ESO

Workgroup Consultation

GC0163: GB Grid Forming (GBGF) - Removal of Virtual Impedance restriction

Overview: The purpose of this modification is to clarify the Grid Code with regard to the treatment of Virtual Impedance as defined within a Grid Forming Plant.

Modification process & timetable

1. **Proposal Form**
   02 October 2023
2. **Workgroup Consultation**
   22 January 2024 - 12 February 2024
3. **Workgroup Report**
   13 March 2024
4. **Code Administrator Consultation**
   02 April 2024 - 02 May 2023
5. **Draft SG Modification Report**
   22 May 2024
6. **Final SG Modification Report**
   03 June 2024
7. **Implementation**
   05 July 2024

Have 5 minutes? Read our Executive summary

Have 20 minutes? Read the full Workgroup Consultation

Have 30 minutes? Read the full Workgroup Consultation and Annexes.

Status summary: The Workgroup are seeking your views on the work completed to date to form the final solution to the issue raised.

This modification is expected to have a: Low impact
Generators, Manufacturers, Interconnectors

Modification drivers: New Technologies, System Security, Net Zero

Governance route	Self-Governance modification being assessed by a Workgroup.	
Who can I talk to about the change?	**Proposer:** Ronak Rabbani, ESO Ronak.rabbani@nationalgrideso.com	**Code Administrator Chair**: Jonathan Whitaker jonathan.whitaker@nationalgrideso.com 07354901925
How do I respond?	Send your response proforma to grid.code@nationalgrideso.com **by 5pm on 12 February 2024**	

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Executive summary

This modification proposes minor changes to the European Connection Conditions (ECC) and the Glossary & Definitions within the Grid Code to provide flexibility to developers as to how the impedance between the internal voltage source and Grid Entry Point or User System Entry Point (if Embedded) is provided. The current Grid Code only permits this to be achieved by a real impedance. Following publication of the GB Grid Forming Best Practice Guide in April 2023, it was agreed that with the necessary compliance processes in place, this requirement could be relaxed permitting developers to provide this impedance either virtually (i.e., through software), or retaining the use of real physical components or a combination of the two. In practice, it is envisaged that developers will in the main use a combination of virtual and real impedances which will result in greater flexibility and cost savings. The purpose of this modification is to clarify the Grid Code with regard to the treatment of Virtual Impedance within a Grid Forming Plant.

What is the issue?

National Grid ESO implemented Grid Code GC0137 "Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability)" in February 2022 following Ofgem's approval. As a follow-up, the ESO in coordination with national and international stakeholders published a GB Grid Forming Best Practice Guide in April 2023. One of the widely debated topics of concern highlighted by group members was on the restriction of using a real impedance within a Grid Forming Inverter (GBGF-I). This restriction was initially introduced through the GC0137 proposal due to the concerns over increased stability risk. Based on the findings of the Best Practice Group, and the need to undertake compliance studies (network frequency perturbation plots or equivalent) to ensure there are no negative interactions with the total system or other Users plant and apparatus, it was agreed that the use of a virtual impedance could be permitted. Rather than restricting the type of impedance used, it was proposed that the Grid Code should focus on the performance of the converter output rather than the method of achieving the requirement against the backdrop of ensuring a Grid Forming Converter would not result in negative interactions with the Total System or other Users connected to the Total System.

What is the solution and when will it come into effect?

Proposer's solution: It is proposed to make minor changes to the European Connection Conditions (ECC) and the Glossary & Definitions within the Grid Code to require only an internal impedance rather than specifying that the impedance comprises of real physical values. N.B. Changes will be also reflected in the ESO GB Grid Forming Compliance Guidance Note for relevant developers and manufacturers (https://www.nationalgrideso.com/document/289921/download).

Implementation date: 05 July 2024

What is the impact if this change is made?

This modification is expected to have a low impact on generators, manufacturers, and interconnectors and if anything will result in greater flexibility and cost savings for manufacturers and developers.

As the power system variables that are required to be complied with are already captured within the Grid Code requirements and the GB Best Practice Guide together with the Grid Forming Compliance Guidance Note, the ESO and wider industry stakeholder community agree that the Virtual Impedance restriction can be removed without loss of system security.

Interactions

The modification follows the development of National Grid ESO's GB Grid Forming Best Practice Guide and the implementation of GC0137 "Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability).

What is the issue?

National Grid ESO implemented Grid Code GC0137 "Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability)" in February 2022 following Ofgem's approval. As a follow-up, the ESO's GB Grid Forming Best Practice Group further co-developed National Grid ESO's GB Grid Forming Best Practice Guide with a wide range of external stakeholders in the UK and wider afield. Its key aims being:

a. Provide the necessary guidance on the existing Legal Text following Grid Code Modification GC0137*.

b. Identify any potential Grid Code modifications required to facilitate future GB Grid Forming applications.

c. Appropriately capture good practice and suggestions from a wide range of members of the GBGF Best Practice Group for future improvements of the GB Grid Code.

Note*: For the avoidance of doubt, this GB Grid Forming Best Practice Guide should be used in conjunction with GC0137 rather than as a standalone document.

In line with (b), one of the widely debated topics of concern highlighted by group members was the restriction which prevented the use of a Virtual Impedance within a GBGF Inverter (GBGF-I).
Rather than restricting the type of impedance used, it was proposed that the Grid Code should focus on the performance output of the converter rather than the method of achieving the requirement (against the backdrop of ensuring a Grid Forming Converter would not result in negative interactions with the Total System or other Users connected to the Total System).
As the power system variables that are required to be complied with are already captured within the Grid Code requirements, together with the information in the GB Best Practice Guide and the Grid Forming Compliance Guidance Note, the ESO and wider industry stakeholder community agree that the Virtual Impedance restriction can be removed without loss of system security.

Why change?

Allowing the GBGF-I's impedance to include a combination of physical and Virtual Impedances will enable a manufacturer to design and build a system which has a much greater level of flexibility whilst also resulting in cost savings. This will provide a more stable network and prevent unnecessary exclusion of some converters from the market.

ESO have also reviewed the European Network of Transmission System Operators' (ENTSO-E) Proposed Requirements for Generators (RfG) 2.0 during the ENTSO-E consultation stage in addition to the European Regulators (ACER) post consultation comments, and this potential change would result in greater consistency and harmonisation .

As discussed, and commonly agreed within the ESO's GB Grid Forming Best Practice Group, which included a comprehensive representation from the UK and further afield*, the following points were noted:

- The equivalent Internal Voltage Source should be defined as a Grey Box rather than a White Box (Grey Box and White Box are defined as Model approaches as a Black Box is also used within the Grid Code and EMT

modelling section. RMS model is also classed as Grey Box), where its functionality & performance as well as inputs/outputs should be clearly defined. The proposal of a Grey Box has been widely supported by stakeholders during the GB Grid Forming Best Practice Group discussions and individual stakeholder engagement during the consultation purposes.

- The Internal Voltage Source should be defined as the Grey Box so the clause, definition and figures relevant to Virtual Impedance should be removed.

*Note:- For details of those stakeholders, please see the Section of “Acknowledgements” (Pages 5-6) of GB Grid Forming Best Practice Guide in the Reference as listed in this form.

What is the proposer’s solution?

It is proposed to make minor changes to the European Connection Conditions (ECC) and the Glossary & Definitions within the Grid Code to require only an internal impedance rather than specifying that the impedance comprises of real physical values. N.B. Changes will also be reflected in the ESO GB Grid Forming Compliance Guidance Note for relevant developers and manufacturers.
(https://www.nationalgrideso.com/document/289921/download).

Workgroup considerations

The Workgroup convened 2 times to discuss the perceived issue, detail the scope of the proposed defect, devise potential solutions and assess the proposal in terms of the Applicable Code Objectives.

Consideration of the Proposer’s solution

The Proposer shared background information as to the origin of the proposal and suggestions from the GB Grid Forming Best Practice Group that a combination of virtual and physical impedance would be of benefit to developers and potentially the end consumer in reducing costs and providing greater flexibility.

The White/Grey box definition
The proposed legal text changes to the Grid Code Glossary (for ‘Internal Voltage Source’ or IVS) and Grid Code section ECC 6.3.19.3 were shared with the Workgroup.

In response to a Workgroup member’s question, it was clarified by an ESO engineer in the meeting that reference to a ‘grey box’ versus a ‘white box’ definition was not critical to the solution (as the solution focusses on the performance requirements rather than this definition).

Benefits of removing the restrictions
An ESO observer (a Subject Matter Expert) outlined the importance of the solution for allowing manufacturers more freedom by removing restrictions, and therefore making it easier and more flexible to meet the requirements. The benefits were expressed as cost savings (through to the consumer) and consistency with European proposals (via RFG 2.0 which includes a Grid Forming capability) based on the recent consultation is proposed to be introduced in 2025 with a three-year implementation period). Please see page 31 of the

GB Grid Forming Best Practice Guide. It was noted that while the exact EU drafting is not finalized, this modification should ensure greater consistency between the proposed European proposals and the GB Grid Forming requirements.

Comprehensive reviews of potential impacts

A Workgroup member questioned the impact of the solution on other users, for example if software fails, and whether the solution would set a precedent for a virtual impedance to be introduced to other parts of the system. The ESO observer confirmed that in relation to other users, the analysis techniques and compliance terms reviewed as part of the GB Grid Forming Best Practice Group's work should mitigate the impact on the Total System and other Users. In relation to the use of a virtual impedance on other areas of the system, it was confirmed that the scope for GC0163 was narrowly set to grid forming only and didn't prevent physical impedances from still being used (GC0163 will just allow virtual impedance to be used within the Grid Forming solution whereas it is currently prohibited). It was noted that a physical impedance will always be a significant part of the system and cannot be totally replaced by a virtual impedance. This is on the basis that in an electronic converter, the power electronic switches (Insulated Gate Bipolar Transistors (IGBTs)) simply switch the power waveform into a set of pulses and since it is not possible to change the current flowing through an inductance instantaneously, some form of real impedance is required to ensure a sine wave is developed at the output. However, since a transformer (which has its own natural impedance - generally this is far more inductive than resistive) is generally installed between a Power Electronic Converter and the System at the Grid Entry Point or User System Entry Point, then it permits developers and manufacturers to use a virtual impedance within the converter itself which provides for significant flexibility and cost saving.

Virtual: Physical Impedance Ratios

Workgroup members expressed that from an Original Equipment Manufacturer (OEM) perspective, manufacturers welcomed this change which would introduce more flexibility and cost savings. An OEM Workgroup member (for Static Synchronous Compensators – STATCOMs) noted that a virtual impedance allows STATCOMS to perform better for the grid. An OEM Workgroup member (for wind turbines) noted that a reasonable ratio of virtual to physical impedance was needed as available studies imply that too much virtual impedance would cause instability. They suggested that performance tests would be important for compliance to check that the right ratio between virtual and real impedances has been applied. Performance techniques for assessing these issues such as Network Frequency Perturbation (NFP) plots are described in the GB Grid Forming Best Practice Guide.

A Workgroup member questioned whether there will be simulations to offer guidance on the virtual/physical ratio to apply, to which the ESO observer recommended the Workgroup review the GB Grid Forming Best Practice Group's guide (page 30) which covers these issues. Additional material relating to real/virtual impedance is detailed in the reference section of this document.

Stability modelling

A Workgroup member asked whether the ESO were considering Electromagnetic Transient (EMT)-type modelling/simulations for proof of stability, to which the ESO confirmed this to be the case as EMT modelling is a requirement in the Grid Code (PC.A.9) for new plant.

The Chair checked with the Workgroup members involved with the initial Panel discussions for this modification that discussions had been sufficient to address the Panel's questions.

This was confirmed, with the caveat that wider consultation was needed to gauge if any other parties may be affected by the solution.

The Chair invited the Workgroup to raise any cross-code implications that are applicable but haven't been considered. No suggestions were made.

Draft legal text

Full draft legal text for this change can be found in Annex 4.

Proposed changes to Grid Code Section ECC.6.3.19.3:

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** shall be capable of behaving at the **Grid Entry Point** or **User System Entry Point** or terminals of the individual unit(s) as an **Internal Voltage Source** behind an impedance~~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** and **Apparatus** connecting the **Synchronous Generating Unit** or **Power Park Unit** or **HVDC System** or **Electricity Storage Unit** (such as a transformer) to the **Grid Entry Point** or **User System Entry Point** (if **Embedded**)~~.

Proposed changes to the Glossary & Definitions section of the Grid Code:

Internal Voltage Source or **IVS**	For a **GBGF-S**, a real magnetic field, that rotates synchronously with the **System Frequency** under normal operating conditions, which as a consequence induces an internal voltage ~~-~~(which is often referred to as the Electro Motive Force (EMF)) in the stationary generator winding that has a real impedance. In a **GBGF-I**, switched power electronic devices are used to produce a voltage waveform, with harmonics, that has a fundamental rotational component called the **Internal Voltage Source (IVS)** that rotates synchronously with the **System Frequency** under normal operating conditions. For a **GBGF-I** there must be an impedance ~~with only real physical values~~, between the **Internal Voltage Source** and the **Grid Entry Point** or **User System Entry Point**. ~~For the avoidance of doubt, a virtual impedance, is not permitted in~~ ~~**GBGF-I**.~~

What is the impact of this change?

Proposer's assessment against Grid Code Objectives	
Relevant Objective	**Identified impact**
(a) To permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity	**Neutral**
(b) Facilitating effective competition in the generation and supply of electricity (and without limiting the foregoing, to facilitate the national electricity transmission system being made available to persons authorised to supply or generate electricity on terms which neither prevent nor restrict competition in the supply or generation of electricity);	**Positive** Allowing GB Grid Forming Inverters (GBGF-I's) that comprise a Virtual Impedance will increase flexibility and reduce costs thereby allowing a more competitive market.
(c) Subject to sub-paragraphs (i) and (ii), to promote the security and efficiency of the electricity generation, transmission and distribution systems in the national electricity transmission system operator area taken as a whole;	**Positive** The use of a Virtual Impedance provides greater flexibility and if tuned appropriately may result in an enhanced stability performance. It also results in greater flexibility and cost savings.
(d) To efficiently discharge the obligations imposed upon the licensee by this license and to comply with the Electricity Regulation and any relevant legally binding decisions of the European Commission and/or the Agency; and	**Neutral**
(e) To promote efficiency in the implementation and administration of the Grid Code arrangements	**Neutral**

Standard Workgroup consultation question: Do you believe that GC0163 Original proposal better facilitates the Applicable Objectives?

When will this change take place?

Implementation date
This modification will be implemented 5 working days after the appeals window closes on 28/06/24, providing no objections have been raised.

Date decision required by
30 May 2024

Implementation approach
No internal systems or process changes will be required. Changes will be reflected in the ESO GB Grid Forming Compliance Guidance Note for relevant developers and manufacturers.

Standard Workgroup consultation question: Do you support the implementation approach?

Interactions

☐Grid Code	☐BSC	☐STC	☐SQSS
☐European Network Codes	☐ EBR Article 18 T&Cs[1]	☐Other modifications	☐Other

How to respond

Standard Workgroup consultation questions

1. Do you believe that the Original Proposal and/or any potential alternatives better facilitate the Applicable Objectives?
2. Do you support the proposed implementation approach?
3. Do you have any other comments?
4. Do you wish to raise a Workgroup Consultation Alternative request for the Workgroup to consider?

Specific Workgroup consultation questions

5. Do you have any concerns with the proposal to remove the requirement mandating the use of a real impedance in a GB Grid Forming Converter? If so, please state why you believe this to be the case.
6. Does the change impact your business?
7. Do you have experience with virtual impedance vs real impedance control?
8. Do you think the modification's title is a fair reflection of the modification?

The Workgroup is seeking the views of Grid Code Users and other interested parties in relation to the issues noted in this document and specifically in response to the questions above.

[1] If the modification has an impact on Article 18 T&Cs, it will need to follow the process set out in Article 18 of the Electricity Balancing Regulation (EBR – EU Regulation 2017/2195) – the main aspect of this is that the modification will need to be consulted on for 1 month in the Code Administrator Consultation phase. N.B. This will also satisfy the requirements of the NCER process.

Please send your response to grid.code@nationalgrideso.com using the response pro-forma which can be found on the GC0163 modification page.
In accordance with Governance Rules, if you wish to raise a Workgroup Consultation Alternative Request, please fill in the form which you can find at the above link.

If you wish to submit a confidential response, mark the relevant box on your consultation proforma. Confidential responses will be disclosed to the Authority in full but, unless agreed otherwise, will not be shared with the Panel, Workgroup or the industry and may therefore not influence the debate to the same extent as a non-confidential response.

Acronyms, key terms and reference material

Acronym / key term	Meaning
ACER	Agency for the Cooperation of Energy Regulators
BSC	Balancing and Settlement Code
CUSC	Connection and Use of System Code
EBR	Electricity Balancing Regulation
ECC	European Connection Conditions
EMT	Electromagnetic Transient
ENTSO-E	European Network of Transmission System Operators
ESO	Electricity System Operator
EU	European Union
GBGF	Great Britain Grid Forming
GBGF-I	Great Britain Grid Forming Inverter
GC	Grid Code
IGBT	Insulated Gate Bipolar Transistors
NFP	Network Frequency Perturbation
OEM	Original Equipment Manufacturer
RfG	Requirements for Generators
STATCOM	Static Synchronous Compensators
STC	System Operator Transmission Owner Code
SQSS	Security and Quality of Supply Standards
T&Cs	Terms and Conditions

Reference material

- ESO's GC0137 "Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability)" as implemented in February 2022.
- ESO's GB Grid Forming Best Practice Guide as issued in April, 2023.
- Grid Forming Compliance Guidance Note
- European Union Agency for the Cooperation of Energy Regulators (ACER) draft amendments to the Network Code on Requirements for Generators

- Unified Sequence Impedance Models of Synchronous Generator- and Virtual Oscillator Based Grid-Forming Converters
- On the Passivity of Grid-Forming Converters – Role of Virtual Impedance
- Unified Modeling and Analysis of Sequence Impedance of Grid-Forming Converters with Multi-loop Control
- Sequence Impedance Modeling and Stability Comparative Analysis of Voltage-Controlled VSGs and Current-Controlled VSGs

Annexes

Annex	Information
Annex 1	Proposal Form
Annex 2	Terms of Reference
Annex 3	Self-Governance statement
Annex 4	Legal Text