** is between 0.95pu and 1.05pu inclusive. Operating at any point within this reactive range should not limit the ability to provide the values set out in Parts A 2.1 and A 2.2.

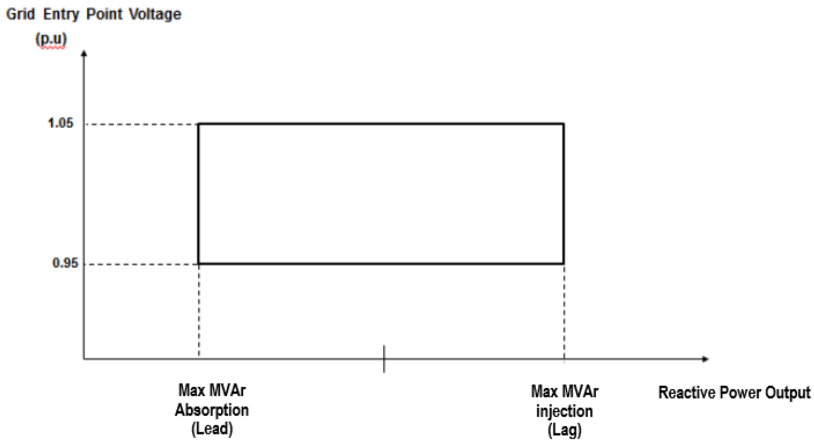

Figure 7 – Reactive Capability requirement for **GBGF-S Plants** not specified in the Grid Code

[2] Please note that where bays have been reserved for the Stability Pathfinder solutions (please refer to the connections approach document for details), a maximum of ±100MVAr has been studied per reserved bay and should tenderers wish to exceed this value, this can be discussed with the TO at the connection application stage post contract award.

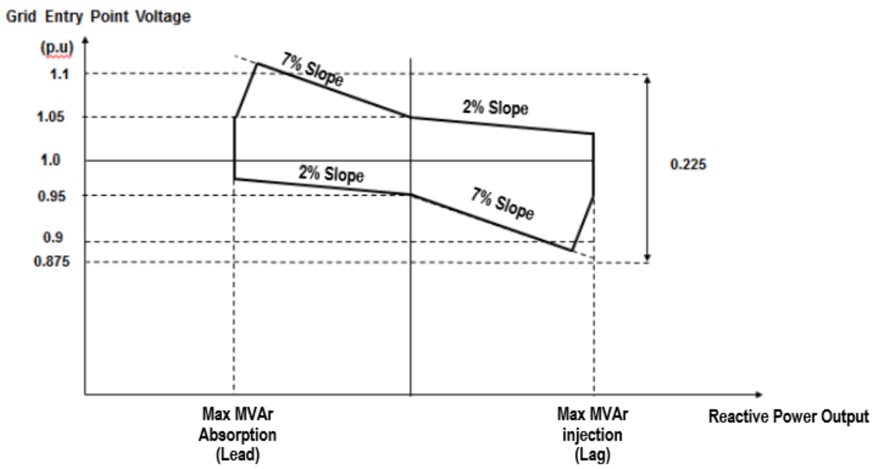

Figure 8 – Reactive Capability requirement for **GBGF-I Plants** not specified in the Grid Code

5. **For GBGF- I Plants,** the maximum reactive injection and absorption capability should be symmetrical around the 0MVAr point such that the slopes depicted in Figure 8 remain achievable.
6. The **Facility**'s excitation and voltage control shall be in accordance with the applicable sections of the Grid Code (e.g. ECC.6.3.8) and as specified in the Facility's Bilateral Connection Agreement. For the avoidance of doubt, **GBGF-S Plants** and **GBGF-I Plants** not explicitly catered for in ECC.6.3.8 should meet the requirements of ECC.6.3.8.3 and ECC.6.3.8.4 respectively.

Part C - Control and Indication Facilities

1. Where applicable, the transformer tap position shall be provided for by the Provider at **The Company's** operational metering system control and data acquisition (SCADA) outstation interface, as specified in the Provider's Bilateral Connection Agreement.
2. Where applicable, the following facilities for voltage control to the Company's instructions shall be provided by the Provider at a manned control point:

   2.1. Start-up of machine and transition to Stability Compensation mode.

   2.2. Shut-down of Stability Compensation mode.

   2.3. Target voltage setting (resolution 1kV) (for *Target Voltage* control mode).

   2.4. Control mode selection (Target Voltage).

   2.5. Slope setting (range 2% to 7%, resolution 0.5%.)

3. The following additional facilities for voltage/reactive power control shall be provided by the Provider. The Provider shall use all reasonable endeavours to adjust any of the following specified quantities on **The Company**'s instruction within 24 hours' notice. Adjustments including 3.1 and 3.2 shall not be made unless instructed by **The Company.**

   3.1. Change the voltage limits for Target Voltage mode (The setting shall be within range 0.93 to 1.07 pu. with a resolution of 0.005 pu).

4. In order to accurately monitor the performance of a **Grid Forming Plant**, **each Grid Forming Plant** shall be equipped with a facility to accurately record the following parameters at a rate of 10 ms : -
   4.1. System Frequency using a nominated algorithm as defined by **The Company**.
   4.2. The ROCOF rate using a nominated algorithm as defined by **The Company** based on a 500 ms rolling

average.

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

5. Detailed specifications for **Grid Forming Capability** dynamic performance including triggering criteria and sample rates, communication protocol and recorded data shall be specified by **The Company**.

6. 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**:

6.1. 1 kHz for **Grid Forming Plant** signals including fast fault current measurements.
6.2. 100Hz for the other **Grid Forming Plant** tests.

Part D - Model Provision

1. The Provider will prior to commissioning the **Facility**, submit a dynamic (Root mean Square - RMS) model and an electromagnetic transient (EMT) model in accordance with Grid Code PC.A.5.3.2 c option 2 or PC.A.5.4.2 as appropriate which provides a true and accurate reflection of the **Facility's Grid Forming Capability**.
2. **The Company** may accept an open RMS model (i.e. Transfer functions visible with no encryption on any block diagrams, equations or macros and not contain DLL code or requiring set up script to function) produced in DIgSILENT PowerFactory in a software version that is agreeable between the Company and the Provider.
3. The provider must submit an EMT model in a software that is agreeable between **The Company** and the Provider before commissioning of the **Facility**.
4. The Provider will submit a **Performance Chart** in accordance with Grid Code OC2.4.2.1.

Part E – Compliance Requirements

1. The **Company** shall provide a full set of test requirements no less than one (1) year before the **Scheduled Commercial Operations Date**.
2. For **Grid Forming Plant Owners,** the Operational Notification Process contained in ECP.5 to ECP.7 shall apply in relation to the type of Plant to which the **Grid Forming Capability** is provided (be it a **GBGF-S Plant** or **GBGF-I Plant**) in order for the User's **Facility** to become operational.