Draft Grid Code – Grid Forming Converter Specification

30 March 2021_Final

Key – Black Text – Original Grid Code

Red Underlined Text – New requirements introduced for GC0137

Grid Forming Capability	Is 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** or **Dynamic Reactive Compensation Equipment** whose **Active Power** output is directly proportional to the magnitude and phase of its **Internal Voltage Source**, the magnitude and phase of the voltage at the **Grid Entry Point** or **User System Entry Point** and the sine of the **Load Angle**. As a consequence, a **Plant** which has a **Grid Forming Capability** is one where the frequency of 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. 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** or **User System Entry Point**) with a bandwidth that is less than a defined value as shown by the system's **NFP** Plot. Exceptions to this rule are allowed only during transients caused by **System** faults, voltage dips/surges and/or a step or ramp changes in the phase angle which are large enough to cause damage to the **Grid Forming Plant** via excessive currents.
Grid Forming Plant	A **Plant** which is classified as either a **GBGF-S** or a **GBGF-I**
GBGF-S	Is a **Synchronous Power Generating Module**, **Synchronous Electricity Storage Module** or **Synchronous Generating Unit** with a **Grid Forming Capability**.
GBGF-I	Is any **Power Park Module**, **HVDC System**, **DC Converter**, **OTSDUW Plant and Apparatus**, **Non-Synchronous Electricity Storage Module**, **Dynamic Reactive** or **Compensation Equipment** which is connected or partly connected to the **Total System** via an **Electronic Power Converter** which has a **Grid Forming Capability** **(GBGF-I)**.
ROCOF Response Power	**ROCOF Response Power** is defined as the Phase-based **real Inertia Power** plus the **Control-Based Real Droop Power** that can be supplied by a **Grid Forming Plant** when subject to a rate of change of the **System Frequency**.
ROCOF	**Rate of Change of System Frequency**

Control Based Real Droop Power	**Control Based real Droop Power** output is the transfer of **Active Power** injected or absorbed by a **Grid Forming Plant** to and from the **Total System** during a **System Frequency** deviation away from the normal **System Frequency**. For a **GBGF-I Plant** this is very similar to **Primary Response** but with a response time to achieve **Maximum Capacity** or **Registered Capacity** within 1 second. For **GBGF-I Plant** this can rapidly add extra **ROCOF Response Power** in addition to the phase-based **Real Inertia Power** to provide a system with desirable **NFP** plot characteristics.
Grid Forming Electronic Power Converter	A **Grid Forming Plant** whose output is derived from a static solid state **Electronic Power Converter** with a **GBGF-I** capability.
Grid Forming Unit	A **Power Park Unit** or **Electricity Storage Unit** or a **Synchronous Power Generating Unit**. with a **Grid Forming Capability**
Fast Fault Current Injection	The ability of a **Grid Forming Plant** to supply reactive current, that starts to rise in less than 5 ms, into the **Total System** when the voltage falls below 90% of its nominal value.
Real Inertia Power	The transfer of **Active Power** injected or absorbed by a **Grid Forming Plant** to and from the **Total System** during a **System Frequency** change. Since the frequency of rotation of the **Internal Voltage Source** of a **Grid Forming Plant** is the same as the **System Frequency** for normal operation, the **Active Power** supplied or absorbed by the **Grid Forming Plant** is a function of the energy storage capability of the **Internal Voltage Source**. For the avoidance of doubt, this includes the rotational inertial energy of the complete drive train of a **Synchronous Generating Unit**. **Real Inertia Power** is an inherent capability of a **Grid Forming Plant** to respond naturally, within less than 5 ms, to changes in the **System Phase** and **System Frequency**. For the avoidance of doubt the **Real Inertia Power** can have frequency components to over 1000 Hz.

Internal Voltage Source or **IVS**	For a **GBGF-S Unit** a real magnetic field, that rotates synchronously with the **System Frequency** under normal operating conditions, which as a consequence induces an **Internal Voltage Source** in the stationary generator winding that has a real impedance. In a **GBGF-I** design, 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** the impedance, between the **Internal Voltage Source** and the **Grid Entry Point** or **User System Entry Point** can only have real physical values. 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** or **User System Entry Point**.
Non-CUSC Party	A Party who does not accede to the **Connection and Use of System Code** (**CUSC**).
Damping Active Power	The **Active Power** naturally supplied by a **Grid Forming Plant** as a result of oscillations in the **Total System**. More specifically, **Damping Active Power** is the result of an oscillation between the voltage at the terminals of a **Grid Forming Unit** and the voltage of the **Internal Voltage Source** of the **Grid Forming Unit**. For the avoidance of doubt, **Damping Active Power** is an inherent capability of a **Grid Forming Plant** that starts to respond naturally, within less than 5 ms.
Defined Damping Active Power	The **Damping Active Power** supplied by a **GBGF-I Plant** when it is operating at the **Grid Oscillation Value** defined in Table ECC.6.3.19.3.2 of ECC.6.3.19.3(vii).
Grid Oscillation Value	This has a defined amplitude of 0.05 Hz peak to peak at a frequency of 1 Hz and is used for the rating of the **Defined Damping Active Power**.
Peak Current Rating	For a **GBGF-I Plant** this is the larger of either the: - • Maximum current to supply the **ROCOF Response Power** plus the **Defined Damping Active Power**; or. • The maximum current to supply the **Phase Jump Angle limit power**, or. • The maximum current defined by the **User** or **Non-CUSC Party**.

Phase Jump Active Power	The transient **Active Power** transferred from a **Grid Forming Plant** to the **Total System** as a result of changes in the phase angle between the **Internal Voltage Source** of the **Grid Forming Plant** and the **Grid Entry Point** or **User System Entry Point**. In the event of a disturbance or fault on the **Total System**, a **Grid Forming Plant** will instantaneously supply **Phase Jump Active 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**. **Phase Jump Active Power** is an inherent capability of a **Grid Forming Plant** that starts to respond naturally, within less than 5 ms, and can have frequency components to over 1000 Hz.
Phase Jump Angle Limit	The minimum defined **Phase Jump Angle** for a **GBGF-I Plant** remaining in linear control without current limiting
Phase Jump Angle Withstand	The maximum **Phase Jump Angle** for a **GBGF-I Plant** remaining in operation and with current limiting
Phase Jump Angle Rating	The actual **Phase Jump Angle** for a **GBGF-I Plant** when operating in the linear mode of operation and where the **Peak Current Rating** has not been exceeded. **This angle** can be a higher value than the **Phase Jump Angle Limit** value.
Control Based Real Power	**Control Based Real Power** output supplied by a **Grid Forming Plant** through controlled means (be it manual or automatic). For **GBGF-I Plant** is equivalent to that of a **Synchronous Generating Unit** with a traditional governor coupled to its prime mover or traditional **Automatic Voltage Regulator** coupled to its **Excitation System**. **Control Based Real 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**.
Control Based Reactive Power	**Control Based Reactive Power** output supplied by a **Grid Forming Plant** through controlled means (be it manual or automatic).
Voltage Jump Reactive Power	The transient **Reactive Power** transferred from a **Grid Forming Plant** to the **Total System** as a result of either a step or ramp change in the difference between the voltage magnitude and the voltage of the **Internal Voltage Source** of the **Grid Forming Plant** and **Grid Entry Point** or **User System Entry Point**. In the event of a voltage magnitude and phase change at the **Grid Entry Point** or **User System Entry Point**, a **Grid Forming Plant** will instantaneously supply **Voltage Jump Reactive Power** to the **Total System** as a result of the voltage magnitude change.
Dynamic Reactive Compensation Equipment	**Plant** capable of supplying or absorbing **Reactive Power** in a controlled manner which could include but not limited to a Synchronous Compensator, Static Var Compensator (SVC), or STATCOM.

Network Frequency Perturbation Plot	A **Network Frequency Perturbation (NFP) Plot** is a form of Bode Plot which plots the amplitude (%) of the output oscillation and Phase (degrees) to the frequency of an applied input oscillation. The purpose of which is to assess the capability and performance of a **Grid Forming Plant** and to ensure it does not pose a risk to other **Plant** and **Apparatus** connected to the **Total System**. For **GBGF-I Plant**, these are used to provide data to **The Company** which together with the associated **Nicholls Chart** defines 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 Apparent Power**. For the avoidance of doubt **GBGF-S Plant** provide their data using the existing formats and do not need to supply **NFP** plots.
Nicholls Chart	For a **GBGF-I Plant** a **Nicholls chart** is derived from the open loop Bode plots that are used to produce an **NFP Plot**. The **Nicholls 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 immediately defined for use in defining the **GBGF-I's** equivalent **Damping Factor**
Electronic Power Converter	A design which uses switched solid state power electronic devices to produce a real voltage waveform, that has a fundamental component with harmonics.
Control Based	**Control Based** are changes in the positive phase sequence Root Mean Square **Active Power** or **Reactive Power** produced at fundamental **System Frequency** by the control system of a **Grid Forming Unit** that occur due to changes in the outer control loops of a **Grid Forming Plant** or as a result of a change to an externally supplied setpoint or parameter (such as **Active Power**, **Reactive Power**, voltage, **System Frequency**, **Droop** or **Slope**) or to a parameter at the **Grid Entry Point** or **User System Entry Point** (if **Embedded**) connected to the control system. For **GBGF-I Plant** these **Control Based** changes have a bandwidth limited to 5 Hz. The "outer" control loops of a **Grid Forming Plant** refer to those functions classically provided in a **Synchronous Generating Unit** by a traditional governor coupled to its prime mover, or by an **Automatic Voltage Regulator (AVR)** coupled to its **Excitation System**. The "outer" control loops do not include the "inner" parts of a **GBGF-I's** control system which emulate the inertia and damping functions provided by a real **Synchronous Generating Unit.** **A GBGF-I** system has the ability to provide higher **Damping Factors** than a typical **Synchronous Generating Unit**, and higher or lower inertia constants than a typical **Synchronous Generating Unit**.

Damping Factor (ζ)	It is 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 **Nicholls 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.

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Extracts from the Connection Conditions

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CC.6.3.5 It is an essential requirement that the **National Electricity Transmission System** must incorporate a **Black Start Capability**. This will be achieved by agreeing a **Black Start Capability** with a number of strategically located **Black Start Service Providers**. For each **Black Start Service Provider The Company** will state in the **Bilateral Agreement** whether or not a **Black Start Capability** is required. For the avoidance of doubt, a **GBGF-I Plant** designed with a with a **Black Start Capability** would also be required to have a **Grid Forming Capability** in accordance with the requirements of ECC.6.3.19.

Extracts from the European Connection Conditions

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ECC.6.3.5.3 Where an **EU Code User** has entered into a **Black Start Contract** to provide a **Black Start Capability** in respect of a **Type C Power Generating Module** or **Type D Power Generating Module** (including **DC Connected Power Park Modules)** the following requirements shall apply.

(i) The **Power-Generating Module** or **DC Connected Power Park Module** shall be capable of starting from shutdown without any external electrical energy supply within a time frame specified by **The Company** in the **Black Start Contract**;

(ii) Each **Power Generating Module** or **DC Connected Power Park Module** shall be able to synchronise within the **System Frequency** limits defined in ECC.6.1.2 and, where applicable, voltage limits specified in ECC.6.1.4;

(iii) The **Power Generating Module** or **DC Connected Power Park Module** shall be capable of connecting on to an unenergised **System**;

(iv) The **Power-Generating Module** or **DC Connected Power Park Module** shall be capable of automatically regulating dips in voltage caused by connection of demand;

(v) The **Power Generating Module** or **DC Connected Power Park Module** shall:

be capable of **Block Load Capability**

be capable of operating in **LFSM-O** and **LFSM-U**, as specified in ECC.6.3.7.1 and ECC.6.3.7.2

control **System Frequency** in case of overfrequency and underfrequency within the whole **Active Power** output range between the **Minimum Regulating Level** and **Maximum Capacity** as well as at houseload operation levels be capable of parallel operation of a few **Power Generating Modules** including **DC Connected Power Park Modules** within an isolated part of the **Total System** that is still supplying **Customers**, and control voltage automatically during the system restoration phase,

be capable of satisfying the **Grid Forming Capability** requirements defined in ECC.6.3.19;

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ECC.6.3.16 **FAST FAULT CURRENT INJECTION**

ECC.6.3.16.1 General **Fast Fault Current injection**, principles and concepts applicable to Type B, Type C and Type D Power Park Modules and HVDC Equipment

ECC.6.3.16.1.1 In addition to the requirements of ECC.6.1.4, ECC.6.3.2, ECC.6.3.8 and ECC.A.7, 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** shall be required to satisfy the following requirements. For the purposes of this requirement, current and voltage are assumed to be positive phase sequence values. For the avoidance of doubt, any **Type B**, **Type C** and **Type D Power Park Module** or **HVDC Equipment** which has a **Grid Forming Capability** need only satisfy the requirements of ECC.6.3.19 and the requirements of ECC.6.3.16 shall not apply.

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ECC.6.3.19 **GRID FORMING CAPABILITY** FOR GREAT BRITAIN

ECC.6.3.19.1 In order for the **National Electricity Transmission System** to satisfy the stability requirements defined in the **National Electricity Transmission System Security and Quality of Supply Standards**, it is an essential requirement that an appropriate volume of **Grid Forming Plant** is available and capable of providing a **Grid Forming Capability**.

ECC.6.3.19.2 **Grid Forming Capability** is not a mandatory requirement but one which will be delivered through market arrangements, the details of which shall be published on **The Company's Website**. **Grid Forming Capability** can be implemented by any technology including **Electronic Power Converters** with a **GBGF- I** ability, rotating **Synchronous Generating Units** or a combination of the two.

ECC.6.3.19.3 As noted in ECC.6.3.19.2, **Grid Forming Capability** is not a mandatory requirement, however where a **User** (be they a **GB Code User** or **EU Code User**) or **Non-CUSC Party** wishes to offer a **Grid Forming Capability**, then they will be required to ensure their **Grid Forming Plant** meets the following requirements.

(i) 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**).

(ii) 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** or **User System Entry Point** (if **Embedded**) 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** or **User System Entry Point** (if **Embedded**).

(iii) 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).

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

(v) Each **GBGF-I Plant** shall be capable of:-

(a) Providing a symmetrical ability for importing and exporting **ROCOF Response Power**, **Phase Jump Active Power**, **Damping Active Power** and **Control Based Real 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 system with time limited output ratings.

(b) Operating as a voltage source behind a real reactance.

(c) being designed so as not to cause any undue interactions which could cause damage to the **Total System** or other **User's Plant** and **Apparatus** connected to it.

(d) include a **Control Based** part of the control system that can respond to changes in the **Grid Forming Plant** or external signals from the **Total System** available at the **Grid Entry Point** or **User System Entry Point** but with a bandwidth below 5 Hz to avoid AC **System** resonance problems.

(e) meeting the requirements of ECC.6.3.13 irrespective of being owned or operated by a **GB Code User**, **EU Code User** or **Non-CUSC Party**. As an additional requirement, all **GBGF-I Plant** are required to have a rate of change of **System Frequency** withstand setting of 2Hz/s.

(f) operate over the range shown in Figure ECC.6.3.19.3. **GBGF-I Plant** with an importing capability mode of operation such as **DC Converters**, **HVDC Systems** and **Electricity Storage Modules** are required to operate over the full import and export range. 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

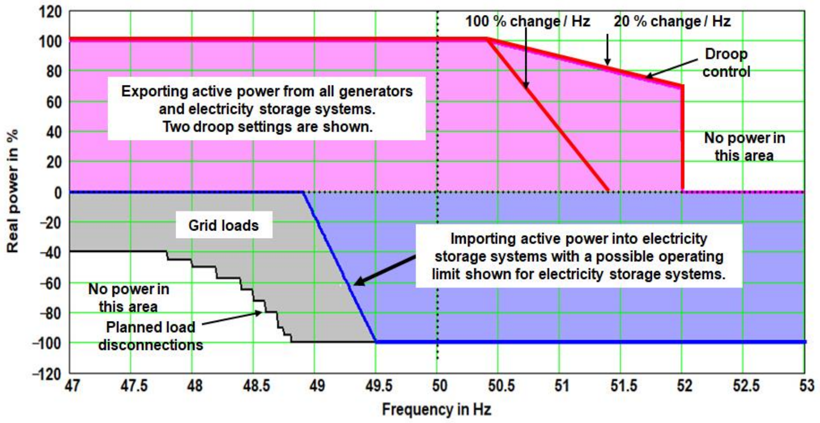

Figure ECC.6.3.19.3

(vi) Each **User** shall design their **GBGF-I** system with a **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 **System** impedance at the **Grid Entry Point** or **User System Entry Point**.

The output of the **Grid Forming Plant** shall be designed such that following a disturbance on the **System**, the **Active Power** output and **Reactive Power** output shall be adequately damped. The damping shall be judged to be adequate if the corresponding **Active Power** response to a disturbance decays within two cycles of oscillation.

(vii) 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 **Nicholls chart** (or equivalent as agreed with **The Company**) which shall be assessed in accordance with the requirements of ECP.A.3.9.3.

Each **User** or **Non-CUSC Party** is required to supply a high level equivalent architecture diagram of their **Grid Forming Plant** as shown in Figure ECC.6.3.19.3.1 together with the equivalent linear classical block diagram model (using the Laplace Operator) of their **Grid Forming Plant** which should be in the general form shown in Figure ECC.6.3.19.3.2 (a) or Figure ECC.6.3.19.3.2 (b). For submitting either Figure ECC.6.3.19.3.2 (a) or Figure ECC.6.3.19.3.2 (b), each **User** or **Non-CUSC Party** can use their own design, that may be very different to the Figures ECC.6.3.19.3.2 (a) or ECC.6.3.19.3.2 (b), but should contain all relevant functions.

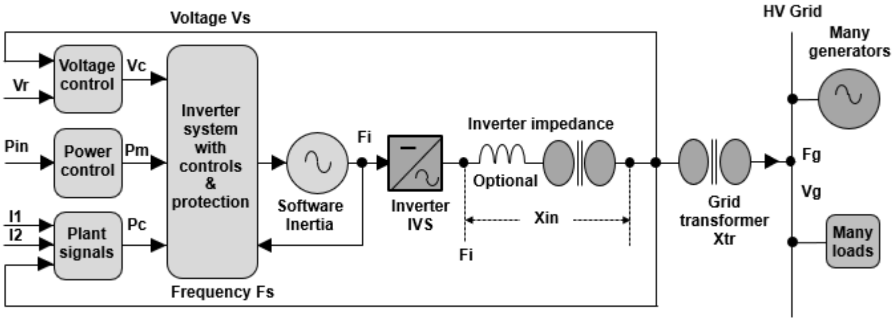

Figure ECC.6.3.19.3.1

Typical simulation model 1

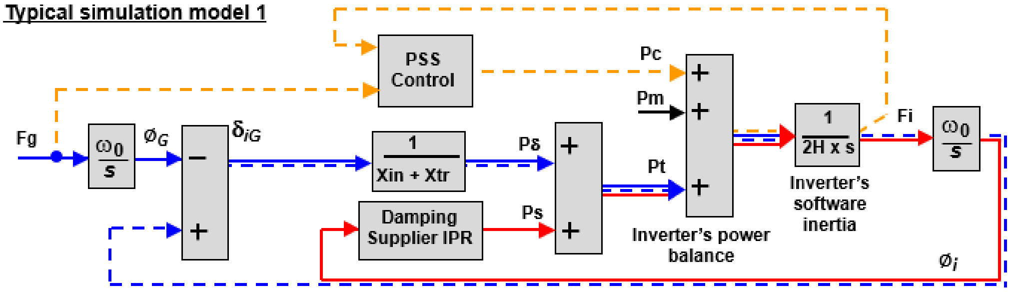

Figure ECC.6.3.19.3.2 (a) Simplified diagram of a **GBGF-I Plant** with a **Power System Stabiliser "PSS"** that can add damping to the **GBGF-I Plant**'s closed loop function shown by the solid red line and the dotted blue line.

Typical simulation model 2

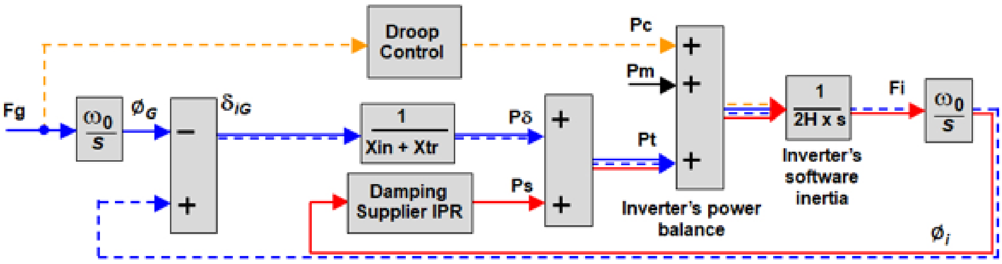

Figure ECC.6.3.19.3.2 (b) - Simplified diagram of a system with a droop control ability that can add **Control-Based Real Droop Power.** This diagram does not add damping to the **GBGF-I Plant's** closed loop function shown by the solid red line and the dotted blue line.

(vii) 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 Plant** in accordance with Figures ECC.6.3.19.3.1 and ECC.6.3.19.3.2 **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 ECC.6.3.19.3.1 defines the notation used in Figure ECC.6.3.19.3.1

Parameter	**Symbol**	**Units**
The primary reactance of the **Grid Forming Unit**, in pu.	Xin	pu on MVA **Rating of Grid Forming Unit**
The additional reactance, in pu, between the terminals of the **Grid Forming Unit** and the **Grid Entry Point** or **User System Entry Point** (if **Embedded**).	X_{tr}	pu on MVA **Rating of Grid Forming Unit**
The rated angle between the **Internal Voltage Source** and the input terminals of the **Grid Forming Unit**.		radians
The rated angle between the **Internal Voltage Source** and **Grid Entry Point** or **User System Entry Point** (if **Embedded**).		radians
The rated voltage and phase of the **Internal Voltage Source** of the **Grid Forming Unit**. The voltage is taken to be 1pu and the Grid as 0 degrees		Voltage - 1pu Phase - radians
The rated electrical angle between current and voltage at the input to the Grid transformer.		radians

Table ECC.6.3.19.3.1

(vi) In order 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 Plant** in in accordance with Table ECC.6.3.19.3.2 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**.

Quantity	**Units**	**Range (where Applicable)**	**User Defined Parameter**
Type of **Plant** (eg **Generating Unit**, **Electricity Storage Module**, **Dynamic Reactive Compensation Equipment**	N/A		
Maximum Continuous Rating			
Primary reactance X (see Table 1)	pu on MVA		
Additional reactance X_{tr} (See Table 1)	pu on MVA		
Maximum Capacity	MW		

ROCOF Response Power (MW) supplied or absorbed at 1Hz/s **System Frequency** change	MW		
Phase Jump Angle Withstand	degrees		60 degrees specified
Phase Jump Angle limit	degrees		5 degrees recommended
Phase Jump Angle Rating for **Current Limit**	degrees		
Phase Jump Power (MW) at the rated angle	MW		
Defined Damping Active Power for a **Grid Oscillation Value** of 0.5 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 real transient output of the **Grid Forming Plant**	MWs		
Inertia Constant using equation 1	H		
Continuous Overload Capability	% on MVA		
Short Term duration Overload capability			
Duration of Short Term Overload Capability	s		
Peak Current Rating	pu		
Nominal **Grid Entry Point** or **User System Entry Point** voltage	kV		
Grid Entry Point or **User System Entry Point**	- Location		
Continuous or defined time duration MVA Rating	MVA		
Continuous or defined time duration MW Rating	MW		
For a **GBGF-I Plant** the inverters maximum **Internal Voltage Source (IVS)** for the worst case condition.	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

Table ECC.6.3.19.3.2

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

Equation 1

ECC.6.3.19.4 In addition to the requirements of ECC.6.3.19.1 – ECC.6.3.19.4 each **Grid Forming Plant** shall be capable of:-

(i) Satisfy the requirements of ECC.6.3.19.5.

(ii) As a minimum, each **Grid Forming Plant** shall be capable of operating at a minimum short circuit level as defined by **The Company** which would be dependent upon the location of the **Grid Entry Point** or **User System Entry Point**.

(iii) 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** in accordance with the requirements of ECP.A.3.9.2.

(iv) 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), each **Grid Forming Plant** owner whose **Grid Forming Plant** has a **Connection Point** to the **National Electricity Transmission System**, shall agree any additional quality of supply requirements, including but not limited to Temporary Over-voltage limits (TOV's) and **System Frequency** bandwidth limitations, with **The Company**. Such requirements would be pursuant to the terms of the **Bilateral Agreement**.

ECC.6.3.19.5 **Fast Fault Current Injection** applicable to **GBGF-I Plant**

ECC.6.3.19.5.1 For any balanced fault which results in the positive phase sequence voltage falling below the voltage levels specified in CC.6.1.4 or ECC.6.1.4 (as applicable) at the **Grid Entry Point** or **User System Entry Point** (if **Embedded**), a **Grid Forming Plant** shall, as a minimum be required to inject a reactive current above the heavy black line shown on the right-hand side in Figure ECC.16.3.19.5(a) for a **Peak Current Rating** of 1.0 pu. The line defining the limit for the reactive current depends on the systems **Peak Current Rating** and Figure ECC.16.3.19.5(a) show typical limit lines for a **Peak Current Rating** of 1.0 pu and 1.5 pu.

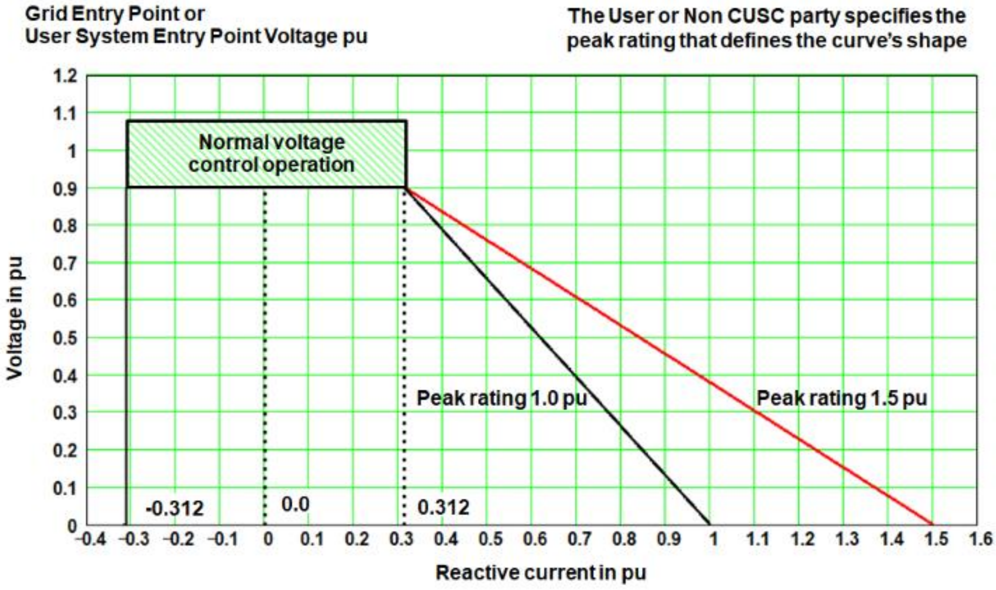

Figure ECC.6.3.19.5(a)

ECC.6.3.19.5.2 Figure ECC.6.3.19.5(a) defines the reactive current to be supplied under a faulted condition which shall be dependent upon the pre-fault operating condition and the retained voltage at the **Grid Entry Point** or **User System Entry Point** voltage. For the avoidance of doubt, each **Grid Forming Plant** (and any constituent element thereof), shall be required to inject a reactive current which shall be not less than its pre-fault reactive current and which shall as a minimum, increase each time the voltage at the **Grid Entry Point** or **User System Entry Point** (if **Embedded**) falls below 0.9pu whilst ensuring the overall rating of the **Grid Forming Plant** (or constituent element thereof) shall not be exceeded.

ECC.6.3.19.5.3 In addition to the requirements of ECC.6.3.19.5.1 and ECC.6.3.19.5.2, each **Grid Forming Plant** shall be required to inject reactive current above the shaded area shown in Figure ECC.6.3.19.5(b) when the retained voltage at the **Grid Entry Point** or **User System Entry Point** falls to 0pu. Where the retained voltage at the **Grid Entry Point** or **User System Entry Point** is below 0.9pu but above 0pu the injected reactive current component shall be in accordance with Figure ECC.6.3.19.5(a).

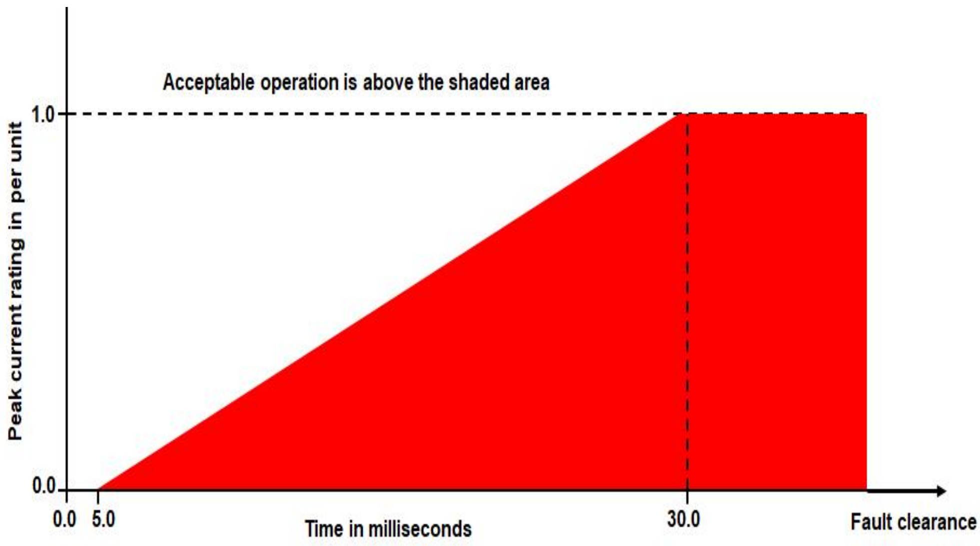

Figure ECC.16.3.19.5(b)

ECC.6.3.19.5.4 The injected current shall be above the shaded area shown in Figure ECC.6.3.19.5(b). 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 transient or steady state rating as defined in Table ECC.6.3.19.3.2 of ECC.6.3.19.3(x).

ECC.6.3.19.5.5 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 power **System Frequency** over voltages (TOV's), each **Grid Forming Plant** will be required to satisfy the transient overvoltage limits specified in the **Bilateral Agreement**.

ECC.6.3.19.5.6 For the purposes of this requirement, the maximum rated current would be the **Peak Current Rating** declared by the **Grid Forming Plant** owner in accordance with Table ECC.6.3.19.3.2 of ECC.6.3.19.3(ix).

ECC.6.3.19.5.7 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.

ECC.6.3.19.5.8. Each **Grid Forming Plant** shall be designed to reduce the risk of transient over voltage levels arising following clearance of the fault and in order to mitigate the risk of any form of instability which could result. The requirements for the maximum transient overvoltage withstand capability and associated time duration, shall be agreed between the **User** or **Non-CUSC Party** and **The Company** as part of the **Bilateral Agreement**.

ECC.6.3.19.5.9 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 **Fast Fault Current** to the **System** each time the voltage at the **Grid Entry Point** or **User System Entry Point** falls outside the limits specified in CC.6.1.4 or ECC.6.1.4 (as applicable). **Grid Forming Plant** owners should inform **The Company** of the maximum number of repeated operations that can be performed under such conditions and any limiting factors to repeated operation such as protection or thermal rating.

ECC.6.3.19.5.10 In the case of a **Power Park Module** or **DC Connected Power Park Module**, where it is not practical to demonstrate the compliance requirements of ECC.6.3.19.5.1 to ECC.6.3.19.5.5 at the **Grid Entry Point** or **User System Entry Point**, **The Company** will accept compliance of the above requirements at the **Power Park Unit** terminals.

ECC.6.3.19.5.11 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 retained unbalanced voltage without exceeding the transient **Peak Current Rating** of the **Grid Forming Plant** (or constituent element thereof).

ECC.6.3.19.5.12 In the case of an unbalanced fault, the **User** or **Non-CUSC Party** shall confirm to **The Company** their ability to prevent transient overvoltages arising on the remaining healthy phases and the control strategy employed.

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ECC.6.6.1.8 The facilities for quality of supply and dynamic system behavior monitoring shall include arrangements for the **HVDC System Owner** and **The Company** and/or **Relevant Transmission Licensee** to access the information electronically. The communications protocols for recorded data shall be agreed between the **HVDC System Owner**, **The Company** and the **Relevant Transmission Licensee**.

ECC.6.6.1.9 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 : -

- **System Frequency with a high immunity to Grid phase jumps**
- Rate of change of **System Frequency**
- Grid Phase Jumps

ECC.6.6.1.10 Detailed specifications for **Grid Forming Capability** dynamic performance including triggering criteria and sample rates are listed as **Electrical Standards** in the **Annex** to the **General Conditions**. For **Grid Forming Capability** dynamic monitoring, the specification for the communication protocol and recorded data shall also be included in the **Electrical Standard**.

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ECC.6.6.3.2 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**:

(i) 1 Hz for reactive range tests

(ii) 10 Hz for **System Frequency** control tests

(iii) 100 Hz for voltage control tests

(iv) 1 MHz for **Grid Forming Plant** tests

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Extracts from the European Compliance Processes

APPENDIX 3

ECP.A.3.9 **Grid Forming Plant** verification and validation

ECP.A.3.9.1 This section applies to **Users** and **Non CUSC Parties** who own and operate **GBGF-I Plant** to demonstrate the ability of their **Grid Forming Plant** to satisfy the requirements of ECC.6.3.19. For the avoidance of doubt these requirements are not necessary from owner and operators of **GBGF-S Plant**.

ECP.A.3.9.2 For initial approval **Users** and **Non CUSC Parties** are required to submit the following data of their **Grid Forming Plant** to **The Company**: -

a) The representation of their **Grid Forming Plant** in a format either the same as Figure ECC.6.3.19.3.1 of ECC.6.3.19.3(viii) or in an equivalent format.

b) The data associated with their **Grid Forming Plant** as required in Table ECC.6.3.19.3.1 and Table ECC.6.3.19.3.2 of ECC.6.3.19.3.

c) A linearised model and parameters of the **Grid Forming Plant** in the frequency domain in the same format as Figure ECC.6.3.19.3.2(a) or Figure ECC.6.3.19.3.2 (b) as shown in ECC.6.3.19.3(viii) or equivalent.

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

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

ECP.A.3.9.3 For **GBGF-I Plant** 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**.

ECP.A.3.9.4 For final approval **Users** and **Non CUSC Parties** are required to demonstrate that the **GBGF I Plant** model is capable of supplying **ROCOF Response Power**, and **Phase Jump Active Power**, and submit a full 3 phase simulation study in the time domain representing the response of the **Grid Forming Plant** over a range of operating conditions. The simulation study shall comprise of the following stages.

i) A simulation study to the equivalent shown in Figure ECP.A.3.9.4.

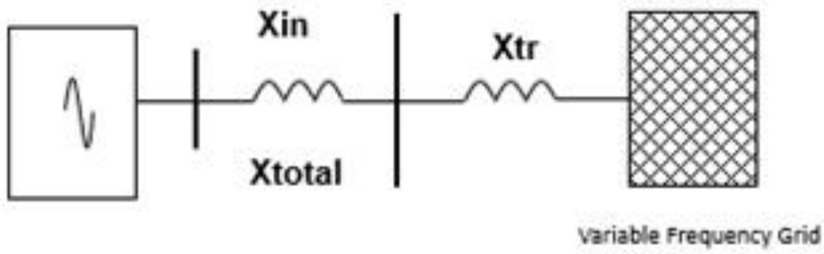

Figure ECP.A.3.9.4

ii) The first simulation test is to demonstrate that the **GBGF-I Plant** model is capable of supplying **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 full load, the Grid **System Frequency** is increased from 50Hz to 51Hz at a rate of 1Hz/s with measurements of the **Grid Forming Plant's 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

iii) The second simulation test is to demonstrate the **GBGF-I Plant's** ability to supply **ROCOF Response Power** and asses its withstand capability under extreme **System Frequencies**. The Grid **System Frequency** is increased from 50Hz to 52Hz at a rate of 1Hz/s with measurements of the **ROCOF Response Power**, **System Frequency** and time in (ms). This repeated when the Grid **System Frequency** is increased from 50Hz to 52Hz at a rate of 2 Hz/s with measurements of the **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.

iv) The third simulation is to demonstrate the **Grid Forming Plant's** ability to supply **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 **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 **ROCOF Response Power**, **Reactive Power**, voltage and **System Frequency**.

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

v) The fourth simulation is to demonstrate the **Grid Forming Plant's** ability to supply **Phase Jump Active 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.

(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.

vi) The fifth simulation is to demonstrate the **Grid Forming Plant's** ability to supply **Phase Jump Active 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.

vii) The sixth simulation is to demonstrate the **Grid Forming Plant's** ability to supply **Fault Ride Through** and **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** and voltage control) 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 Plant's** current limit should be observed to operate.

(d) Repeat steps (a) to (c) but on this occasion with fault ride through, **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.

ECP.A.3.9.5 To demonstrate the **GBGF-I Plant** model is capable of supplying **ROCOF Response Power** and **Phase Jump Active 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.

i) The **User** or **Non CUSC Party** in respect of **GBGF-I Plant** should supply a simulation study to **The Company** equivalent to Figure ECP.A.3.9.5.

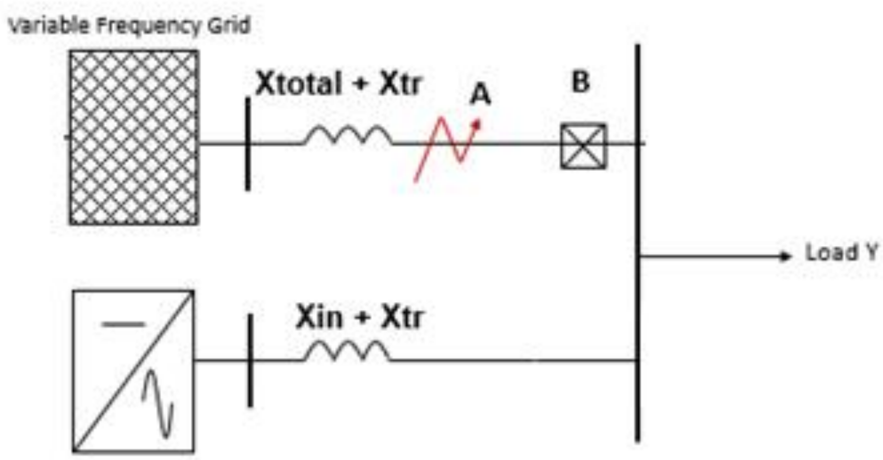

Figure ECP.A.3.9.5

ii) 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.**

iii) With the system running in steady state the **GBGF-I Plant** 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.

iv) 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.

v) 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.

ECP.A.3.9.6 To demonstrate the **Grid Forming Plant** model is capable of contributing to **Damping Active Power**, the **GBGF-I Plant** owner is required to supply a simulation study by injecting a **Test Sine Wave** into the **GBGF-I Plant** model as supplied in ECPA.3.9.2.

The test Sine wave comprises of a 50 Hz fundamental with a low frequency disturbance equivalent to balance positive sequence changes produced by a varying load. This is produced by a Test Sine Wave with equations:

- Fac(t) = Sine (50 x 2 x Pi x t).
- Fac(t) is the basic 50 Hz sine wave.

- Amp(t) = 1 + A1 x Sine (Ft x 2 x Pi x t).
- Amp(t) is the variation in the amplitude of the 50 Hz sine wave.
- Where A1 is the low frequency defined amplitude.
- Where Ft is the defined low-test frequency.

- Test(t) = Amp(t) x Fac(t).
- Where Test(t) is the complete test signal.

- Test(t) = (1 + A1 x Sine(Ft x 2 x Pi x t)) x Sine (50 x 2 x Pi x t)).

The **GBGF-I Plant** 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 and the following tests completed and results supplied to verify the following criteria: -

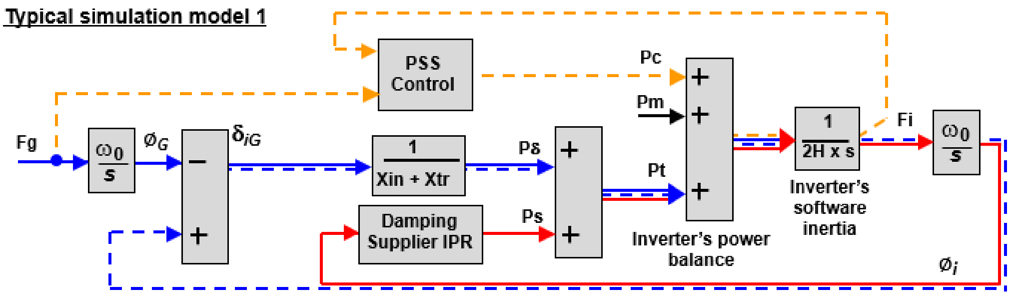

Figure ECP.A.3.9.6(a)

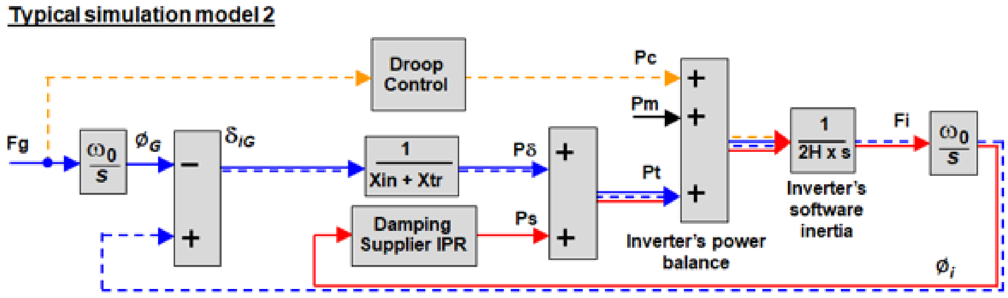

Figure ECP.A.3.9.6(b)

i) Demonstration of phase based **Damping Active Power** (or Pδ) by injecting the **Test Sine Wave** at the **Grid Oscillation Value** and frequency into the Grid Fg input as shown in Figure ECP.A.3.9.6(b) to demonstrate damping power supplied through the **GBGF-I Plant's** impedance. An acceptable performance would be judged when the result matches the **NFP Plot** declared by the **Grid Forming Plant** owner as submitted in ECC.6.3.19.3(viii).

ii) Test i) is repeated for **Test Sine Wave** inputs starting at 0.5 Hz in steps of 0.5 Hz to 10 Hz with a test amplitude of 0.01 per unit which is a total of 20 tests. An acceptable performance would be judged when the result matches the **NFP Plot** declared by the **Grid Forming Plant** owner as submitted in ECC.6.3.19.3(viii).

iii) Demonstration of phase based **real control output power** (or Pc) by injecting a normal 2Hz sine wave with an amplitude of 0.1 per unit into the **Grid Forming Plant** controller to demonstrate that the **Control Based Real Power** output is supplied below the 5Hz bandwidth limit An acceptable performance would be judged where the overshoot and decay matches the **Damping Factor** declared by the **Grid Forming Plant** owner as submitted in ECC.6.3.19.3(viii) 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.

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Extracts from ECP Appendix 4

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ECP.A.4.3.6 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** would also be required to undertake the necessary testing of their **Plant** in accordance with the requirements of ECC.A.4 and OC5 as applicable.

	Each **Grid Forming Plant** at **Grid Entry Point** or **User System Entry Point**
ECP.A.4.3.6(a) Real Time Downloadable	• Rate of change of **System Frequency** • Grid phase jumps • **ROCOF Response power** • **Phase Jump Active Power** • **Load angle** • Injected signals applied to the **Grid Forming Plant**

APPENDIX 9

COMPLIANCE TESTING FOR GRID FORMING PLANT

ECP.A.9.1 SCOPE

ECP.A.9.1.1 This Appendix outlines the general testing requirements for **Users** or **Non-CUSC Parties** to demonstrate compliance with the relevant aspects of the **Grid Code**, **Ancillary Services Agreement** and **Bilateral Agreement**. The tests specified in this Appendix will normally be sufficient to demonstrate compliance of a **GBGF-I Plant**, however **The Company** may:

i) agree to an alternative set of tests provided **The Company** deem the alternative set of tests sufficient to demonstrate compliance with the **Grid Code**, **Ancillary Services Agreement** and **Bilateral Agreement**; and/or

ii) require additional or alternative tests if information supplied to **The Company** during the compliance process suggests that the tests in this Appendix will not fully demonstrate compliance with the relevant section of the **Grid Code**, **Ancillary Services Agreement** or **Bilateral Agreement**; and/or

iii) require additional tests if control functions to improve damping of power system oscillations or additional functions to prove the capability of the **GBGF-I Plant** is required by the **Bilateral Agreement** or included in the control scheme; and/or

iv) agree a reduced set of tests for the subsequent **GBGF-I Plant** following successful completion of the first **Grid Forming** tests in the case of an installation comprising of two or more **GBGF-I Plant's** which **The Company** reasonably considers to be identical if: -

(a) the tests performed pursuant to ECP.A.9.1.9 in respect of subsequent **GBGF-I Plants** do not replicate the full tests for the first **GBGF-I Plant**; or

(b) any of the tests performed pursuant to ECP.A.9.1.9 do not fully demonstrate compliance with the relevant aspects of the **Grid Code**, **Ancillary Services Agreement** and / or **Bilateral Agreement.**

ECP.A.9.1.2 The **User or Non-CUSC Party** is responsible for carrying out the tests set out in and in accordance with this Appendix and the **User** or **Non-CUSC Party** retains the responsibility for the safety of personnel and plant during the test. **The Company** will witness all of the tests outlined or agreed in relation to this Appendix unless **The Company** decides and notifies the **User** or **Non-CUSC Party** otherwise. For all on site at **The Company** witnessed tests, the **User** or **Non-CUSC Party** must ensure suitable representatives from the **Grid Forming Plant's** manufacturer (if appropriate) are available on site for the entire testing period. In all cases and in addition to any recording of signals conducted by **The Company**, the **User** or **Non-CUSC Party** shall record all relevant test signals as outlined in ECP.A.4.

ECP.A.9.1.3 In addition to the dynamic signals supplied in ECP.A.4, the **User or Non-CUSC Party** shall inform **The Company** of the following information prior to the commencement of the tests and any changes to the following, if any values change during the tests:

(i) All relevant transformer tap numbers, if used.
(ii) Number of **Grid Forming Units** in operation.

ECP.A.9.1.4 The **User or Non-CUSC Party** shall submit a detailed schedule of tests to **The Company** in accordance with ECP.6.3.1, and this Appendix.

ECP.A.9.1.5 Prior to the testing of the **GBGF-I Plant** the **User** or **Non-CUSC Party** shall complete the **Integral Equipment Tests** procedure in accordance with OC.7.5.

ECP.A.9.1.6 Full **GBGF-I Plant** testing as required by ECP.7.2 is to be completed as defined in ECP.A.9.1.9.

ECP.A.9.1.7 **The Company** will permit relaxation from the requirements in ECP.A.9.1.9 where an **Equipment Certificate** for **GBGF-I Plant** has been provided which details the characteristics from tests on a representative installation with the same equipment and settings and the performance of the **GBGF-I Plant** can, in **The Company's** opinion, reasonably represent that of the installed **GBGF-I Plant** at that site. The relevant **Equipment Certificate** must be supplied in the **Users Data File structure**.

ECP.A.9.1.8 Prior to any **GBGF-I Plant** tests taking place, the **User** or **Non-CUSC Party** shall have completed the relevant compliance tests on the **GBGF-I Plant, Power Generating Module** or **Generating Unit** as required under ECP.A.5 or OC5. A.2 (as relevant) or **Power Park Module** as required under ECP.A.6 or OC5. A.3 (as applicable) or **HVDC Systems** or **DC Converters** as required under ECP.A.7 or OC5. A.4 (as applicable).

ECP.A.9.1.9 Demonstration of **Grid Forming Capability**

ECP.A.9.1.9.1 This section details the procedure for demonstrating **ROCOF Response Power**. Ideally if the test is being completed as part of a type test on an isolated network and it is possible to change the frequency of the isolated network then the tests should be completed using a variable network **Frequency**. **The Company** recognise that it is not possible in a large number of cases to adjust the network frequency of the network to which the **Grid Forming Plant** is connected. If a suitable test network is not available, performance of the **GBGF-I Plant** will need to be demonstrated through online monitoring as detailed in CC.6.6 or ECC.6.6 and simulation studies as required under ECP.A.3.9.4 would be required during the Interim Operational Notification Process as provided for under CP.6 or ECP.6 (as applicable).

ECP.A.9.1.9.2 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 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.

ECP.A.9.1.9.3 These tests are required to assess the **Grid Forming Plant's** withstand capabilities under extreme **System Frequencies**.

(i) 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 ROCOF Response Power**, **System Frequency** and time in (ms).

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

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

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

ECP.A.9.1.9.4 This test is to demonstrate the **Grid Forming Plant's** ability to supply **ROCOF Response Power** over the full **System Frequency** range.

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

(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 **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 **ROCOF Response Power**, **Reactive Power**, voltage and frequency.

ECP.A.9.1.9.5 This test is to demonstrate the **Grid Forming Plant's** ability to supply **Phase Jump Active Power** under normal operation.

(a) With the frequency of the test network set to 50Hz, the **GBGF-I Plant** 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.

(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 indicatively shown in Figure

ECP.A.9.1.9.5). This specific test can be repeated on site as required for a routine performance evaluation test.

(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.

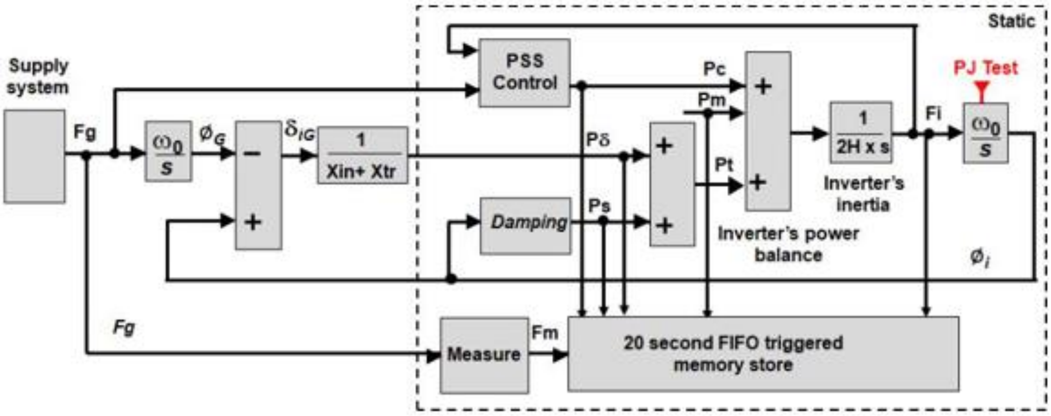

Figure ECP.A.9.1.9.5

ECP.A.9.1.9.6 This test is to demonstrate the **Grid Forming Plant's** ability to supply **Phase Jump Active 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.

(b) Apply a phase jump of 60 degrees at the connection point of the **GBGF-I Plant** 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.

ECP.A.9.1.9.7 This test is to demonstrate the **GBGF-I Plant's** ability to supply **Phase Jump Active Power**, **Fault Ride Through** and **Fast Fault Current Injection** during a faulted condition. Where it is not possible to undertake this test as part of a type test, **The Company** will accept demonstration through a combination of simulation studies as required under ECP.A.3.9.4(vii) and online monitoring as required under CC.6.6 and ECC.6.6.1.9.

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

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

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

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

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

ECP.A.9.1.9.8 The final test required is to demonstrate the **GBGF-I Plant** is capable of contributing to **Damping Active 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.9.1.9.8(a) or Figure ECP.A.9.1.9.8(b) as applicable.

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:-

i) Inject a 2Hz sine wave into the **Grid Forming Plant** controller to demonstrate the **Control Based Real Power** output is supplied below the 5Hz bandwidth limit An acceptable performance would be judged where the overshoot or decay matches the **Damping Factor** declared by the **Grid Forming Plant** owner as submitted in ECC.6.3.19.3(viii) 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.