Draft Grid Code – Grid Forming Converter Specification

3rd September 2020

Grid Forming Capability	Is a **Power Generating Module**, **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** without any control actions occurring in the associated control system. 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. The associated control system can vary the magnitude of the **Control Based Real Power** and **Control Based Reactive Power** supplied at the **Grid Entry Point** or **User System Entry Point** either to add damping or to respond to defined external control requirements, however these **Control Based** changes can only happen slowly with a bandwidth below 5 Hz.
Grid Forming Plant	A **Power Generating Module**, **HVDC System**, **Generating Unit**, **Power Park Module**, **DC Converter**, **OTSDUW Plant and Apparatus**, **Electricity Storage Module** or **Dynamic Reactive Compensation Equipment** which have a **Grid Forming Capability.**
Grid Forming Unit	A **Power Park Unit** or **Electricity Storage Unit** with a **Grid Forming Capability** 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.

Inertia Active 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**. For the avoidance of doubt, **Inertia Active Power** is an inherent capability of a **Grid Forming Plant** to respond naturally, within less than 5 ms, to **System Phase** and **Frequency** changes without any supplementary control and is automatically produced when there is a difference between the generated **Power** and supplied **Load** at a magnitude that varies with the resulting rate of change of frequency up to at least 1 Hz / s
Internal Voltage Source	For a **Grid Forming Synchronous Generating Unit** a real magnetic field, that rotates synchronously with the **System Frequency** under normal operating conditions, which induces an **Internal Voltage Source** in the stationary generator winding that has a real impedance. For a **Grid Forming Electronic Power Converter** it uses switched power electronic devices to produce a real voltage waveform, with harmonics, that has a fundamental component that rotates synchronously with the **System Frequency** under normal operating conditions to produce the real **Internal Voltage Source** that is connected to a one or more real impedances.
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. The **Damping Active Power** has three components that are detailed in ECC.6.3.19.3 (vi)

Phase Jump Active Power	The transient **Active Power** transferred from a **Grid Forming Plant** to the **Total System** as a result of a step change in the phase angle between the **Internal Voltage Source** of the **Grid Forming Plant** and phase angle at 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 the avoidance of doubt, **Phase Jump Active Power** is an inherent capability of a **Grid Forming Plant** that starts to respond naturally, within less than 5 ms.
Control Based Real Power	**Control Based Real Power** output supplied by a **Grid Forming Plant** through controlled means (be it manual or automatic)
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 a step change of the difference in voltage magnitude between the **Internal Voltage Source** of the **Grid Forming Plant** and phase angle at the **Grid Entry Point** or **User System Entry Point**. In the event of a voltage magnitude 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 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**. The input is oscillations in the **System s Frequency** and the output can either be oscillations in the **System's** power or oscillations in the **Internal Voltage Source**.
Electronic Power Converter	An electronic power converter which uses switched solid state power electronic devices to produce a real voltage waveform, with harmonics, that has a fundamental component that rotates to produce the real **Internal Voltage Source**.
Control based	**Control based** are changes in the **System's Real Power** or **Reactive Power** produced by the control system of a **Grid Forming Unit** that occur due to changes in an external signal connected to the control system. These **Control based** changes have a bandwidth limited to 5 Hz

ECC.6.3.19 <u>GRID FORMING CAPABILITY FOR GREAT BRITAIN (GFC-GB)</u>

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** and rotating synchronous machines 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), **European Connection Conditions** (ECC's), **European Compliance Processes** (ECP's), **Operating Codes**, **Balancing Codes** and **Data Registration Code** (DRC).

(ii) Each **Grid Forming 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 be made up of several discrete reactances including but not limited to 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 and between 0 and 180 degrees transiently unless abnormal conditions of fault conditions prevail.

(iv) When subject to a fault or disturbance, or **System Frequency** change, each **Grid Forming Plant** shall be capable of supplying **Inertia Active 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) The **Grid Forming Plant** shall be capable of:-

(a) Providing a symmetrical ability for importing and exporting **Inertia Active Power**, **Phase Jump Active Power**, **Damping Active Power** and **Control Based** real power under both rising and falling **System Frequency** conditions.

(b) Exporting within the limitations of ECC.6.1.2, ECC.6.3.3 and ECC.6.3.7 during **System Frequencies** between 47Hz – 52Hz. Excluding ECC.6.1,2.1,2 for system with time limited output ratings

(c) Importing **Inertia Active Power**, **Phase Jump Active Power**, **Damping Active Power** and **Control Based real Power** during **System Frequencies** between 47Hz – 52Hz within the limitations of ECC.6.1.2 and ECC.6.3.7.1 in addition to limiting importing **Active power** below 49.6 Hz with an adjustable output limiting droop between 20 % and 100 % per Hz in line with ECC 6.1.3.7.1.2.

(d) Operating as a voltage source behind an effective reactance.

(e) For frequencies below 5Hz additional power can occur due to **Control Based** real power requirements"

(f) The **Grid Forming Plant** shall be designed so as not to cause any undue or harmful interactions with the **Total System** or other **User's Plant** and **Apparatus** connected to the **Total System**.

(g) The control system can respond to changes in external signals but with a bandwidth below 5 Hz to avoid AC **System** resonance problems.

(h) A **Grid Forming Converter** comprising an **Electronic Power Converter** is required to have a rate of change of **Frequency** withstand setting of 2Hz/s. A **Grid Forming Converter** comprising a **Synchronous Generating Unit** is required to have a rate of change of Frequency withstand capability of 1 Hz/s in accordance with ECC.6.3.13.2

(vi) Each **User** shall design their **Grid Forming Plant** with a **Damping Factor** of between 0 and 1, where 1 is critically damped.

For a **Grid Forming Synchronous Power Generator** the three circuits providing damping are shown on Figure 1

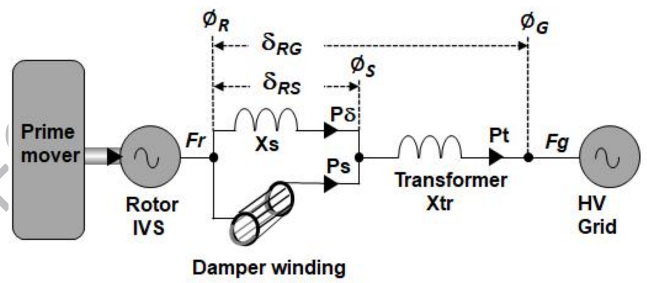

Figure 1.

For the avoidance of doubt the circuits providing damping are:

- The real damping current P δ flowing in the generator's windings Xs.
- The real damping current Ps flowing in the generator's damper windings X"d
- The real damping current Pc produced by the action of the Control system

The **Control Based Damping power** produced by the Control system has a bandwidth limit of 5 Hz and can be varied but is turned off for testing and specifying the system's **Damping Factor**

The sum of P_δ and P_c is the **Damping power** Pt that is fixed by the design of the **Synchronous Power Generator** and Pt is used to specify the systems **Damping Factor**

For a **Grid Forming Electronic Power Converter** the three circuits providing damping are shown on Figure 2

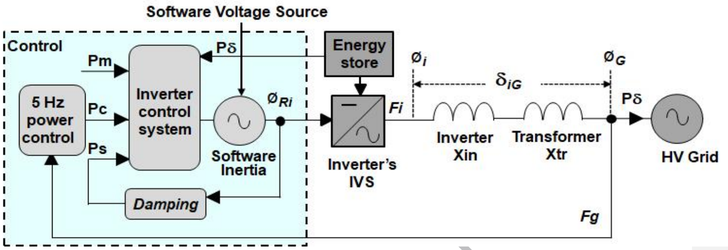

Figure 2

The circuits providing Damping are:

- The real damping current P δ flowing in the converter's impedances Xin plus Xtr.
- The software damping current Ps produced by software to damp the software based inertia.
- The **Control Based damping current** Pc also produced by the action of the Control system.

The **Control Based Damping power** produced by the Control system has a bandwidth limit of 5 Hz and can be varied but is turned off for testing and specifying the system's **Damping Factor**

The sum of P_δ and P_c is the **Damping power** Pt that can be varied by the systems software and Pt is used to specify the systems **Damping Factor.**

The **User** can choose to implement these settings internally within the **Grid Forming Unit's** control system or through the selective use of external electrical elements within the **Grid Forming Plant**. The correct selection of the **Damping Factor** would be assessed through a **Network Frequency Perturbation Plot**.

In addition, 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.

(vii) Each **Grid Forming 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** which shall be assessed in accordance with the requirements of ECPXXX.

Commented [J(A1]: This reference will be added when the ECP's have been updated.

(viii) In order to participate in the **Grid Forming Capability** market, **User's** and **Non-CUSC Parties** are required to provide data of their **Grid Forming Plant** in accordance with Figures 1 and 2. The User shall also supply the closed loop transfer function of the **Grid Forming Plant**. **Users** in respect of **Grid Forming Plants** should indicate if the data is submitted on a unit or aggregated basis. Table 1.0 defines the notation used in Figure 1 and 2. In the Table the upper symbol is for **Synchronous Generating Units** and the lower symbol is for **Power Electronic Converters**.

Parameter	Symbol	Units
The primary reactance of the **Grid Forming Unit**, in pu.	X"d Xi	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} X_{tr}	pu on MVA **Rating of Grid Forming Unit**
The rated angle between the **Internal Voltage Source** and stator terminals of the **Grid Forming Unit**.	δ_{RS} δi_{S}	radians
The rated angle between the **Internal Voltage Source** and **Grid Entry Point** or **User System Entry Point** (if **Embedded**).	δ_{RG} δi_{G}	radians
The rated voltage and phase of the **Internal Voltage Source** of the **Grid Forming Unit**. The voltage is taken to be 1pu.	$1\angle\phi_{R}$ $1\angle\phi i$	Voltage - 1pu Phase - radians
The rated voltage and phase of the **Total System** at the **Grid Entry Point** or **User System Entry Point**. The voltage is taken to be 1pu	$1\angle\phi_{G}$ $1\angle\phi_{G}$	Voltage – 1pu Phase - radians
The rated electrical angle between current and voltage at the stator terminals.	Power Factor Power Factor	radians
Damping Factor.	Z ζ	

Table 1.0

(ix) 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 **Grid Forming Plant** in in accordance with Table 2.0 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	User Defined Parameter
Type of **Plant** (eg **Generating Unit**, **Electricity Storage Module**, **Dynamic Reactive Compensation Equipment**	N/A	
Primary reactance X (see Table 1)	pu on MVA	
Additional reactance X_{tr} (See Table 1)	pu on MVA	
Maximum Capacity	MW	
Rated output time duration if not continuously rated		
Real Inertia Power (MW) supplied or absorbed at 1Hz/s frequency change	MW	
Maximum **Phase Jump** angle for rated **Phase Jump Active Power**	Degrees	
Phase Jump Power (MW) at the rated angle	MW	
Damping Power type P for a Grid oscillation of 0.5 Hz peak to peak at 2 Hz	MW	
The cumulative energy delivered for a 1Hz/s 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		
Overload Capability	% on MVA	
Duration of Overload Capability	s	
Nominal **Grid Entry Point** or **User System Entry Point** voltage	kV	
Grid Entry Point or **User System Entry Point**	N/A - Location	
Continuous or defined time duration MVA Rating	MVA	
Continuous or defined time duration MW Rating	MW	
Method of delivery – Defined time, Overating, Deloading or Continuous Operation	N/A	
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	
Diagram of single phase and three phase fault infeed during the first 0.5 seconds following fault inception	Diagram	

Additional transient or continuous steady state power available either before or after the supplied **Inertia Power**.	MW and MVAr Time duration	
Will the **Grid Forming Plant** contribute to any other form of commercial service – for example Dynamic Containment, Firm Frequency Response,	Details to be provided	
Damping Factor.	ζ	

Table 2.0

H = (Real Inertia Power at 1 Hz / s x 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) During a fault or voltage depression which falls below 0.9 pu at the **Grid Entry Point** or **User System Entry Point** or **Transmission Interface Point**, the phase, magnitude and frequency of the **Internal Voltage Source** of the **Grid Forming Plant** will remain fixed (within its **Load Angle** limits) at its pre-fault value during and immediately after the fault. These specific requirements shall be agreed between the owner of the **Grid Forming Plant** and **The Company** which shall vary depending upon the technology employed in the **Grid Forming Plant**. In the event that the resulting fault current would have exceeded its maximum overload capability or rated capability, a reduced fault current can be supplied up to its maximum overload capability.

(ii) Each **Grid Forming Plant** shall be capable of continuous voltage support through the injection of reactive current during a faulted 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 generator would also be considered appropriate for this requirement.

(iii) In the event where the voltage at the **Grid Entry Point** or **User System Entry Point** falls below the voltage level specified in ECC.6.1.4, each **Grid Forming Plant** shall be capable of supplying reactive current injection instantaneously at the **Grid Entry Point** or **User System Entry Point** in response to the instantaneous phase change**.** For the avoidance of doubt, **Generators** and **HVDC System Owners** and **Non-CUSC Parties** who are selected to provide a **Grid Forming Capability** through market arrangements are not required to satisfy the requirements of ECC.6.3.16.

(iv) As a minimum, each **Grid Forming Plant** shall be capable of operating over 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**.

(v) Each **User** and **Non-CUSC Party** should confirm the ability of their **Grid Forming Plant** to operate repeatedly through balanced and unbalanced faults and **System** disturbances each time the voltage at the **Grid Entry Point** or **User System Entry Point** or **Transmission Interface Point** falls outside the limits specified in ECC.6.1.4. Demonstration of this capability would be satisfied by **User's** supplying the protection settings of their **Grid Forming Plant**, informing **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.

(vi) In addition to the requirements of ECC.6.3.19.3(vii), each **User** or **Non CUSC Party** should provide a model of their **Grid Forming Plant** which provides a true an accurate reflection of its **Grid Forming Capability**.

(vii) In addition to the quality of supply requirements detailed in ECC.6.1.5, ECC.6.1.6 and ECC.6.1.7, each **Grid Forming Plant** owner shall agree any additional quality of supply requirements, including but not limited to Temporary Over-voltage limits (TOV's) and frequency bandwidth limitations, with **The Company**.