SGRE Response to GC0137 Consultation on Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability.

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Contents

References

[1] National_Grid_ESO, “Workgroup Consultation: GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability,” 2021. .

[2] National_Grid_ESO, “Draft Grid Code – Grid Forming Converter Specification 30 March 2021_Final,” 2021. https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required.

[3] A. J. Roscoe and T. Knueppel, “GC0137 20200430 SGRE Response to VSG_Grid_Code_Draft_Specification_V6_AJ010420 R1. [Annex 11 in GC0137 2021 Consulation],” 2020. [Online]. Available: https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required.

[4] ENTSO-E, “High Penetration of Power Electronic Interfaced Power Sources (HPoPEIPS),” 2017. .

1 Comments on consultation document

This document makes specific comments on "Workgroup Consuitation: GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability" [1] and the Grid Forming Converter Specification 30 March 2021 [2].

1.1 When is conformity to be required?

"*This modification proposes to add a non-mandatory technical specification to the Grid Code, relating to GB Grid Forming Capability*". If your device is operating in a grid forming manner, but you are not being paid for any of the grid forming services (grid stiffness, inertia etc.), then how many of the grid-forming grid code sections would you need to comply with? Could you ignore all the new sections if they are non-mandatory and you are not being paid?

1.2 Definition of "Grid Forming Capability" : [1] P19, [2] Definitions

SGRE welcomes the removal of the 5 Hz "clause" from the fundamental definition of GF (where it did not belong). We agree that NFP plot shapes (both magnitude and especially phase) should be used to derive acceptability, in comparison to, and the context of, historical GBGF-S response.

We feel that the introductory paragraph on "Grid Forming Capability" is not particularly robust, and does not really describe the properties of a grid-forming device. The ENTSO-E document [4] provides a list of properties that could be referred to, for example:

Grid Forming PPMs or HCSs

In addition to capabilities of PPMs or HCSs Classes 3 and 2, provide PPM or HCSs controls with single cycle support services allowing 100% power electronic penetration, including:

- Creates system voltage (does not rely on being provided with firm clean voltage)
  - Contributes to Fault Level (PPS & NPS within first cycle)
  - Contributes to Total System Inertia (limited by energy storage capacity)
- Supports fast dynamics (first cycle) survival for system splits and from brown & black outs
  - Giving survival time for LFDD to operate
  - Restoration including Brown & Black Start
  - Contributes to first swing stability, e.g. through dynamic breaking
- Controls act to prevent adverse control system interactions
  - Avoids contribution to super synchronous instability, e.g. through controller bandwidth limitation
  - Avoids contribution to sub synchronous resonance, e.g. through controller bandwidth limitation
  - Does not make full system dynamic studies impractical through complex non-fundamental frequency interactions
- Act as a sink to counter harmonics & inter-harmonics in system voltage
- Act as a sink to counter unbalance in system voltage

1.3 “ROCOF Response Power” definition : [2] Definitions

As presently defined, “*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.*” This statement confuses a response to ROCOF (df/dt) with a drooped response proportional to Δf.
To put this right, either:

- ROCOF Response Power should be redefined so that it ONLY refers to Inertia Power, and the Control-based droop power is NOT included in ROCOF Response Power

OR

- A separate Control-based power, proportional to a measured df/dt, needs to be defined, and used in the definition for “ROCOF Response Power”, in place of ”Control based droop power”.

1.4 “Real Inertia Power“ name, definition : [2] Definitions

The definition of “Real Inertia Power” is slightly confusing. The core important components of active-power response, lumped into “Real Inertia Power” are:

- Phase Jump Active Power (with bandwidth components to 1000 Hz)
- ROCOF Response Power (that does NOT have bandwidth components to 1000 Hz, as it is a 1/s^2 response to phase)
- Damping Power

Essentially, Real Inertia Power appears to be defined as the sum of these three. So, it does have bandwidth components to 1000 Hz as described in [2] (Definitions).

The problem here is with semantics. For low/zero inertia GBGF-I systems, the best example being VSM0H, these provide Phase Jump Active Power and Damping Power but no significant ROCOF Response Power. Therefore, a VSM0H device would provide “Real Inertia Power” because “Real Inertia Power” is defined as “Phase Jump Active Power” PLUS “ROCOF Response Power” PLUS “Damping Power”

This is misleading because then VSM0H provides “Real Inertia Power” by that naming and definition.

It would seem that if a term is to be defined and used to represent “Phase Jump Active Power” PLUS “ROCOF Response Power” PLUS “Damping Power”, then it should be named so that a finite response does not REQUIRE a ROCOF response which provides an inertia function.

A better name would be ? “Grid Forming Power” ? or similar. Basically, the term can allow for ROCOF Response Power being very low or zero, while the contribution from the other two “Grid Forming Power” components can be significant.

1.5 Definition, testing and compliance with 5 Hz “Control Bandwidth” : [1] P20, [2] P5 “Control Based”, ECC.6.3.19.3 (v)(d) and ECC.6.3.19.3 (vii)

The exact definition of the ‘“outer” control loops’ and ‘Control Based’ changes is still not perfectly defined, and subject to ambiguity of interpretation. For example in figure ECP.A.3.9.6(a) and (b), signals derived from grid phase/frequency Fg pass through blue signal paths that are deemed NOT to be control-based, and directly impact on power balance. Meanwhile the same signal source Fg provides signals which pass through orange paths, which again result directly in changes to the power balance. These are termed “Control Based” in the draft grid code. In different manufacturers control diagrams, that may have different forms to figure ECP.A.3.9.6(a) and (b), there will be significant difficulty in defining what is “Control based” and what is not.

In terms of input signals available that the user/customer can usually adjust in the outside world, for example power, voltage, and droop slope setpoints, it can relatively easily be arranged that the responses to changes to these inputs will have <5 Hz bandwidth, while the responses to grid voltages (which the user/customer cannot readily change) can be compliant with suitable NPF plot masks. These scenarios encompass what appears to be referred to in [2] as “outer”/”control-based” and “inner VSM” control functions. Perhaps a better definition of a “Control based” action is one that results from a change to a user-available setpoint?

We also note that it is an existing requirement for us to be able to ramp active power from 0 to 1 pu in 5 seconds, and also to be able to ramp Q from 0 to 90 % within 1 second. As an existing requirement, this means there is also a certain minimum bandwidth which we must be able to respond with. There might be a specification conflict here. Has this been checked against other existing requirements?

Importantly, there are other control functions which do not fit neatly into “inner VSM” or “outer control based”, and fall between the two “definitions”.

As a specific example, within wind turbines, there are some internal damping mechanisms with bandwidths which extend to 10-15 Hz that can be active at low per-unit power levels, when tower or blade oscillations are detected, that need to be damped. There are no external control or electrical grid inputs to these functions. The algorithms do not directly measure grid-side frequency, voltage, or phase angle. The inputs from sensors and rotor speed are part of the internal closed-loop turbine control at each turbine, and normally the small power fluctuations created at each wind turbine are uncorrelated with each other, and also buried beneath the natural power fluctuations that occur due to fluctuating wind speed at each turbine. The only time the drivetrain damping power fluctuations might be evident to an outside observer would be after a significant grid event/fault that caused all turbine towers/rotors to flex, in a common-mode fashion across a whole park, resulting in required damping actions at all turbines in a coordinated fashion. This scenario might (if the event is large enough) fall under the “Exceptions to the rule” defined in “Grid Forming Capability”, where bandwidth excursions are allowed during transients caused by system faults.

All large wind turbines probably include such drivetrain damping control loops with up to ~15 Hz bandwidth and, to date, no concern has been made about their impact on the network. Normally the drivetrain damping actions are uncorrelated across the turbines in a park/region, being due to wind gusts/fluctuations which vary at each turbine. Removal of these functions from the turbine would not be viable as the result would be dramatic shortening of turbine lifetimes, and/or mechanical failures during operation.

To illustrate the point, Figure 1 shows a much simplified and “generic” VSM algorithm, taken from **[3]**, and augmented with a typical drivetrain damping loop. The main power setpoint input, due to user constraints or available wind assessment at each turbine, can relatively easily be constrained to a 5 Hz bandwidth. However the drivetrain damping components for the rotor cannot be constrained to a 5 Hz bandwidth and could extend to 15 Hz. This drivetrain damping loop has to be present to avoid turbine damage/destruction, and does not include any external inputs which the user can control or influence. Normally the dominant path is from fluctuating/gusting/turbulent wind at each turbine, which produces small power fluctuations that sometimes require to be damped to avoid certain mechanical resonant modes from becoming excited. These power fluctuations will not be correlated between turbines. There is also another path, which can become active if a large grid fault or transient excites common-mode tower flexing and/or mechanical torques across all turbines in a farm. In this case, there will be some correlated damping power across all turbines exposed to the grid transient. The power involved in these damping actions is limited to a small proportion of rated power. Following a correlated grid-driven event, the drivetrain damping powers at each turbine will become uncorrelated as time passes, and local turbine conditions (wind, rotor speeds, etc.) will quickly re-randomise and decorrelate any damping actions required across a particular power park.

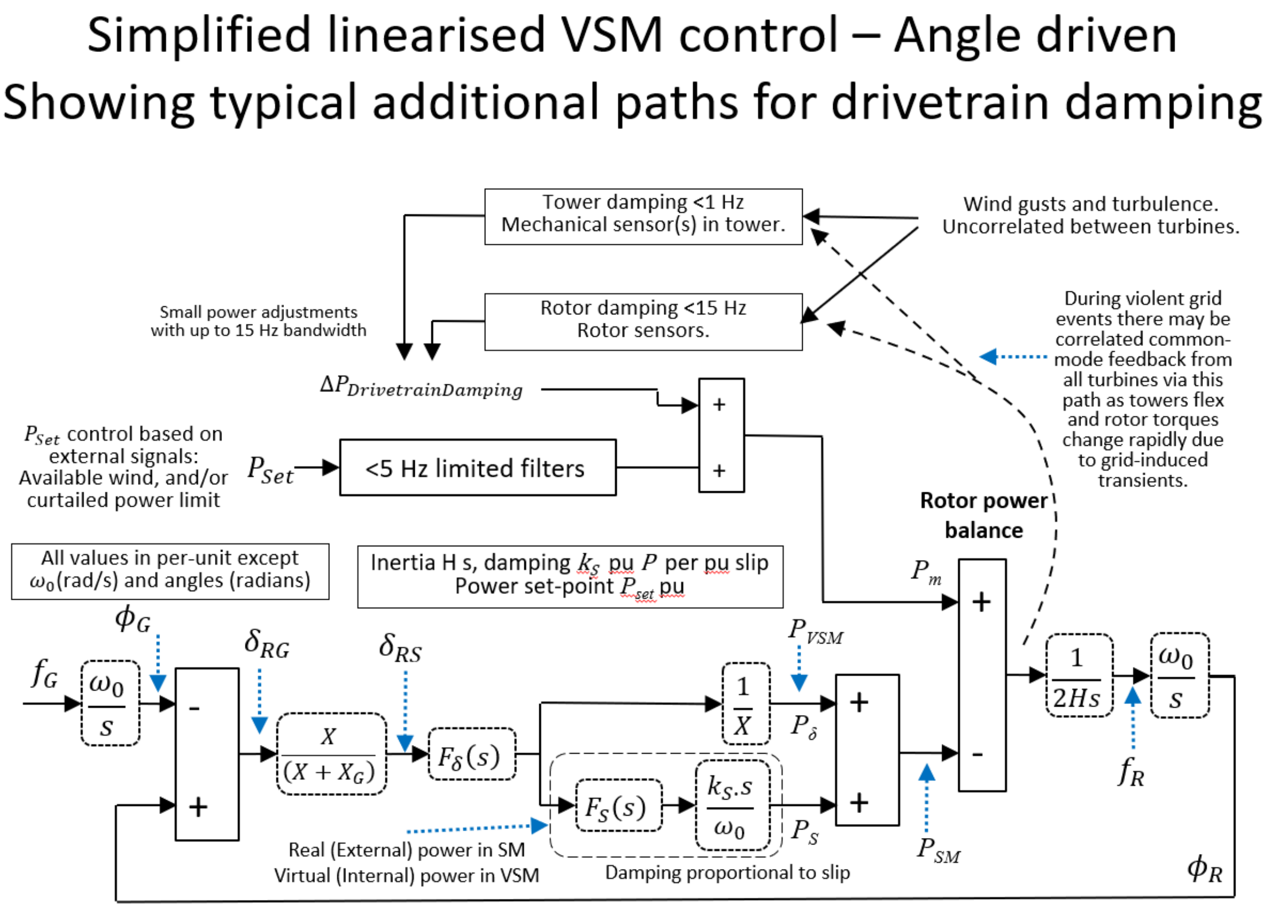

Figure 1 : Simplified diagram, based on augmenting Figure 4-2 from [3], the linearised model of VSM embedded within a power system. This shows the concept of the drivetrain damping path with up to 15 Hz components within wind turbines.

No actual testing of the 5 Hz “outer loop” or “control based” functions seems to be proposed in the later sections of [2]. The assessment seems to be based on the assessment of a diagrammatic model of the control system, as described in ECC.6.3.19.3 (vii) [2]. Some dialogue will be required to avoid a situation where wind turbine controllers are not suddenly described as “non compliant” because they include essential internal damping features, that have been in place for many years, that might (or might not) be considered to be “outer loops” or “control based”.

1.6 Damping coefficient ζ 0.2 to 5.0 : [1] P21, [2] ECC.6.3.19.3 (vi)

SGRE welcomes the option for a wide acceptance of damping ratios, especially the values exceeding 1.0.

1.7 High level equivalent architecture diagram. [2] ECC 6.3.19.3. vii)

The requirement to provide "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)" may be surplus to requirements, since such diagrams already need to be provided as part of the deliverables with customer system models under pre-existing grid code and contractual requirements. For example:

CP.10.2 A **Manufacturer's Data & Performance Report** in respect of **Power Park Units** may cover one (or part of one) or more of the following provisions of the Grid Code:

(a) Fault Ride Through capability CC.6.3.15

(b) **Power Park Module** mathematical model PC.A.5.4.2

There are significant IP and patent issues surrounding the circulation of such diagrams. There is a question of how much abstraction is permitted within these diagrams. For instance, the exemplar in Figure ECC.6.3.19.3.2 (a) shows a block abstracted with "Damping Supplier IPR". How much of these diagrams can be abstracted as "Supplier IPR"?

Appropriate simulation models with documentation might be more widely acceptable to manufacturers.

It is highly likely that the diagrams from some manufacturers will differ markedly from the examples given. For example, the algorithm or logic providing inertia may not have any clearly identifiable component that represents "H" or damping in isolation. These properties may be combined within algorithms that do not obviously resemble a "VSM" architecture, although they may provide a completely acceptable overall grid-forming behaviour.

It might be counter-productive to include the examples in Figure ECC.6.3.19.3.2 (a) and (b) in the actual grid code text.

1.8 Values depending on conditions, especially damping : [2] Tables ECC.6.3.19.3.1 and ECC.6.3.19.3.2

Some of the values in these tables, for a wind park, will depend upon how many turbines are operating at a particular time. The form might need to be filled out 2 or 3 times, with (for example) all turbines operating, half the turbines operating, or just a single turbine operating. The effective upstream impedance changes on a per-unit basis of the rating of turbines operating, which changes some response characteristics, including the "rated angles" and some of the impedance values. In particular, while inertia as a per-unit H value can remain the same as more turbines are brought online (or taken offline) at a park, the damping coefficient ζ will vary as the number of operating turbines varies from its highest value (just one turbine operating) to a lower value (all turbines operating common-mode). The tables might need to allow for a range of values to be returned, considering different operating scenarios and effective per-unit upstream impedances.

1.9 What level of ROCOF does response need to be linear to? [2] Table ECC.6.3.19.3.2

The ROCOF withstand limit is clearly stated as 2 Hz/s, and there are numerous references to tests carried out at 1 Hz/s. Also there is an entry in table ECC.6.3.19.3.2 which asks for the "*ROCOF Response Power (MW) supplied or absorbed at 1Hz/s System Frequency change*". Does this 1 Hz/s level describe the maximum ROCOF for which the power response needs to be linear? The ROCOF level for which the response needs to be linear needs to be clearly stated.

1.10 How is "decays" defined? : [2] ECC.6.3.19.3 (vi)

"*The damping shall be judged to be adequate if the corresponding Active Power response to a disturbance decays within two cycles of oscillation*." This needs to be defined quantitatively, with some fixed per-unit threshold or mask that defines when a power flow has "decayed" to an acceptable level. The distrurbance type and magnitude also needs to be quantified, so that manufacturers know how such a test will be applied.

1.11 Analysis of damping coefficient ζ : [1] P26, [2] Definitions (Nichols Chart) (misspelling in [2]) and ECC.6.3.19.3 (vii)

It would probably be wise to also adjust any text which refers to the determination of damping from the NFP plot, to allow for "The Nichols chart or other suitable analysis methods" to be used to determine damping from the NFP plot. This is in case a different computational or mathematical tool turns out to be equally or more useful, in practice, than a Nichols Chart. In fact clause ECC.6.3.19.3 (vii) already includes such text.

Nichols is incorrectly spelt Nicholls which should be corrected throughout.

There will need to be some clarity provided in the "Best Practice Guide", as to how to create the Nichols chart from the NFP plot(s), and a transparent description of how the independent analysis/calculation of damping coefficient ζ will be made, with examples.

We also feel that a guarantee of non-interaction with other plant cannot be given on the basis of only the single NFP plot that assesses active power P response against a stimulus of Δf modulations. There are other assessments which will need to be made, using (examples):

- The other 3 plots in the "NFP" family, e.g. Q response to ΔV modulations, and the cross-products of P response to ΔV modulations, and Q response to Δf modulations
- Time-domain simulations using client user models, etc.

1.12 Phase shift to cause 1pu P: [1] P29, [2] ECC.A.9.1.9.5

The phase shift to cause a 1 pu deviation in active power is not necessarily 5 degrees. It depends on the GBGF-I local reactance, and also the location where the phase-step is applied, and the additional upstream impedance between the GBGF-I device and the phase-step location. Likewise, if the phase-step is injected as per [2] ECC.A.9.1.9.5 then the power response will depend upon the magitude of the total grid impedance between the GBGF-I converter under test, and the upstream point which can be considered to be something with "infinite bus" properties.

1.13 Phase jump withstand to 60 degrees : [1] P29, [2] ECP.A.9.1.9.6

SGRE anticipates some discussion around the need to ride through a 60 degree 3-phase phase-step at full volts. It might be possible to comply with this, using GBGF-I technology, but it might also become a significant barrier.

If the Phase Jump Angle Withstand limit is to be 60 degrees, then this should also be applied (and tested) for all other non-grid-forming converters and generators, and also to GBGF-S devices.

1.14 Remove/replace the word “injection” with respect to fault response : [2] Definitions, ECC.6.3.16, ECC.6.3.19.3, ECC.6.3.19.5, ECP.A.3.9.4, ECP.A.9.1.9.7

The phrase “Current injection” and the word “inject” is used several times throughout the draft grid code. The word “inject” and “injection” is not the correct word in the context of GBGF-I or GBGF-S. A better phrase would be “Current provision” and the words “provide” and “provision” would be more appropriate than “inject” and “injection”.

As defined in the initial definition of “Grid Forming Capability” the device is supposed to function as a voltage source, not a current source. During a fault, some GBGF-I devices ***might*** revert to a current-source control method in some form, as allowed during the fast transients. But, some GBGF-I devices, especially those attempting to remain in true grid-forming mode, will not. Therefore, fault currents are not “injected” but are drawn from the GBGF-I or GBGF-S device by the network. The GBGF-I or GBGF-S device can influence the currents by manipulation of the “voltage behind a transient reactance” but the currents are not “injected”.

1.15 Fault compliance

Our interpretation is that the new code proposes new section ECC.6.3.19 and that for a GBGF-I device you do NOT need to follow the Fast Fault sections in the existing grid code section ECC.6.3.16. The FAST part is being redefined for GBGF-I, which is only a few of the FRT tests. The main FRT parts of the grid code already exist in CC.6.3.15 and will all still stand, so the grid forming device would still need to pass all the CC.6.3.15 tests.

Figure ECC.6.3.19.5 (a) shows simply “Voltage in pu” on the Y axis and “Reactive current in pu” on the x axis. Since most faults are complex unbalanced events, it is difficult to interpret this diagram in the context of unbalanced scenarios. What exactly is the definition of “Voltage in pu” and “Reactive current in pu” in a highly unbalanced case? What measurement processing is applied to determine “Voltage in pu” and “Reactive current in pu”. Are these positive-sequence values for example, and, if so, what measurement window is used to make the evaluation? One cycle, 5 cycles, 10 cycles? Or are these assessments made with “faster” measurements, and if so, what is the algorithm and window?

The similar comments apply for Figure ECC.6.3.19.5 (b). In particular, what algorithm and measurement window function is used to determine “Peak current rating in per unit”. The choice of measurement algorithm and processing will significantly influence the shape of the test result from a converter, when the times being assessed are <20 ms and down to 5 ms. The code will need to specify exactly the measurement processing is to be applied, and will need to be completely transparent with this so that manufacturers can understand the true requirement.

1.16 Monitored signals require research and/or standardisation with open-source algorithms made available [2] ECP.6.6.1.9

ECC.6.6.1.9 refers to 3 signals which are highly problematic to produce and disaggregate from each other. Without standardisation and open-source sharing of algorithms, these signals will be pointless to gather as they will be incomparable to each other unless every manufacturer uses the same algorithm or follows the same strict standard. The ongoing vast effort to standardise PMU performance (10 or more years) is evidence of this difficulty, and existing PMU standards do not even yet have standardisations for frequency and ROCOF that are particularly tolerant to dynamic events. In particular, the concept of measuring “System Frequency with a high immunity to Grid phase jumps” is an extremely difficult thing to define. I am not aware of any algorithms which have successfully claimed to be able to split out frequency from phase steps, as a disaggregated pair of measurands. Even if this proves possible, thresholds need to be defined so that the difference between "phase step" and "not a phase step" would need to be agreed. To begin to standardise such measurands so that any gathered data would be at all meaningful would require a multi-year research project involving metrological institutions, universities, and industrial acceptance of new measurement standards.

1.17 Excessive 1 MHz sample rates : [1] P26, ECC.6.6.3.2

SGRE believes that the requirement for a 1 MHz sample rate is an excessive requirement, which will preclude many users from making site measurements with available equipment that might be limited to more conventional PQ analysis sample rates. The calculation described on page 29 of [1] is over-simplistic in that it ignores:

- The "time taken" for a phase shift if not defined by the number of degrees and the fundamental frequency. The "time taken" can be instant, even for a 90 degree shift. The calculation on p29 is not analysing the correct parameters.
- Any currents that are caused, and the resulting active and reactive power responses, can be captured suitably using conventional PQ analyser acquisition rates, e.g. 10 kHz, 14.4 kHz (the preferred rate for accurate PQ assessment at 50 and 60 Hz by IEC-61869-9).
- A real post-analysis of a phase step in Vabc can probably be made much more practically by using the Fourier transform approach to the sampled Vabc data, over a 1-10 cycle window, allowing determination of the instant of phase step within a reasonable error margin, with a reasonable noise performance. Phasor measurement units are designed to be able to do this, for example, using conventional sample rates in the 10 kHz - 14.4 kHz sample-rate bracket. Since, in the tests proposed, the magnitude of the phase step is known, then to a large extent the stimulus signal is known, and the measurements of the voltages during the step will just confirm the presence of that step stimulus. In fact, when the step is applied internally as proposed in EPA.A.9.1.9.5, then the stimulus signal is not applied to Vabc directly, and the logic for requiring such a high sample rate would clearly not be applicable.
- SGRE believes that for grid-forming compliance testing, acquisition rates of 10 kHz, 14.4 kHz (the preferred rate for accurate PQ assessment at 50 and 60 Hz by IEC-61869-9), or, optionally, at up to 100-200 kHz for a few carefully defined tests, would be eminently suitable for all the testing required. Note that file sizes and the practicality of data gathering become serious concerns when sample rate rises above 10 kHz and multiple channels are being logged for periods of time, with data running into hundreds of GB or into the TB range.

1.18 Simulation test of Damping Power [1] P28, [2] ECP.A.3.9.6

There are tests defined to perform spot or swept analyses of parts or whole of the NFP plots in [1] P28 and [2] ECP.A.3.9.6. However, these are ambiguous in places.

It should also be noted that in many GBGF-I implementations, the damping power is buried inside the total power response and cannot be extracted as an individual unique "damping power", as suggested by the models in ECP.A.3.9.6(a) and (b). In particular, GBGF-I converters will likely use "internal" damping and as such, the damping power is not "direct", but the effects are more subtle, in that the GBGF-I itself will damp itself, and resist being disturbed, but the actual power flow causing this is hard to isolate, from underneath the dominant Phase-Jump and Inertial power responses.

In [1] P28 it should be specified that the injection of the 2 Hz sine wave is into the Fg or ϕ_G inputs (either can be made to work, although the NFP plot as described in [3] uses the Fg input.

In ECP.A.3.9.6 the test waveform is described as a 50 Hz fundamental with amplitude modulation applied. This is **not the correct waveform** to be applied to generate the standard frequency-power NFP plots, using the diagrams of GBGF-I plant models shown in ECP.A.3.9.6 a) or b). In those frequency-domain models, the input Fg should be a steady-state value (nominal frequency or zero, for a fully linearised model) plus the frequency deviation from steady-state, which will be a 2 Hz sinusoid. No 50 Hz signal should be applied to the Fg input unless a 50 Hz disturbance is being analysed at the far ”right hand” edge of an NFP plot.

ECP.A.3.9.6 also states that the model to be used should be ”the GBGF-I Plant model as supplied in ECPA.3.9.2. But in ECPA.3.9.2, two completely different types of model are required to be delivered:

- A time-domain model similar to Figure ECC.6.3.19.3.1
- 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.

So, to be consistent, a piece of qualifying text is required in ECP.A.3.9.6 to clarify that the linearised model from ECPA.3.9.2 is to be used.

The above comments all assume that the intention in [1] P28 and ECP.A.3.9.6 is to use the linearised plant models.

If the intention is to use the full time-domain simulation models, then the modulations applied to the Vabc inputs of the full time-domain simulation models will be fundamental 50 Hz sinewaves with additional frequency/phase modulation, **not** amplitude modulation, in order to generate the normal frequency/power NFP plot. The test Vabc waveforms would also be 3-phase (for larger devices), so the test waveform for that test would need to be defined as a three-phase waveform set. An amplitude modulation of the Vabc grid voltages would only be used to generate one of the ”other” NFP plots such as voltageMagnitude/P and voltageMagnitude/Q. This is all described in [3].

1.19 Signals for witness tests : [2] ECPA.4.3.6

ECP Appendix 4 is "ONSITE SIGNAL PROVISION FOR WITNESSING TESTS"

The table of signals includes some that are problematic.

- Grid Phase Jumps. See response earlier in section 1.16
- ROCOF Response Power cannot be disaggregated from Phase Jump Active power (or damping power). Only the net Power will be available.
- Load angle. This would need to be defined. Load angle between where and where? If this is between converter bridge and the MV terminals of the turbine, or the park connection point, then this angle will have to be estimated as there will be no direct measurements available.

1.20 Compliance testing phase step tests using injection : [2] ECPA.9.1.9.5

When using an injected phase-step signal into the control system, the assessment of response should be made using measurements of the actual power flowing, via Vabc and Iabc voltage and current measurements. The signal paths shown in Figure ECPA.9.1.9.5 will not exist in some GBGF-I devices, as (for example) damping power and Pδ do not exist as separate powers that can be extracted. Only the sum power may be available for some GBGF-I devices. For consistency, therefore, and practical considerations, the assessment should standardise on measurements of the actual terminal voltages, currents and power flows at an appropriate measurement point.

1.21 Compliance testing ROCOF could include injected ROCOF : [2] ECPA.9.1.9.4

In the similar manner to the phase step tests carried out using injected phase steps, described in ECPA.9.1.9.5, it is possible to likewise carry out ”synthetic” ROCOF event testing on-site using a similar method. This could be introduced as an option within ECPA.9.1.9.4. The benefit is that these tests can be run on site at multi-MW or even GW scale, without having to actually have a test source or environment that is capable of hosting such an experiment.

In general, we feel that being able to carry out either phase-step or ROCOF tests using an actual test network may be impractical, even for a single multi-MW turbine, due to the prohibitive cost of such a multi-MW test network and the logistics of arranging such test(s). The simulation and signal-injection test method options would appear to be much more practical approaches. Carrying out such tests on an entire power park at >100 MW rating would certainly not be possible using real applied phase steps or ROCOF ramps.

1.22 Figure 1.0, VSM0H capabilities : [1] P6.

On [1] P6, there is a red “No” and 4 orange “Possibles” for VSM0H as shown as below.
There is no particular reason nor presented evidence that VSM0H would be any less capable than VSM, in terms of these 4 criteria. VSM0H can provide a lot of damping through its drooped response, provides good phase-step power response, and can be modelled with RMS models equally well to VSM (with inertia) solutions. These four blocks should be coloured green “YES”, if VSM is allocated green “YES”, unless particular evidence can be presented to show otherwise.

Solution	Estimated Cost	RoCoF	Sync Torque/Power (Voltage Stability/Ref)	Prevent Voltage Collapse	Prevent Sub-Sync Osc. / SG Compitable	Hi Freq Stability	RMS Modelling	Fault Level	Post Fault Over Volts	Harmonic & Imbalance	System Level Maturity	N
Constrain Asyncronous Generation	High	I	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Proven	These technologies are or have the potential to be Grid Forming / Option 1
Syncronous Compensation	High	I	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Proven	
VSM	Medium	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	P	Modelled	
VSM0H	Low	No	Yes	Yes	No	P	P	P	Yes	P	Modelled	Has the potential to contribute but relies on the above Solutions
Synthetic Inertia	Medium	Yes	No	No	P	No	No	No	No	No	Modelled	
Other NG Projects	Low	Yes	P	Yes	No	No	No	P	P	No	Theoretical	

Key	
No	Doesn't Resolve Issue
P	Potential
I	Improves
Yes	Resolves Issue

Figure 2 : VSM0H capability should also be considered to be Yes in these boxes, if VSM is considered to be Yes.

1.23 Virtual impedances : [2] Definitions

SGRE notes the statement that “For the avoidance of doubt a virtual impedance, is not permitted in GBGF-I Plant”.

We think that further clarification will be required here, to more thoroughly describe exactly what functions this rules out, and what functions would be allowed. There are many potential interpretations of the since sentence as it exists now.

1.24 Harmonic and unbalance performance

There is no specific mention of harmonic or negative sequence performance in the legal text. The behaviour of GBGF-I devices will be different to current-control converter devices, as GBGF-I devices are operated as voltage sources.

The existing grid code says (for example) "*Current Injection at each harmonic for each Power Park Unit and for each Power Park Module*".

As voltage sources, as described in section 1.14, any use of the term "inject" with respect to GBGF-I devices should be avoided, unless there is a very good reason. Currents are drawn from the device. based on the bridge voltage behaviour, and the behaviour of the grid voltages at the point of common coupling.

As stated in [4]:

Grid Forming PPMs or HCSs
In addition to capabilities of PPMs or HCSs Classes 3 and 2, provide PPM or HCSs controls with single cycle support services allowing 100% power electronic penetration, including:
…
- *Act as a sink to counter harmonics & inter-harmonics in system voltage*
- *Act as a sink to counter unbalance in system voltage*

The performance of a GBGF-I device, in terms of unbalance and harmonic performance, is dominated by the "voltage source behind a reactance" concept.

Therefore, the only way an upper harmonic or negative sequence current threshold criteria can be set for a GBGF-I device is if the test environment has an exceptionally clean and stiff sinusoidal, positive sequence voltage source. In all other cases, the unbalanced currents and voltages are defined as much by the (test) environment as the performance of the GBGF-I device.

A thorough set of acceptable criteria for GBGF-I devices, with respect to harmonic and unbalance performance, would need to assess the voltage qualities of unbalance and harmonics, at the point of common coupling, across a range of grid conditions ranging from near-perfect to contaminated grid, to show that:

- The GBGF-I device does not make **otherwise good** U_2 or THD_V rise **above certain threshold values**, when the device is connected and operated.
- The GBGF-I device makes **otherwise poor** U_2 or THD_V **reduce, perhaps by calculated/defined amounts**, when the device is connected and operated.