

GBGF-I Phase Angle Jump Behaviour

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Overview

This document sets out the expected behaviour and performance of **GB Grid Forming Inverter (GBGF-I)** based plant in response to Phase Angle Jump changes. This document is provided for users engaging in the Grid Code compliance process with NESO or partaking in Network Service Tenders, this document has been developed with the aim of helping users through these processes. This document has been published as supplementary guidance to the Grid Forming Guidance Note – Issue 3.

Expected Behaviour

The Phase Angle Jump response of a Grid Forming plant to a phase angle change at the PoC (Point of Connection) is an inherent part of a Grid Forming plant's functionality. The Active Power output of a Grid Forming plant in a linear operating region can be approximately expressed through Equation 1:

$$(1) \text{ Active Power} = \frac{(V_{ivs}V_G)}{X} \sin(\phi_{ivs} - \phi_G)$$

Where:

V_{ivs} is the Voltage Magnitude of the Internal Voltage Source of the plant.

V_G is the Voltage Magnitude of the Grid at the PoC

X is the equivalent total reactance between the internal voltage source and PoC

ϕ_{ivs} is the angle of the plant's internal voltage source.

ϕ_G is the angle of the Grid Voltage at the PoC.

From Equation 1, it can be understood that if the angle of the Grid Voltage changes there will be an instantaneous change in the active power output of the plant. This active power response of the Grid Forming Plant will be in anti-phase to any Phase Angle Jump that occurs. For instance, a positive phase angle jump in the grid voltage would result in an additional negative active power response from the plant and likewise a negative phase angle jump in the grid voltage would result in additional positive active power being supplied into the Grid. A graphical representation of this relationship is shown in Figure 1.



Figure 1: Active Power vs Phase Angle Difference ($\phi_{IVS} - \phi_G$)

In Figure 1, there are two different Phase Angle Jumps presented (B and C). Using Equation 1 any phase angle change at the Grid will have an opposite impact on the active power output of the plant i.e. an increase in the Grid Phase Angle will cause a decrease in the Active Power output and vice versa.

An example of this behaviour, through Equation 1, is shown below. When the phase angle difference between V_{IVS} and V_G is increased, more active power will flow, whereas when this difference is reduced the corresponding active power will reduce.

Taking X as 0.1 p.u, V_{IVS} and V_G as both 1 p.u, with an ϕ_{IVS} of 20 degrees and ϕ_G of 10 degrees the active power output of the plant will be:

$$Active\ Power\ (p.u.) = \frac{(1 \times 1)}{0.1} \sin(20 - 10) = 1.73\ p.u.$$

When a Phase Angle Jump of +5 degrees occurs at the Grid (ϕ_G is therefore 15 degrees), the active power output of the plant will now be:

$$Active\ Power\ (p.u.) = \frac{(1 \times 1)}{0.1} \sin(20 - 15) = 0.87\ p.u.$$

For inverter-based resources which have installed a Grid Forming capability (GBGF-I) plant, current limiters are typically used to protect the IGBTs (Insulated Gate Bipolar Transistors) in the inverter from overload. The withstand mode is used to describe the state of operation when the inverter reaches its current limit, as shown in Figure 2. It should be noted that this is only a graphical representation of this behaviour and is a representative performance only of the plant operating at 0MW and 0MVar before the Phase Jump occurs.

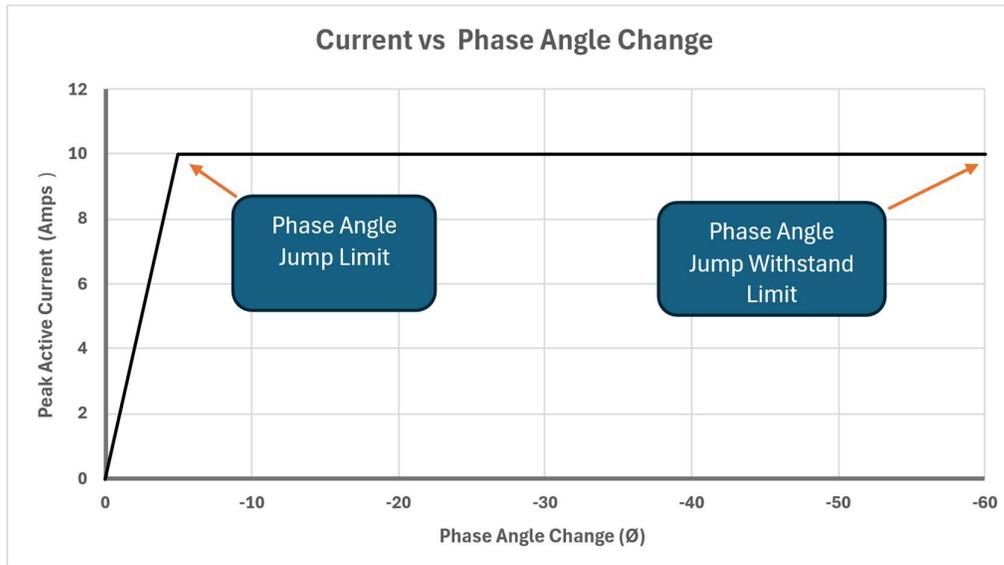


Figure 2: Phase Angle Jump Withstand Mode

It should be noted that Figure 2 is not a time-series graph, the X axis represents the Phase Angle change that will occur, with the corresponding Peak Value of Active Current that will be delivered for this change on the Y axis.

The Grid Code, defines two key points of performance. The **Phase Jump Angle Limit** and the **Phase Jump Angle Withstand Limit**. The **Phase Jump Angle Limit** is the angle upto which the GBGF-I plant will result in a linear controlled response such that any further increase in the Phase Angle (beyond the Phase Jump Angle Limit) would activate the current limiting functions of the plant. The **Phase Angle Jump Withstand Limit** is the angle beyond which the plant is no longer able to remain connected to the system as any further angle increase is too large for the plant to remain connected.

When the plant response is not limited by the current limiting functions, the requirements of Equation 1 must be fulfilled. When the plant transitions into and out of the withstand mode, this must be a smooth transition as to have a limited impact upon other users of the system.

When a phase angle jump larger than the **Phase Jump Angle Limit** occurs, the initial performance of the plant before it saturates should still be that of a voltage source behind an impedance. This is to mean, that before the plant enters the withstand mode, an anti-phase active power performance should be demonstrated from the plant when the angle change occurs. For instance, if a -60 degree angle jump occurs, which forces the plant into the withstand

mode, the initial performance of the plant before entering the withstand mode should be to inject active current into the system up to the **Phase Jump Angle Limit**.

Further to this, when the plant returns to its pre-event operation point, this transition must happen in a stable manner.

An example illustration of the performance of the plant to a phase angle jump larger than the **Phase Angle Jump Limit** is shown in Figure 3. It should be noted that this is an illustration only of the idealised process of the plant reaching its withstand mode, with the plant operating at 0MW and 0MVAR before the Phase Jump occurs. This illustration does not include any resynchronisation elements of the plant either. Therefore, the current response after reaching its limit may not represent the actual behaviour of a GBGF-I plant in practice.

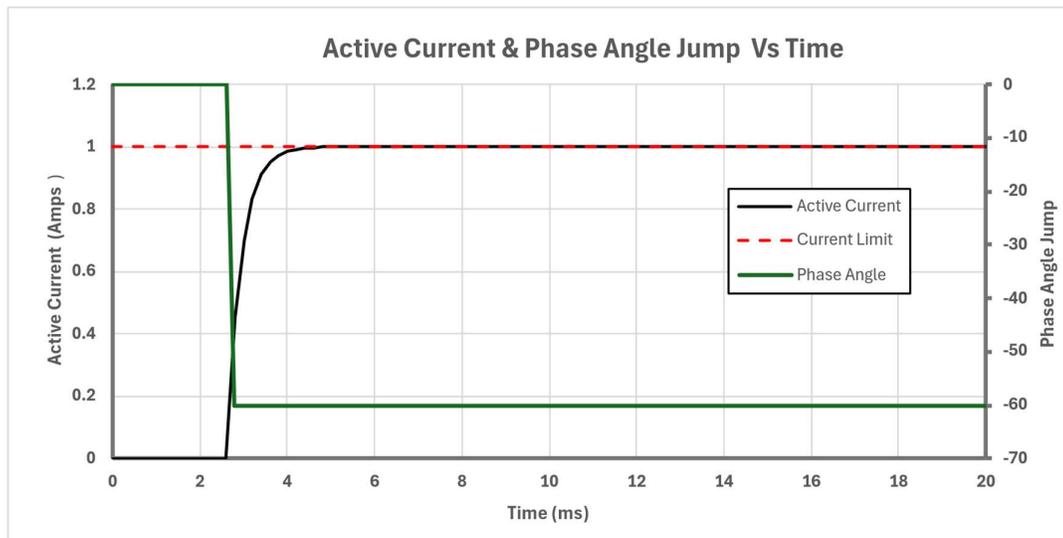


Figure 3: Idealised Phase Angle Jump Active Current Performance

Definitions

<p>GB Grid Forming - Inverter (GBGF-I)</p>	<p>Is any Power Park Module, HVDC System, DC Converter, OSTDUW Plant and Apparatus, Non-Synchronous Electricity Storage Module, Dynamic Reactive Compensation Equipment or any Plant and Apparatus (including a smart load) which is connected or partly connected to the Total System via an Electronic Power Converter which has a Grid Forming Capability (GBGF-I)</p>
<p>Phase Jump Angle Limit</p>	<p>The maximum Phase Jump Angle when applied to a GBGF-I which will result in a linear controlled response without activating current limiting functions. This is specified for a System angle near to zero which will be considered to be the normal operating angle under steady state conditions.</p>
<p>Phase Jump Angle Withstand Limit</p>	<p>The maximum Phase Jump Angle change when applied to a GBGF-I which will result in the GBGF-I remaining in Stable Operation with current limiting functions activated. This is specified for a System angle near to zero which will be considered to be the normal operating angle under steady state conditions.</p>