Item. **Data for the Grid Forming Best Practice Workgroup - GFBPW.**

Document. **Data on GBGF models and NFP plots – Enstore 3 – 001F.**

Issued to. **NGESO and the GFBPW.**

Signed by. **E A Lewis** - Eric Lewis Company director **Enstore**.

Date. **18 October 2021**.

Table of Contents

1. Commercial conditions:

1. This document has a reference "**Data on GBGF models and NFP plots – Enstore 3 – 001F"** hence called **The Data.**
2. **The Data** has been independently produced by **Enstore** to send to **GFBPW** to help the **GFBPW** understand Grid Forming technology**.**
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Signed by…**Eric A Lewis** … Eric A Lewis BSc (Eng) CEng MIET- Company Director. 18-10-2021.

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2. Acronyms.

BEIS	Department for Business, Energy and Industrial Strategy.
EMF	The AC voltages of a **GBGF-S** generator are also called its Electro Motive Force.
ESS	Energy storage system.
f	AC frequency in Hz
FFC	Fast Fault Current
Fgrid	Frequency of the AC Grid.
Fivs	Frequency of the **IVS** for **GBGF- I** inverters and **GBGF-S** generators.
G1(ω), G3(ω)	Frequency domain gain functions.
Gd(ω)	Frequency domain damping function.
GBGF	GB Grid Forming technology.
GBGF- I	GB Grid Forming static inverter system.
GBGF- S	GB Grid Forming rotating synchronous generator.
GFBPW	Grid Forming Best Practice Workgroup.
GWdays	Energy measured in Giga Watts multiplied by days.
H, Hg, Hi	The **NGESO** definition of stored energy for the **Active Inertia Power.**
Igrid	Current into the AC Grid from a **GBGF** system.
IVS	Internal voltage source of **GBGF- I** inverters and **GBGF-S** generators.
J	Inertia parameter in 1 / per unit / second and in simulations **J = 2 x H**
Lac	Inductance of the AC supply.
NFP plot	Network Frequency Perturbation plot.
NGESO	National Grid Electric System Operator.
Pc	Power requested by an internal control system
PLL	Phase Locked Loop control used by the **original static** inverter systems.
Pm	Power supplied into the Prime mover
Pr	Renewable power supplied to an inverter.
Ps	Internal damping power of a **GBGF- I** inverter
Pt	Power in the AC supply
PWM	Pulse Width Modulation.
Rac	Resistance of the AC supply.
RoCoF	Rate of Change of Frequency.
Td	Time that an energy store can deliver its stored energy
T"d	Sub transient time constant of the AC grid in seconds
Vgrid	Voltage of the AC Grid.
Vivs	Voltage of the **IVS.**
X(f)	AC impedance at the frequency of f Hz.
Xac	Impedance of the AC supply as used in some simulation models.
X"d	Impedance of a **GBGF-S** generator at 50 Hz.
Xtr	Impedance of the Grid transformer.
Xts	The total AC supply impedance of a **GBGF- I** inverter.
Zac(ω)	Supply impedance in the frequency domain.
ω	Angular frequency in radians per second = 2 x π x frequency.
Φgrid	Phase angle of the AC Grid's voltage.
Φig	Phase angle between **Φivs** and **Φgrid.**
Φivs	Phase angle of the **IVS** voltage.
s	The Laplace s domain operator.

The Acronyms for certain figures are not listed as they are listed in the relevant reference.

3. Introduction to time domain simulation models.

In the September meeting of the **GFBPW** the presentations included a range of time domain simulation models that appear to be very different which resulted in the need for more data on this topic.

This report clarifies that all the **GBGF** time domain simulations models are based on the same fundamental model and the differences are the different **Types** used for implementing the AC supply impedance and system damping:

- **Type 1 is based on the standard NGESO simulation model for GBGF-S generators.**

  This **Type 1** defines phase as the integral of frequency which is correct for **GBGF-S** generators that cannot have **Phase Jumps** in their **EMF** voltage.

  This **Type 1** also defines the AC supply impedance based on the standard power equation that has an impedance which gives a step output response for a step input signal. This impedance is **X"d + Xtr** on **Figure 3.3** and uses different symbols on the other Figures.

- **Type 2 is based on the normal industrial simulation model for GBGF- I inverters.**

  This **Type 2** defines phase as the primary value which is correct for **GBGF- I inverters** that do have **Phase Jumps** in their **IVS** voltage.

  This **Type 2** also defines the AC supply impedance as **(Rac + j x ω x Lac)** which is the same as **(Rac + s x Lac)** which has a fast time constant output response for a step input signal.

- **Type 3 is based on the normal university simulation models for VSM systems.**

  These simulation models normally use a **PLL** system and or **D + Q** current control loops.

  These simulation models are not relevant to **GBGF** systems.

The following are the time domain simulation models presented in the four presentations made to the **GFBPW,** see references 1 to 4.

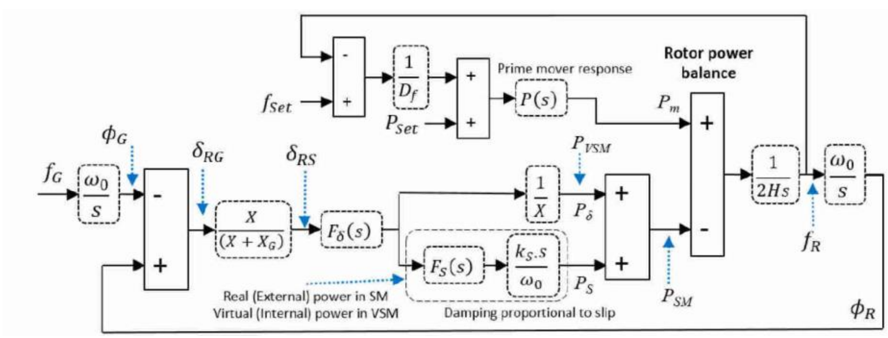


Figure 3.1. SGRE GBGF-S generator time domain simulation model - Type 1.

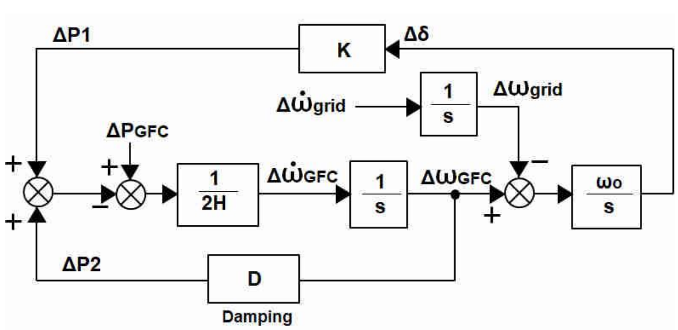


Figure 3.2. Strathclyde University GBGF-S generator time domain simulation model - Type 1.

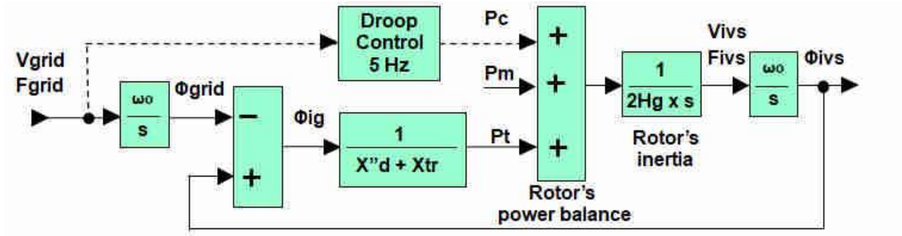


Figure 3.3. Enstore GBGF-S generator time domain simulation model - Type 1.

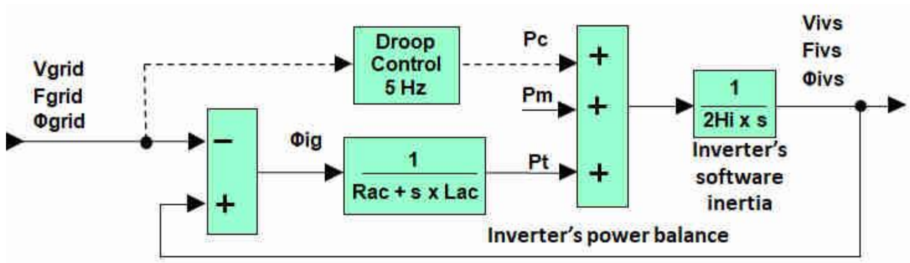


Figure 3.4. Enstore GBGF- I inverter basic time domain simulation model - Type 2.

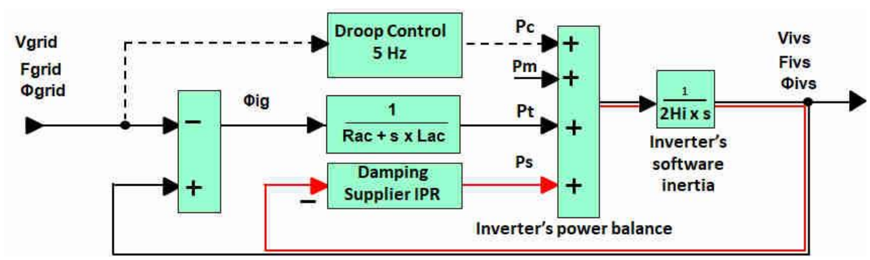


Figure 3.5. Enstore GBGF- I inverter full time domain simulation model - Type 2.

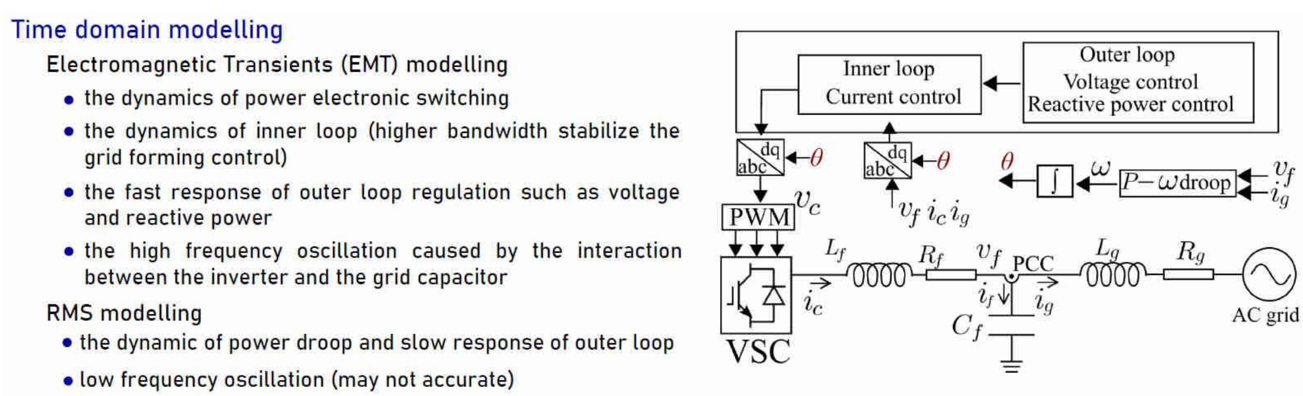


Figure 3.6. Cardiff University VSM time domain simulation model - Type 3.

4. Comparison of the time domain simulation models.

To show the fundamental simulation models the features for adding control and damping have been removed.

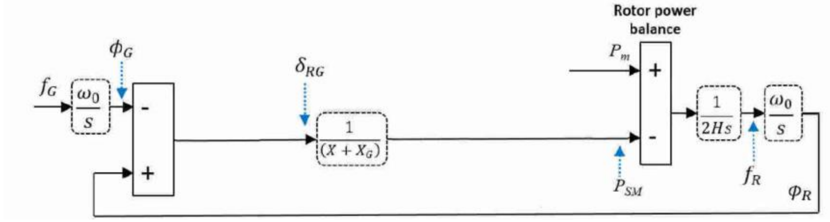


Figure 4.1. SGRE simplified model for the GBGF-S generator time domain simulation - Type 1 – Step 1.

For the **Figure 4.1** the following have either been removed or simplified compared with the **Figure 3.1**:

- The control feature for the prime mover response.
- The additional damping function ***(ks x s / ω0)*** that is a differential function.
- The 2 boxcar filters $F\delta(s)$ that are used to aid the system's simulation as defined in the **SGRE** full data.
- Merging the impedances ***X / (X + Xg)*** and **1 / *X*** into a simpler function.

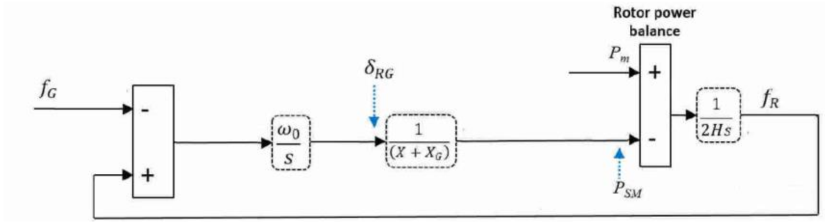


Figure 4.2. SGRE simplified model for the GBGF-S generator time domain simulation - Type 1 – Step 2.

The **Figure 4.2** has moved the two **(*ω0 / s*)** blocks into one common location.

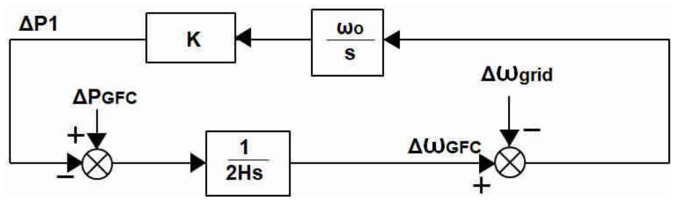


Figure 4.3. Strathclyde University simplified GBGF-S generator time domain simulation model - Type 1.

For the **Figure 4.3** the following have either been removed or simplified compared with the **Figure 3.2**:

- The damping has been removed.
- The **S** has been moved into the **1 / 2 H** function.
- The **ω** differential functions are not needed when the **S** and **1 / 2H** functions are merged.
- The **K** and **ω0 / s** functions are moved to be together.

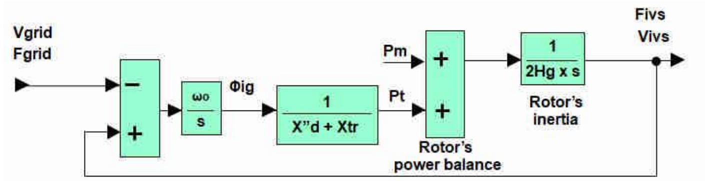


Figure 4.4. Enstore simplified GBGF-S generator time domain simulation model - Type 1.

For the **Figure 4.4** the following have either been removed or simplified compared with the **Figure 3.3**:

- The **Droop** control has been removed.
- The two **(ω0 / s)** blocks have been moved into one common location.

The **Figures 4.2, 4.3 & 4.4** show that these three simulation models are identical.

For the **Figures 3.1** to **3.3** these are the **Type 1** simulation models where the main simulation variable is the system's AC frequency in the time domain that is then integrated to give the systems phase.

The **Figure 4.5** shows the simplified **Enstore** time domain simulation model for a **Type 2** system where the main simulation variable is the system's AC phase to define the systems voltages in the time domain.

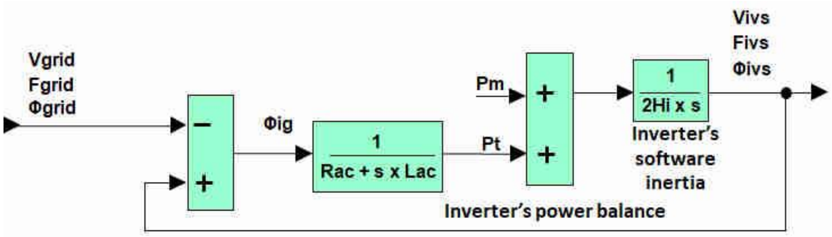


Figure 4.5. Enstore simplified GBGF- I inverter time domain simulation model - Type 2.

The change of **Figure 4.5** compared with **Figure 3.3** is that the **ω0 / s** function and the **1 / (X"d + Xtr)** function have been merged to give the **1 / (s x Lac**) function that retains the integral function.

The **Figure 4.5** then allows the **Rac** resistance to be added which is very important in producing time domain simulations and **NFP** plots with the correct damping due to the resistance of the AC supply.

The **Type 1** simulation model shown on **Figure 3.1 - 3.3** do not have the **Rac** resistance that can give an incorrect peak amplitude value for a **NFP** plot.

Producing a **Phase Jump** is easily achieved in a **Type 2** time domain simulation model but is more difficult in a **Type 1** time domain simulation model which requires the use of either an Impulse function for an instant **Phase Jump** or a Jerk function for a **Phase Jump** occurring in a defined time.

The **Figure 4.6** shows the complete **Enstore Type 2** simulation model for a **GBGF- I** inverter which is a repeat of the **Figure 3.5.**

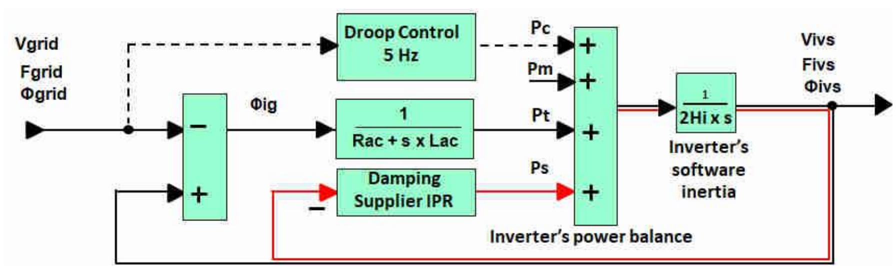


Figure 4.6. Enstore full GBGF- I inverter time domain simulation model - Type 2.

The main features of the **Figure 4.6** are:

- It is the same basic circuit as the **Type 1** simulation models.
- It has the **Rac** function to give the external damping produced by the AC supply.
- It has the **Damping Supplier IPR** function to give the internal software damping.
- It gives accurate damping for **NFP** plots.
- Can vary the internal software damping on site as required by a given system.
- It is very similar to how a real **GBGF- I** inverter control system is likely to be implemented.
- These is only one integral term in the damping loop that gives good system stability which is similar to the **Figure 3.2.**

This simulation model and the **Damping Supplier IPR** function is what **Enstore** has used produce the data presented in various **GBGF** reports. The **GBGF** Grid Code Legal text allows a supplier to use any simulation model and functions to provide a design that is compliant with the **GBGF** requirements.

Enstore can supply more data on the **IPR** of the **Enstore's Damping** function.

In discussions on **GBGF-S** generators and **GBGF- I** inverters three very important questions were proposed:

Question 1.

In **Figure 4.1** the **wo / s** function from frequency $\mathbf{f_R}$ to phase after the **1 / 2Hs** function, as inherently exists in a synchronous machine, helps to hold the internal phase angle $\mathbf{\Phi_R}$ of the **EMF** constant in the first ~100 ms of an AC Grid Phase angle change to give a good **Active Phase Jump power response.**

In **Figure 4.5** should an additional integral term **wo / s** be included after the **1 / (2Hi x s)** function in a **GBGF-I** inverter to hold the internal phase angle $\mathbf{\Phi_{IVS}}$ of the **IVS** constant in the first ~100 ms of an AC Grid Phase angle change to give the same **Active Phase Jump power** response when compared with a **GBGF-S** generator?

Reply 1.

If you compare the **Figures 4.1, 4.3 & 4.5** there are two integrating functions in each loop.

For the **GBGF- S** generator these are:

- The inertia **1 / (2Hs)** function, which is better shown as **1 / (2H x s).**
- The **wo / s** function.

For the **GBGF- I** inverter these are:

- The inertia **1 / (2Hi x s)** function.
- The AC supply impedance **1 / (s x Lac**) function.

If the **Rac** term is set to zero in **Figure 4.5** then all the figures have the same transfer function and will have the same response to changes in the AC Grid.

Also due to the double integral terms in series for all the systems they would be unstable without damping that is provided by the **(** $\mathbf{k_S}$ **x s / wo)** function in the **Figure 3.1**, the **D** function in **Figure 3.2** and the **Rac** function in **Figure 3.4**.

To produce the correct **NFP** plots the damping terms must be set to the correct values for each system.

Question 2.

Is it necessary to do time domain simulations comparing the contribution of **Active Phase Jump power** with and without the additional **wo / s** function block from frequency to phase, as a way to control the phase in a **GBGF-I systems**?

Reply 2.

No simulations are needed as the **K x wo / s** in **Figure 4.3** is equivalent to the **1 / (s x Lac)** term in **Figure 4.5.**

Question 3.

What is the control mechanism that results in the internal phase angle being initially held constant for a **GBGF-I** inverter for an AC supply phase jump and how does the **GBGF- I** inverters **Active Phase Jump power** compare with a **GBGF-S** generator's **Active Phase Jump power?**

Reply 3

In a **GBGF- I** inverter there are four items that must be implemented to have the correct **Active Phase Jump power** response:

- In **Figure 4.5** there is a **1 / (2Hi x s)** integrator term that stops any phase jumps in $\mathbf{\Phi_{IVS}}$ for all control signals when the system is operating under normal conditions.
- The resonant frequency of the **NFP** plot must be below 10 Hz. This is why the proposed resonant frequency limit is set at 10 Hz as a higher **NFP** plot resonant frequency gives a phase jump duration time that is too short to be useful.
- All the control loops have a 5 Hz bandwidth limit to stop the **IVS** of the **GBGF- I** inverter changing rapidly.
- Phase jumps in the **IVS** of a **GBGF-I** inverter are only allowed by the **Phase Test Signal**.

These four items give the same **Active Phase Jump power** response for a **GBGF-S** generators and a **GBGF-** I inverter with the same **NFP** plot resonant frequency and the **GBGF- I** inverter can be set to have either the same, lower or higher **Damping Factor** when the AC grid has a **Phase Jump angle** within the defined limit value**.**

For a larger **Phase Jump Angle** value a **GBGF- I** inverter will go to its current limit value.

5. Production of NFP plots with GBGF – I inverter Type 2 simulation model.

The **NFP** plot definition in the proposed **GBGF** Grid Code is:

A form of Bode Plot which plots the amplitude (%) and phase (degrees) of the resulting output oscillation responding to an applied input oscillation across a frequency base. The plot will be used to assess the capability and performance of a **Grid Forming Plant** and to ensure that it does not pose a risk to other **Plant** and **Apparatus** connected to the **Total System**.

For **GBGF-I**, these are used to provide data to **The Company** which together with the associated **Nichols Chart** (or equivalent) defines the effects on a **GBGF-I** for changes in the frequency of the applied input oscillation. The input is the applied as an input oscillation and the output is the resulting oscillations in the **GBGF-I's Active Power**. For the avoidance of doubt, **Generators** in respect of **GBGF-S** can provide their data using the existing formats and do not need to supply **NFP** plots.

A **NFP** plot can be produced by either a time domain simulation model or a frequency domain calculation.

For a time domain simulation model the **NFP** plot test input signal is defined in the **SGRE** data and a range of different input signals can be used to provide different **NFP** plots that include the reactive current **NFP** plot.

The **Enstore** test input signal is used with time domain simulation models to produce the result of a balanced low frequency oscillation that is typical of phase oscillations in the AC Grid.

For frequency domain **NFP** plot calculations there is no test input signal as the X axis of the **NFP** plot is the test input signal and the **Figure 5.1** simulation model gives the **NFP** plot power response using the modulus function as shown in the example in section 7, as all small AC current oscillations produce active power.

The standard **NFP active** power plot is produced from the **Type 2** simulation model shown on **Figure 5.1** and for a **NFP** reactive power plot a different mode must be used.

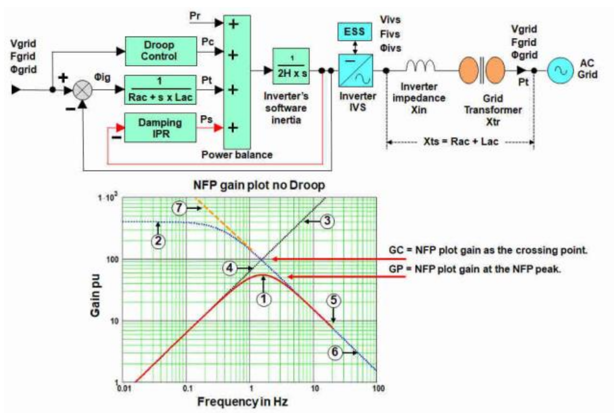


Figure 5.1. Producing a GBGF- I inverter NFP plot with a Type 2 simulation model.

The key features for **Figure 5.1** are:

- The peak of a **NFP** plot "**NP**" depends on the total damping in the system.
- If a system does not have any extra damping the **NP** value is set by the resistance of the **AC Grid line 2** which is a feature of the **Type 2** simulation model.
- The **line 7** is the AC impedance for a **Type 1** simulation model that gives incorrect **NFP** plots for **GBGF- I** inverters.
- This **NFP** plot has high damping from the damping function.
- The **NFP** plot crossing point "**GC**" gives the resonant frequency point 1.
- If a **NFP** plot has values with **GC = GP** the **NFP** plot mathematics gives a **Damping Factor** of 0.5.
- For a basic **NFP** plot, without **Droop control**, the mathematics give **Damping factor** = (**0.5 x GP) / GC.**

The complete mathematics for the **NFP** plots for the **Type 2** simulation models are available in the **Enstore's**

NFP report that includes the effects of **Droop** on **NFP** plots and how to calculate **NFP** plots with Droop.

The **NFP** plots for a **Type 2** simulation model in the frequency domain are produced as shown on **Figure 5.2** that has removed the **Droop** control function.

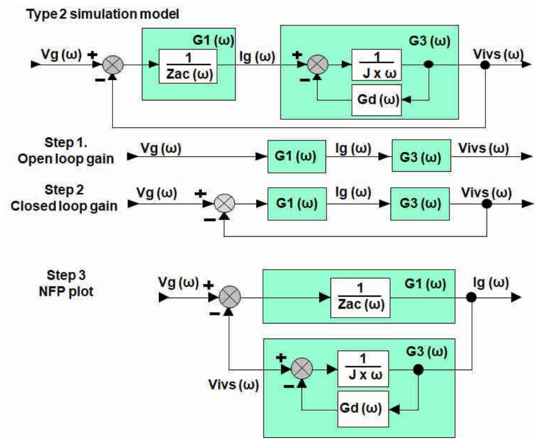


Figure 5.2. Producing NFP plots for a Type 2 simulation model.

The steps are:

- Produce the Open loop gain in the frequency domain using standard Bode diagram methods.
- Produce the Closed loop gain in the frequency domain using standard Bode diagram methods.
- Produce the **NFP** plot in the frequency domain using standard Bode diagram methods.

The **NFP** plot does not produce data on the stability of the Closed loop gain which is why the Nicholls plot is also produced.

A set of typical results are shown on **Figure 5.3.**

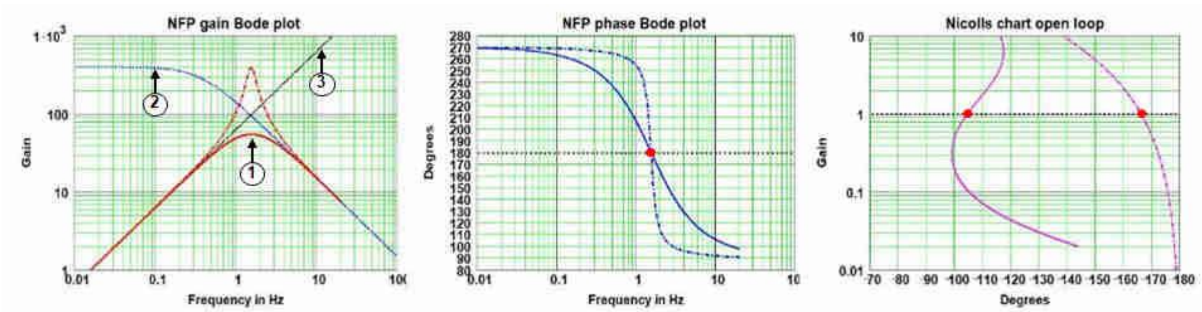


Figure 5.3. Typical results.

This data shows two designs with low and high damping and the **NFP** plot is used at all stages of a design to show the key performance features of a design.

This is especially important at the initial stages of a design as the essential data can be sent to **NGESO** for outline approval before the full system data is available. This enables a supplier to finalise the rating of the systems energy store early in the design as this is a major cost item that cannot be altered late in the design process. This is why it is essential to have agreed limits for **NFP** plots.

In the **Type 2** simulation model the systems external damping due to the AC supply is independent of the systems internal damping produced by the software damping function.

There are active power losses produced by the external AC supply damping but there are no power losses produced by the internal software damping. This is why it is possible to adjust the system damping on site by a software parameter.

A system can add any extra control features that give different **NFP** plot as shown on **Figures 5.4 & 5.5.**

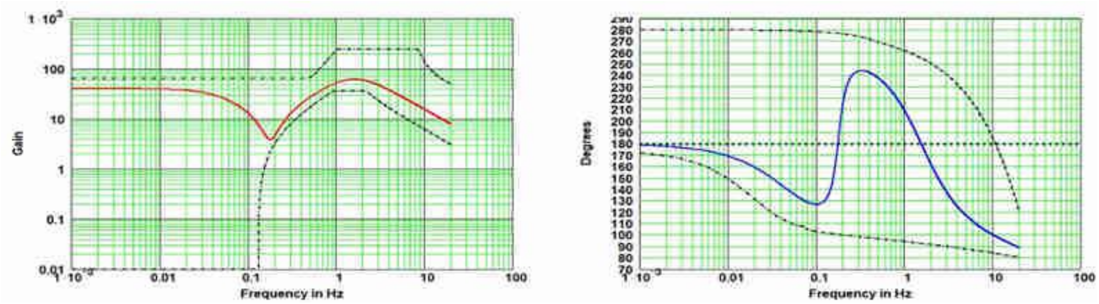


Figure 5.4. NFP plot with low frequency Droop control.

This is the **NFP** plot for a system with low frequency **Droop** control.

This is the control for either a **GBGF–S** generator with a low bandwidth prime mover control or a **GBGF- I** inverter and the dotted black lines are the proposed limits for acceptable **NFP** plots.

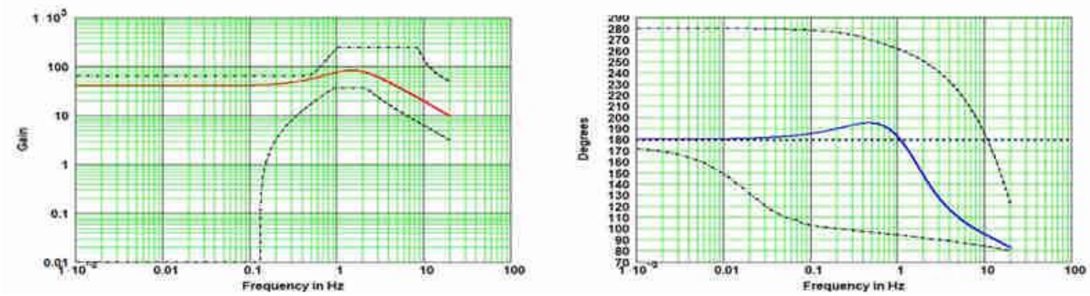


Figure 5.5. NFP plot with full Droop control.

This is the **NFP** plot for a system with Full **Droop** control which is only possible with a **GBGF- I** inverter system.

This is the control used to provide the maximum **RoCoF Response Power** that is described in the **Enstore**'s guide to **GBGF** technology, see reference 5, and a **VSM0H** design has a similar response with a higher **NFP** plot resonant frequency.

When **Droop** control is added it is an open loop feed-forward control feature that alters the shape of the associated **NFP** plot but it does not alter the damping and stability of the closed loop system. This is why a Nicholls chart must also be produced. The **Damping factor** equation is also modified.

When a Power System Stabiliser **PSS** control is added it is a closed loop feature that alters the shape of the associated **NFP** plot and it alters the stability of the closed loop system. This is why a Nicholls chart must also be produced.

The proposed limits for acceptable **NFP** plots are the dotted black lines that have been proposed by **Enstore**. It is very important that the **GFBPW** validates these limits for use by suppliers, see section 8 for more data.

A worked example of a **Type 2 NFP** plot is included in section 7.

The **NFP** plot is used to show the low frequency response of a **GBGF- I** inverters and a Phase Jump response is used to show the systems fast response to **Phase Jumps.**

Both sets of data should be included in any initial data sent to **NGESO.**

6. Production of NFP plots for GBGF-S generator systems.

NFP plots can be calculated based on the **Type1** time domain simulation models but the lack of the damping from the AC supply resistance requires that an extra calculation step is needed to give the correct peak gain at the resonant frequency of the **NFP** plot.

The extra calculation step is to add a software damping function.

The **Figure 3.2** shows a typical damping function but any damping function can be used,

The aim is to have the correct peak gain of the **NFP** plot before any extra control functions are added.

Enstore does not have an equation for relating the gain parameter of the damping function shown in **Figure 3.2** is to the resistance losses in the AC supply.

The **Enstor**e's mathematics for **NFP** plots has shown that the peak gain of a **NFP** plot is set by the losses in the AC supply this how the correct gain of the added software damping function can be set and validated.

For example, if the AC supply losses are 2.5 % the **NFP** plot should have a peak gain of 40.

For **GBGF-S** generators the generator's AC high frequency impedance is defined by the parameters **X"d & T"d.**

The main equations are **X"d = Root ((2 x Pi x 50 x Lacg)^2 + (Racg)^2)** and **T"d = (Lacg / Racg).**

This gives:

- **Lacg =** $$\frac{X''d}{\text{Root}\left(\left(2 \times Pi \times 50\right)^2 + \left(1 / T''d\right)^2\right)}$$
- **Racg = (Lacg / T"d).**

For a large **GBGF-S** generator**:**

- **X"d = 0.2** giving a symmetric fault current of 5 pu.
- **T"d = 0.02 pu.**

The equations for the generator give:

- **Lacg = 0.00063 pu**
- **Racg = 0.031 pu**

Adding a typical AC supply impedance gives:

- **Lac = 0.00106 this is a 50 Hz impedance = 0.333 pu**
- **Rac = 0.035.**

This enables the **NFP** plot to be produced and compared with **(1 / Rac) = 28.5** peak **NFP** plot gain

Once this extra software damping function is calibrated any other control functions can be added that can also alter the gain of the **NFP** plot. This simple method enables accurate **NFP** plots to be produced for **Type 1** simulations.

The **NFP** plot for **GBGF- S** generators can be produced from the time domain simulations.

The **Enstore** analysis has shown that **NFP** plots for a **GBGF-S** generator can also be also be produced in the Frequency domain by using the circuit of **Figure 5.2** that automatically gives the correct AC supply damping.

7. Example of a NFP frequency domain calculation using MathCad.

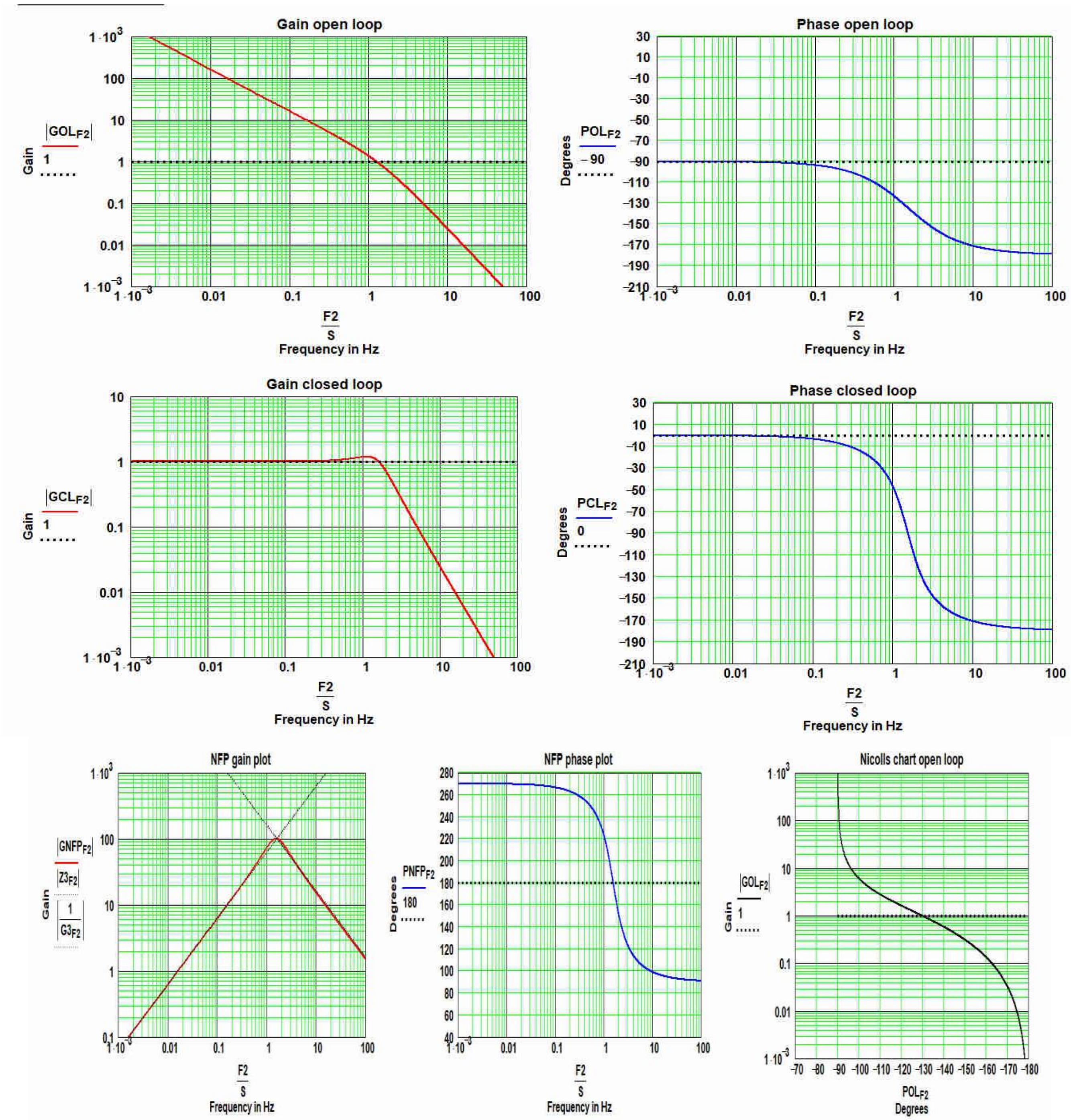
Primary parameters

$F := 1, 2 .. 10^5$	Frequency counter in steps of 0.001 Hz
$S := 1000$	Scale factor for frequency and the graph Y axis
$F2 := 1, 5 .. 10^5$	Counter for frequency graph plotting
$Lac := 0.00106$	AC supply inductance
$Rac := 0.01$	AC supply resistance
$J := 10$	Inertia parameter
$RF := 1 \div \left(2 \times \pi \times \sqrt{Lac \times J}\right)$	Resonant frequency
$RF = 1.546$	

Gain & phase equations

$G1_F := \dfrac{1}{Rac + i \times 2 \times \pi \times Lac \times F \div S}$	AC supply impedance
$G3_F := \dfrac{1}{(i \times 2 \times \pi \times J \times F \div S)}$	Inertia value
$Z3_F := \dfrac{1}{i \times 2 \times \pi \times L \times (F \div S)}$	Inpedance line
$GOL_F := G1_F \times G3_F$	Open loop gain
$POL_F := \arg\left(GOL_F\right) \times 180 \div \pi$	Open loop phase
$GCL_F := \dfrac{(G1_F \times G3_F)}{1 + G1_F \times G3_F}$	Closed loop gain
$PCL_F := \arg\left(GCL_F\right) \times 180 \div \pi$	Closed loop phase
$GNFP_F := \dfrac{(G1_F)}{1 + G1_F \times G3_F}$	NFP gain
$PNFP_F := \arg\left(GNFP_F \times 1\right) \times 180 \div \pi + 180$	NFP phase

Graphs for results



Note the use of the modulus function for the gain plots.

8. Revised limits for NFP plots

The previous meeting of the **GFBPW** presented data on **NFP** plots that have made it possible to proposed a simpler set of limits for **NFP** plots with well-defined reasons for each limit that are shown on **Figure 7.1.**

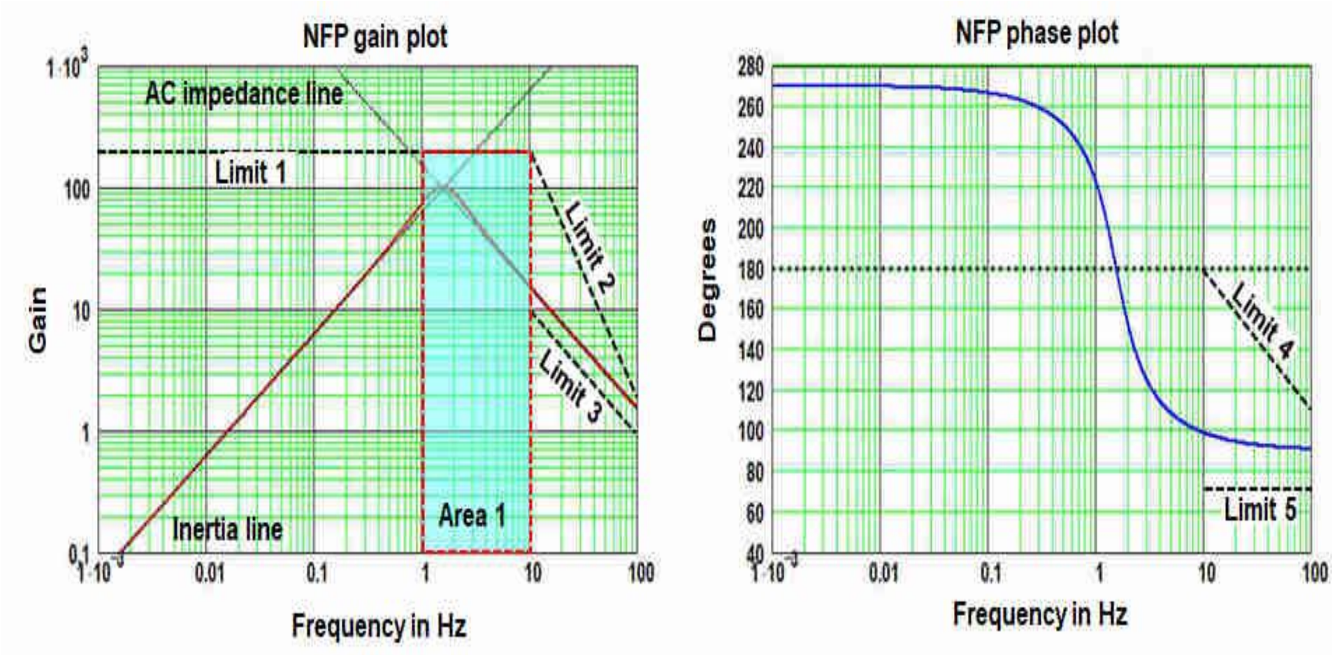


Figure 7.1. Proposed new NFP plot limits.

For **NFP** plots produced in the time domain the method is limit to a maximum frequency range of 20 Hz due to the interactions of the test input signal with the 50 Hz mains frequency.

This limit does not apply to **NFP** plots produced in the frequency domain that are shown up to 100 Hz.

For **GBGF- I** inverters the AC inductance line is shown on the **Figure 7.1** and is a well-defined parameter for a given system with an inductance of **Lac** and a resistance of **Rac**.

For this plot **Lac = 0.00106 pu** Henries which is an impedance **X(f) = 2 x Pi x f x Lac.**

This gives **X(50) = 0.333** pu which is why the AC impedance line has a value of 1/ 0.333 = 3 at 50 Hz on the **Figure 7.1.**

The data on the proposed **Area 1** limit is:

- The resonant frequency of the **NFP** plot must be within this area.
- The upper limit of 10 Hz is proposed to ensure that a viable **Active Phase Jump** power is produced.
- The lower limit of 1 Hz is proposed to ensure compatibility with the rest of the GB AC Grid.
- The maximum gain at resonance is 200 to be compatible with the **Limit 1** line.
- There are no other limits on the actual gain at resonance.
- The validation of these proposed revised limits can only be carried out by **NGESO** as part of a full-scale AC grid simulation.

The data for the five limit lines are:

- The data for the proposed **Limit 1** line is a gain of 200.

  A gain of 200 is a 100 % change of AC power for a 0.25 Hz AC grid frequency change and it is very unlikely that any higher low frequency gain will be required.

  In the **Area 1** a gain of 200 at the peak of a **NFP** plot is an AC supply loss of 0.5 % and this is a very low value.

  Some of the **ENTSO-E NFP** plots have very high values for the maximum gain, see reference 5 **Figure 3.2**. **Enstore** believes that that is because the **ENTSO-E** data is based on a **Type 1** simulation model without adding the damping due to the AC supply resistance.

- The data for the proposed **Limit 2** line is a gain of 200 at 10 Hz falling to 2 at 100 Hz.

  This is based on the AC supply impedance at 50 Hz being more than 0.25 pu.

  Extra data on this item is in reference 5 see **Figure 18.2.**

  This is a **TFL** of 4 pu at 50 Hz and 2 pu at 100 Hz.

  A **NFP** plot higher than this line would suggest that either the AC supply impedance is wrong or the **NFP** plot simulation model is not correct.

- The data for the proposed **Limit 3** line is a gain of 10 at 10 Hz falling to 1 at 100 Hz.

  This is based on the AC supply impedance at 50 Hz being less than 0.5 pu.

  This is a **TFL** of 2 pu at 50 Hz and 1 pu at 100 Hz.

  A **NFP** plot lower than this line would suggest that either the AC supply impedance is wrong or the NFP plot simulation model is not correct. A **NFP** plot below this line is where a **NFP** plot for an **original static** inverter would occur.

- The data for the proposed **Limit 4** line is a phase of 180 degrees at 10 Hz falling to 110 at 100 Hz.

  This is based on the AC supply phase shift being 90 degrees at 50 Hz and above.

  A **NFP** plot higher than this line would suggest that either the AC supply impedance is wrong or the **NFP** plot simulation model is not correct.

- The data for the proposed **Limit 5** line is a phase angle of 70 degrees from 10 Hz to 100 Hz.

  This is based on the AC supply phase shift being 90 degrees at 50 Hz and above.

  A **NFP** plot lower than this line would suggest that either the AC supply impedance is wrong or the **NFP** plot simulation model is not correct.

9. Topics for discussion in the next GFBPW meeting.

Topic 1. Simulation model review data.

Are there any questions on the simulation models?

Topic 2. NFP plot data.

Are there any questions on the NFP plot data?

Topic 3. Validation of the proposed NFP plot Area 1 limit.

This data is very important for suppliers and can only be done by a full-scale system model carried out by **NGESO.**

What will **NGESO** be doing to validate this limit?

Topic 4. Validation of the proposed Limit 1 to 5 lines.

This data is also very important for suppliers.

Are the proposed limits accepted by the **GFBPW**?

Topic 5. Validation of the Grid Oscillation Value.

The data in the proposed GB Grid Forming Grid Code is;

An injected test frequency signal applied at nominal **System Frequency** with a superimposed oscillatory response overlayed onto the nominal **System Frequency** with an amplitude of 0.05 Hz peak to peak at a frequency of 1 Hz and is used for determining the rating of the **Defined Active Damping Power**.

Are the proposed amplitude and frequency correct?

10. References.

Reference 1. Presentation from SGRE.

S_20210930 NG_GC0137 Stiffness and **NFP.**

Reference 2. Presentation from Strathclyde University

UoS_Battery_VSM_PNDC_Tests_20210930.

Reference 3. Presentation from Enstore.

Eric data for BPG – 001.

Reference 4. Presentation from Cardiff University

CU_Outline-30-09-2021.

Reference 5.

A Minimum Specification Required for Provision of GB Grid Forming (**GBGF**) Capability.

https://www.nationalgrideso.com/document/207576/download

This **Enstore's GBGF Guide** can be down loaded by using the **Reference 1** and opening the **Annex 18.**

11. Modification record.

Issue	Date	By	Details
Enstore 3 – 001F	18/10/2021	E A Lewis	Initial issue.