

## Stage 01: Workgroup Report

National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS)

# GSR018: Sub-Synchronous Oscillations (SSO) Workgroup Report

01	Workgroup Report
02	Industry Consultation
03	Report to the Authority

This Workgroup Report summarises the proposals to modify the NETS SQSS and the Grid Code to include Sub-Synchronous Oscillations (SSO) related provisions and clarify the associated accountabilities. This includes the SSO phenomenon that needs to be considered, the definitions of acceptable and Unacceptable SSO conditions and the operating conditions and secured events for which acceptable and Unacceptable SSO conditions should be assessed.

This document contains the findings of the Workgroup which was formed on 02 April 2014 and concluded on **23/09/2015**

**Published on:** 24/11/2015



***The Workgroup recommends:***

Implementation of the modifications proposed to the NETS SQSS and the Grid Code



***High Impact:***

None identified



***Medium Impact:***

Transmission Licensees  
Generators



***Low Impact:***

Networks Operators

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## About this Document

This document is a Workgroup Report which contains the discussions and recommendations of the GSR018: Sub-Synchronous Oscillations (SSO) Workgroup.

## Document Control

Version	Date	Author	Change Reference
1.1	24/11/2015	Workgroup Members*	Draft Workgroup Report

\*Full list of Workgroup members is available in Annex 1



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GSR018 Workgroup

Report

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Version 1.0

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## 1. Executive Summary

- 1.1 The Grid Code and the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) do not explicitly specify that Transmission Licensees are required to ensure that no User equipment is subjected to Unacceptable Sub-Synchronous Oscillations. These requirements are implicit within the Licence Conditions, the principles of the System Instability criteria of the NETS SQSS, and good industry practice.
- 1.2 All Transmission Licensees' investment plans include some reinforcements that may interact with User's Generating Units at sub-synchronous frequencies. These interactions, if not managed, may result in negatively or poorly damped Sub-Synchronous Oscillations that may cause damage to User's equipment as well as transmission plant. So far, the specifications of these reinforcements have included Sub-Synchronous Oscillation mitigation measures.
- 1.3 Users have requested a clear specification of accountabilities in relation to mitigation of the risks associated with Sub-Synchronous Oscillations.
- 1.4 The Workgroup discussed how to clarify these accountabilities in order to provide Users with assurance that their equipment would not be exposed to unacceptable risks due to Sub-Synchronous Oscillations; and that their Access Rights would not be impacted by these risks; while ensuring that Transmission Licensees have the ability to identify the most cost effective mitigation measure.
- 1.5 In order to agree the NETS SQSS requirements on Sub-Synchronous Oscillations, the Workgroup used the requirements for System Instability as a template; discussed the potential issues that may arise from using the same requirements in relation to Sub-Synchronous Oscillations; and agreed the changes required.
- 1.6 The Workgroup discussions were informed by the experience gained by Transmission Licensees through the specification of Series Capacitors and the Western HVDC Link. The modifications proposed took into account the Sub-Synchronous Oscillations mitigation strategy devised under both projects.
- 1.7 The Workgroup agreed that although the principles of the NETS SQSS criteria apply in relation to Sub-Synchronous Oscillations, the letter of the definition may be almost impossible to be met and hence separate criteria for Sub-Synchronous Oscillations need to be specified.
- 1.8 The Workgroup proposes that the NETS SQSS should to be modified to:
  - 1.8.1 include a definition for Sub-Synchronous Oscillations and a definition for Unacceptable Sub-Synchronous Oscillations;
  - 1.8.2 specify within Section 2, Section 4 and Section 7 of the NETS SQSS that following a secured event, there shall be no Unacceptable Sub-Synchronous Oscillations; and
  - 1.8.3 specify within Section 2 and Section 7 of the NETS SQSS that in relation to the power plant under consideration, Sub-Synchronous Oscillations criteria should be met when the Generating Unit is operating at the output level where it is most vulnerable to Sub-Synchronous Oscillations.

No changes have been proposed to the secured events, to the background conditions specified in Section 4, or to the background conditions for plants other than the plant under consideration specified in Section 2 and Section 7 as these were considered sufficient.
- 1.9 The Workgroup proposes to support the Grid Code Modification Proposal GC0077 which stipulates that:
  - 1.9.1 NGET is required to ensure that no User's plant is subjected to Unacceptable Sub-Synchronous Oscillations in accordance with the relevant Licence Standards; and

- 1.9.2 where there is a need, NGET may set some site specific requirements related to damping or mitigation of Sub-Synchronous Oscillations on Users.

Transmission Licensees, other than NGET, will need to meet the same requirement as NGET in accordance with the System Operator Transmission Owner Code (STC).

- 1.10 The potential interactions between the modifications proposed for the Grid Code and the NETS SQSS and the Connection and Use of System Code (CUSC) Section 2.3 (New Connection Sites), Section 6.9 (Modifications), and Section 13 (Enabling Works) were discussed.
- 1.11 The Workgroup established that any User Works, Third Party Works or requirements related to the mitigation of the risks of Unacceptable Sub-Synchronous Oscillations will be identified as a part of the Connection Application or Modification Application processes described in CUSC 2.13 and CUSC 6.9. Where the interactions arise because of new transmission plant, it is expected that Transmission Licensees will prompt the relevant Other Users to submit a Modification Application through a Modification Notification, to be sent by NGET to these Users.
- 1.12 The Workgroup agreed that any works required to mitigate the risks of Unacceptable Sub-Synchronous Oscillations are necessary to be complete ahead of the User's connection date in order to ensure that NGET is able to operate the system in a safe manner. That implies that, in accordance with paragraph 13.2.3.4 of the CUSC, these works will be classified as Enabling Works even if they were triggered by the post-fault criteria of Section 2 or Section 7 of the NETS SQSS.
- 1.13 Practical implementation of the requirements was discussed. This includes a non-exhaustive list of potential requirements some Users may have to meet, the differences between new connections and existing connections, and the differences between different Generating Unit technologies. Although these were not included in the modification proposed the discussions are included in the report in order to clarify how the proposal is going to affect Users.
- 1.14 Policy on Sub-Synchronous Oscillations monitoring was discussed. It is expected that Unacceptable Sub-Synchronous Oscillations are to be mitigated either by design or some other operational arrangement. However, it is acceptable that Transmission Licensees require Users to install Sub-Synchronous Oscillations monitoring equipment such that they are able to assess the effectiveness of Sub-Synchronous Oscillations mitigation measures in place, identify any safety risks, and address any concerns.
- 1.15 Policy on Sub-Synchronous Oscillations protection was discussed. It was highlighted that protection systems are provided in order to protect the system and User equipment against risks that could not otherwise be mitigated. That is, Transmission Licensees, when planning their network, and NGET, when operating the system, do not use protection as a means of meeting the NETS SQSS criteria or the Grid Code criteria. Hence, there will not be a requirement that Users install Sub-Synchronous Oscillation protection relays.
- 1.16 The workgroup believes that the Terms of Reference has been completely discharged and recommends that the NETS SQSS Review Panel and the Grid Code Review Panel approve this workgroup report, and recommend it for industry consultation.

## 2. Purpose & Scope of Workgroup

- 2.1 A NETS SQSS Modification Proposal was raised at the December 2013 NETS SQSS Review Panel Meeting in relation to the treatment of Sub-Synchronous Oscillations (SSO) within the NETS SQSS.
- 2.2 The NETS SQSS Review Panel recommended the formation of a Sub-Synchronous Oscillations Workgroup. The Workgroup was tasked to report on the following points:
  - 2.2.1 The need to include SSO related provisions within the NETS SQSS;
  - 2.2.2 The SSO phenomena that needs to be considered;
  - 2.2.3 The definition of acceptable or Unacceptable SSO conditions; and
  - 2.2.4 The operating conditions and secured events for which acceptable or Unacceptable SSO conditions should be assessed.
- 2.3 In addition, following discussions at the Grid Code Review Panel and feedback on these discussions to the NETS SQSS Review Panel; the Workgroup was tasked to report on the requirement for changes to the Grid Code arising from the Workgroup's proposals also.

### Terms of Reference

- 2.4 A copy of the Terms of Reference can be found in Annex 1.

### Timescales

- 2.5 It was agreed that this Workgroup would report back to the April 2015 NETS SQSS Review Panel. However, due to the complexity of the issues being considered and the change in Terms of Reference, this was delayed until the October 2015 NETS SQSS Review Panel Meeting.
- 2.6 Verbal updates on the progress of this Workgroup have been provided at the NETS SQSS Review Panel Meetings.

### 3. Why Change?



#### Background

- 3.1 In order to avoid building new onshore transmission overhead lines, Transmission Licensees in Great Britain have identified a set of reinforcements that aim to:
- 3.1.1 maximise the capability of existing AC routes via Series Compensation; and
  - 3.1.2 increase the capability of constrained boundaries via the construction of new subsea HVDC Links.

A list of these projects is given in Table 1.

Table 1. Transmission System Reinforcements.

Project	Technology	Transmission Licensee	Need Case	ETYS 2014 EISD*
Harker-Hutton Series Compensation	Thyristor Controlled Series Capacitor (TCSC)	NGET	Increasing the stability limit of the AC interconnection between NGET and SPT	Already in service
Gretna-Harker / Moffat-Harker Series Compensation	Fixed Series Capacitor with Passive SSR Damping Filter	SPT	Increasing the stability limit of the AC interconnection between NGET and SPT	2015
Eccles-Stella West Series Compensation	Fixed Series Capacitor with Passive SSR Damping Filter	SPT	Increasing the stability limit of the AC interconnection between NGET and SPT	2015
Western HVDC Link	CSC HVDC Submarine Cable	NGET / SPT	Primary boundary capability increase	2017
Caithness Moray HVDC Link	VSC HVDC Link (with multi-terminal capability)	SHET	Primary boundary capability increase	2018
Shetland Connection	VSC HVDC Link (to be connected to the Caithness Moray Link)	SHET	Generation connections	2020
Western Isles	VSC HVDC Link	SHET	Generation connections	2020
Orkney	VSC HVDC Link	SHET	Generation connections	2021
Eastern HVDC Link(s)	VSC HVDC Link	NGET / SPT / SHET	Primary boundary capability increase	Post 2024

\*EISD: Earliest In Service Date

- 3.2 Interactions between these new transmission reinforcements and Synchronous Generating Units, Power Park Modules or individual Power Park Units connected to the National Electricity Transmission System (NETS) may result in poorly or even negatively damped power system oscillations at sub-synchronous frequencies. These oscillations impose some risk on User's equipment and may eventually lead to the failure of this equipment.
- 3.3 The obligation that Transmission Licensees design and operate a Transmission System that does not have Unacceptable SSO conditions is implicit under the NETS SQSS criteria for System Instability and is good industry practice. However, the NETS SQSS does not explicitly refer to SSO and the Grid Code refers to such

#### Timeline

##### Workgroup Meeting

##### Dates

- M1 – 21 07 2014
- M2 – 03 10 2014
- M3 – 28 11 2014
- M4 – 24 03 2015
- M5 – 21 07 2015
- M6 – 23 09 2015

oscillations when placing a requirement on HVDC Interconnector Owners to ensure their plant does not cause SSO.

- 3.4 All HVDC Converters and Series Capacitors that have been tendered by Transmission Licensees were specified to ensure that they do not cause any material SSO risks. The specification and detailed design of this equipment required significant liaison between Transmission Licensees and individual Generators who were requested to provide additional data, allow Transmission Licensees and their contractor's access to their plant to fit testing and measurement equipment and, in some cases, fit permanent monitoring equipment on their machines.
- 3.5 This liaison between Transmission Licensees and Generators has taken place on an ad-hoc basis and is not subject to any specific Grid Code or CUSC Clauses other than PC.A.7 of the Grid Code which allows NGET to request additional data. Thereafter, there have been several attempts to clarify the requirements and the responsibilities related to mitigation of SSO risks within the Grid Code and the NETS SQSS.
- 3.6 In August 2013, the Grid Code was modified to include the proposals of "*GC0040: Information Required to Evaluate Sub-Synchronous Resonance*". This modification requires Generators, in relation to their new Synchronous Generating Units, to provide the data required for SSO related studies.
- 3.7 An issue paper, pp13/54, was submitted to the Grid Code Review Panel in August 2013 requesting that the Grid Code ensures that Series Compensation equipment does not cause Sub Synchronous Resonance issues. In response to this paper, a Grid Code Modification Proposal, GC0077, was drafted and sent out for an Industry Consultation in July 2014 and a Modification Proposal was submitted to the NETS SQSS Review Panel to clarify any related requirements that needs to be defined within the NETS SQSS.
- 3.8 "*GC0077: Suppression of Sub-Synchronous Resonance from Series Capacitive Compensation*" proposed a modification to the Grid Code to place an obligation on NGET to ensure that User's Plant and Apparatus are not subject to Unacceptable SSO conditions. It also proposed to stipulate that NGET may specify SSO related requirements in the Bilateral Agreement with the relevant Users. The Industry Consultation on this proposal highlighted some issues that need to be addressed. The Grid Code Review Panel agreed to delay any conclusion on the GC0077 Modification Proposal until the related NETS SQSS proposal had come to a conclusion.
- 3.9 The Modification Proposal submitted to the NETS SQSS Review Panel in April 2014 proposed that an industry Workgroup is set up and tasked to specify how SSO would be better captured within the NETS SQSS. The proposal suggested that the NETS SQSS System Instability criteria was used as a baseline for any SSO related requirements.
- 3.10 The NETS SQSS Review Panel agreed to form the "GSR018: Sub-Synchronous Oscillations" Workgroup to advise on any modification required to the NETS SQSS and, following a request from the Grid Code Review Panel, the Grid Code also.

### Issues for Transmission Licensees

- 3.11 Transmission Licensees consider that there is already an obligation on them to develop and operate a Transmission System that is free from any Unacceptable Sub-Synchronous Oscillations. This obligation arises from their licence obligations to develop, maintain and operate the National Electricity Transmission System in a safe and secure manner. It is also linked to the System Instability criteria defined

within the NETS SQSS which, when met, would ensure that the system is secure against the majority, if not all, Unacceptable Sub-Synchronous Oscillations.

3.12 Hence, from the perspective of a Transmission Licensee, any modification to the Grid Code or the NETS SQSS is only required to:

- provide some assurance to industry partners that SSO risks will be mitigated; and
- provide clarity that, although the main accountability lies with Transmission Licensees, a transmission based solution might not always be the most economic and efficient solution. In such cases, NGET should be able to specify some SSO related requirements in the Bilateral Agreement of the relevant Users.

3.13 While achieving the targets specified in Paragraph 3.12, the modification should not:

- trigger unjustifiable investment;
- dictate the use of any specific technology for their projects (e.g. TCSC);
- be too prescriptive; or
- limit the ability to implement, or require a User to implement, the most cost effective Sub-Synchronous Oscillation mitigation measure.

### Issues for Transmission System Users

3.14 So far, SSO risks on the Transmission System have been limited to Sub-Synchronous Torsional Interactions (SSTI) between DC Converters and nearby Synchronous Generating Units. This risk has been managed through CC.6.3.16 of the Grid Code which places an obligation on the DC Converter owners.

3.15 As for new projects, SSO risks may arise because of potential interactions between Transmission Plant and User Plant. The accountability of managing this risk is not explicitly defined within the Grid Code.

3.16 Ideally, Users would like to have:

- assurance that their plant will not be subjected to risks due to Unacceptable SSO conditions;
- assurance that their Access Rights will not be negatively affected by SSO;
- clarity on which party is accountable for the mitigation of SSO risks; and
- some understanding of what they might be required to provide in order to allow Transmission Licensees to mitigate SSO risks in the most cost effective way.



## 4. Workgroup Discussions

4.1 The first Workgroup meeting was held on 21 July 2014. The Workgroup met 6 times over the period between 21 July 2014 and 23 September 2015.

4.2 The following issues were discussed by the Workgroup:

### Sub-Synchronous Oscillations (SSO)

4.3 Sub-Synchronous Oscillations (SSO) are power system oscillations at frequencies that are less than the power frequency. They arise from modes of oscillation associated with interactions between certain equipment in the electricity Transmission System such as generator shaft systems; series compensated lines; excitation system controllers; power system stabilisers and controllers of power electronic converters of either high voltage direct current transmission equipment or power park modules.

4.4 SSO always exist in a power system, but in most cases they are of low magnitude and are adequately damped. However, in some instances, poorly or negatively damped SSO could have significant implications on the Transmission System.

4.5 Unacceptable SSO are SSO having either negative or zero damping such that the magnitude of oscillations will not eventually decay to zero or very low positive damping such that the combined effect of the low positive damping and the magnitude of oscillation will significantly reduce the lifetime of generator shafts due to fatigue or result in failure of the electrical components of the Generating Unit due to high voltages or currents.

4.6 Unacceptable SSO may arise from interactions between Generating Unit(s) and Series Compensation, Generating Unit(s) and the control systems of HVDC Converters or between different control systems and each other. Interactions between Generating Units and Series Capacitors are referred to as Sub-Synchronous Resonance (SSR). These include the induction generator effect, torque interaction and torque amplification. Interactions between Generating Units and the control systems of HVDC Converters are referred to as Sub-Synchronous Torsional Interactions (SSTI). Interactions between control systems are referred to as Sub-Synchronous Control Interactions (SSCI). The Workgroup noted that other interactions of the same nature may exist but that these may not have been reported in literature in sufficient detail.

4.7 The consequences of SSO vary according to the type of interaction, the magnitude of oscillations and the speed by which it is damped. SSO at or near to any of the natural frequencies of a generator shaft system will induce oscillatory torques at one or more of the shaft sections. These oscillatory torques, depending on their magnitude and the number of cycles before they are damped, could cause the mechanical failure, or at least reduce the life, of the shaft sections. SSO at frequencies other than the natural frequencies of the generator shaft system may result in high voltages and currents that damage the electrical components of the Generating Unit.

4.8 The term SSO does not cover electromechanical oscillations associated with rotor swings despite the fact that the frequency of these oscillations is less than the synchronous frequency.

## SSO on the National Electricity Transmission System

### HVDC Interconnectors

- 4.9 SSO has been a risk to the National Electricity Transmission System since the first HVDC interconnection between Great Britain and neighbouring countries was established. The risk is generally limited to current source converters operating in DC current control, i.e. rectifier, mode and it materialises when the negative electrical damping introduced by the HVDC Link converter controller at the complementary frequency of one of the natural frequencies of the mechanical shaft system of a nearby Synchronous Generating Unit exceeds the positive mechanical damping at that natural frequency.
- 4.10 The HVDC Converter owner, in line with CC.6.3.16 of the Grid Code, has the enduring responsibility to mitigate any SSO risks that arise from the interactions between the HVDC Link and other plant.
- 4.11 This risk is usually mitigated in design timescales by adequate tuning of the HVDC Converter Controller or by fitting the controller with an SSO damping loop. However, there are a few exceptions where the risk has been managed via intertripping the interconnector for specific combinations of transmission system outage conditions.

### The Western HVDC Link

- 4.12 The Western HVDC Link may interact with nearby Synchronous Generating Units in a manner that is similar to HVDC Interconnectors. These risks are mitigated in design timescales by fitting the HVDC Converter Controller with an SSO damping loop backed up by an SSO protection function.
- 4.13 CC.6.3.16 requirements do not cover transmission plant other than OTSDUW HVDC Converters. However, it is implicit that Transmission Licensees are required to mitigate SSO risks in order to ensure that the National Electricity Transmission System is operated in a safe and secure manner.
- 4.14 When the Western HVDC Link was tendered, it was specified that it shall not cause any Unacceptable SSO. SPT and NGET have been liaising with the HVDC Link developers and the relevant Generators in order to ensure that the appropriate SSO mitigation measures are in place.

### Series Compensation

- 4.15 A capacitor connected in series with an inductive Transmission System will create an electrical resonance at a sub-synchronous frequency. If this resonance frequency coincides with the complementary frequency of one of the natural frequencies of a nearby Synchronous Generating Unit or if it coincides with a frequency when the overall equivalent system series resistance is very low or negative, Unacceptable SSO might occur.
- 4.16 Similar to the Western HVDC Link, the Series Capacitors are currently only covered by the implicit requirements that Transmission Licensees should ensure that the system is operable in a safe and secure manner and by the NETS SQSS System Instability criteria.
- 4.17 There are several measures that could be used to mitigate SSO risks associated with Series Capacitors. These measures could be transmission based measures, such as the use of Thyristor Controlled Series Compensation (TCSC), fixed capacitors with damping filters or modifications to the Transmission System topology. They could also be Generating Unit based measures such as blocking

filters, damping controllers or, to a lesser extent, modifications to the generator shaft system.

- 4.18 When NGET's Series Capacitors were tendered, it was specified that it shall not cause any electrical undamping over the frequency range between 5Hz and 45Hz. When SPT's Series Capacitors were tendered, a maximum undamping characteristic was specified and it was required that the electrical undamping resulting from Series Compensation should be below that maximum value.

### **SSO Mitigation Strategy: Design Timescales**

- 4.19 A minimum electrical damping, or maximum electrical undamping, characteristic was specified for the Series Capacitors at the various locations. This specification was informed by the data and mechanical models provided by the manufacturers of nearby Synchronous Generating Units. For NGET's TCSC solution, the maximum undamping allowed over the relevant frequency range (5Hz to 45Hz) was zero. For SPT's fixed Series Capacitor solution, some undamping was allowed provided that there is a sufficient margin between the electrical undamping and the corresponding mechanical damping.
- 4.20 A set of credible pre-fault operational scenarios where the flows across the Anglo-Scottish boundary are high enough to dictate that the Series Compensation should be in service was identified. These scenarios included Intact System conditions (N) and some pre-fault outage conditions (N'). It also included the credible combinations of Generating Units in and out of service. Combinations of pre-fault outage conditions were not considered as these would restrict the flow across the boundary below the stability limit of the uncompensated system which allows the System Operator to bypass the Series Compensation.
- 4.21 The Series Capacitors were specified such that, at all combinations of Intact System, N-1, N-D, N'-1, N'-D and for all the generation background conditions considered and over the entire frequency range, the electrical damping provided by the Series Capacitor should be higher than the minimum electrical damping characteristic.
- 4.22 There were a few cases when the combination of the pre-fault outage and the fault left a single plant connected to the system via a radial series compensated circuit. These cases, despite having sufficient damping levels, were managed by an auto bypass scheme that would bypass the Series Capacitors.

### **SSO Mitigation Strategy: Operational Timescales**

- 4.23 In operational timescales, it is expected that the Series Capacitors will be bypassed unless the flows across the Anglo-Scottish boundary exceed the stability limit of the uncompensated system.
- 4.24 Once the flows exceed that limit, NGET will switch the Series Capacitors into service and arm the auto bypass scheme necessary to deal with contingences described in paragraph 4.21.
- 4.25 For the comprehensive set of operational scenarios considered in design timescales, the Series Capacitors are not expected to impose any SSO risks to the Transmission System either at pre-fault conditions or at post-fault conditions.
- 4.26 If an operational scenario other than those considered in the design timescales materialise (e.g. due to an enduring fault outage or due to an extensive construction programme), the System Operator will have to re-balance the system to secure it for the next fault taking into account thermal, voltage, and stability constraints. While

doing so, it is expected that the flows across the Anglo-Scottish boundary will be reduced to a level below the stability limit of the uncompensated system. In this case, the System Operator will be able to bypass the capacitors to eliminate any SSO risks.

- 4.27 In summary, SSO risks will be mitigated by design, by bypassing the Series Capacitors pre-fault or by bypassing them post-fault. Any actions required from Generators will be instructed via the Balancing Mechanism and in line with the Generator's Access Rights.

## SSO Monitoring

- 4.28 A range of metering and monitoring equipment is installed at various transmission sites. This equipment enables Transmission Licensees to assess the state of the system, highlight any risks and identify any actions they need to take to remain compliant with their Licence Obligations and License Standards. This range varies from simple voltage and current measurement equipment to more sophisticated power quality monitors and fault recorders.
- 4.29 Ideally, metering and monitoring equipment would be located at transmission sites. This is to facilitate access to the equipment and data. However, in some cases, some quantities can be measured more accurately if the measurement and monitoring equipment are located at User sites.
- 4.30 In order to ensure that SSO remain within acceptable limits, Transmission Licensees may find it necessary to monitor these oscillations at some critical sites. Due to the nature of the phenomena involved, and in order to achieve the accuracy required, the monitoring equipment may require to be fitted on the shafts of Synchronous Generating Units.
- 4.31 So far, one Transmission Licensee, SPT, has installed SSO monitoring equipment to some of the Synchronous Generating Units connected near the Series Capacitors and the Western HVDC Link. This equipment will allow NGET, SPT, and the User to monitor SSO and ensure that no plant is exposed to Unacceptable SSO risks.
- 4.32 Ongoing monitoring of SSO also provides data that can be used to refine the models used for generators and other plant in SSO studies. This would improve the confidence in the estimates of the mechanical damping associated with shaft torsional modes, which are important when assessing the stability of such modes.

## SSO Protection

- 4.33 Protection systems are provided in order to protect the system against risks that could not otherwise be mitigated. They will trip if they identify that one or more quantities on the power system exceeded the capability of the equipment they are trying to protect by a specific discrimination margin for a period of time that is sufficient for the protection system to operate. The discrimination margin should be sufficiently large such that protection systems do not trip unnecessarily when the equipment are operated at their maximum capability. The time required for the protection to operate would usually depend on the type of protection and the magnitude of overload.
- 4.34 A genuine trip by a protective relay would indicate that some equipment has been operating beyond its capability for some period of time. Hence, Transmission Licensees, when planning their network, and NGET when operating the system, do not use protection as a means of meeting the NETS SQSS criteria or the Grid Code

criteria. Instead, the system will be reinforced in design timescales and operational measures will be taken in operational timescales to ensure that these criteria are met.

- 4.35 Similarly, Transmission Licensees and NGET need to implement an SSO mitigation strategy in both design and operational timescales such that there is no need for SSO protection. Consequently, there is no requirement for SSO protection equipment to be fitted to User's plant.
- 4.36 Where a Generator opts to install SSO protection, it is expected that this will be done at their own risk and that NGET will not be liable for any compensation following the operation of such protection. It is also expected that the Generator will coordinate the protection settings with NGET.

## **SSO Interactions with Existing Generation Connections**

### Synchronous Generating Units

- 4.37 Interactions between the mechanical shaft system or the rotor electrical system of Synchronous Generating Units on one side and Series Capacitors or HVDC Link Converter Controllers on the other side may cause Unacceptable SSO to occur. These interactions are assessed using well established methodologies and generic models. Input required from manufacturers is usually limited to the parameters required for these models.
- 4.38 Transmission Licensees, and their contractors, have used the machine parameters provided by manufacturers and, where possible, validated by tests to inform the design of the Series Capacitors and the HVDC Link.
- 4.39 Any work that has been required to be done at existing Users' plant that a) exceeded what the Users are required to do under the CUSC, the Grid Code, or the Bilateral Agreement and b) were attributed to the Series Compensation and/or the Western HVDC link projects, were funded by Transmission Licensees as a part of these projects. Examples of these works are provision of generating unit shaft system data and the tests undertaken by Transmission Licensees contractors to determine the natural frequencies of generating units shaft systems.
- 4.40 Modifications to existing Users plant that were attributed to the Western HVDC link and/or the Series Compensation projects were limited to the installation of some monitoring equipment at two Users' sites. This equipment has been specified, designed, and installed by Transmission Licensees who will also be responsible for maintaining this equipment.

### Power Park Modules

- 4.41 There is some scope for interactions between Power Park Units from one side and HVDC Links and Series Capacitors on the other side. These interactions, if not taken into consideration while designing and operating the system, might lead to Unacceptable SSO conditions which may damage these Power Park Modules.
- 4.42 In the case of Power Park Units, Unacceptable SSO could arise from interactions between Series Capacitors or the HVDC Link Converter Controller on one side and the HVDC Converter Controllers of the Power Park Modules on the other side. The models required to assess these interactions are only available to manufacturers.

- 4.43 An SSO event affecting Power Park Units, Doubly Fed Induction Generators (DFIG) in this case, has already taken place in Texas in 2009 where a Unacceptable SSO took place following a second trigger of the Crowbar protection during the post fault recovery period.
- 4.44 So far there have only been a few cases where Transmission Licensees have identified that some Power Park Units are exposed to potential SSO risks. In these cases, Generators were provided with the network impedance characteristics, as seen from their connection point, and were requested to confirm with manufacturers that these impedance characteristics would not result in Unacceptable SSO.
- 4.45 If the Generator, having consulted with the manufacturer, were to indicate that there was a risk of Unacceptable SSO, Transmission Licensees would have liaised with the Generator and the manufacturer to identify the measures to mitigate these risks.

## New Generation Connections

- 4.46 The design of the Series Capacitors and the HVDC Links has taken into account potential interactions with the machines that are already connected to the Transmission System. However, it was impractical to take future generation connections into account at this stage due to uncertainties about their parameters.
- 4.47 Potential SSO risks affecting new plants will be identified by Transmission Licensees once the relevant data has been submitted by the Generators. These risks will be mitigated by either modifying transmission plant, where it is economic and efficient to do so, or by placing some SSO related requirements onto the Synchronous Generating Unit.
- 4.48 The SSO related requirements may include installation of filters, modification of the excitation control system to provide additional damping or modification to the machine shaft system to ensure no adverse interactions take place.
- 4.49 It is expected that Transmission Licensees, during the different stages of connection design, will liaise with Generators and manufacturers, through Generators, to ensure that SSO risks have been identified and that an effective SSO mitigation measure has been put in place prior to the connection of any new plant. This liaison will be coordinated by NGET and will be formulated through the usual Connection Application or Modification Application processes.

## NETS SQSS

- 4.50 The National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) sets out a coordinated set of criteria and methodologies that Transmission Licensees use in the planning and operation of the National Electricity Transmission System (NETS).
- 4.51 Pursuant to the Standard Licence Condition C17, The System Operator, NGET, is required to operate the NETS in accordance with the operational criteria defined within the NETS SQSS. This is achieved by either managing existing transmission plants or by procuring services from Transmission System Users.
- 4.52 Pursuant to the Standard Licence Conditions C17, D3 and E16, Transmission Licensees are required to plan and develop the NETS in accordance with the planning criteria defined within the NETS SQSS. While doing so, they are required to take into account NGET's obligations under Standard Licence Condition C17. The planning criteria are met via investing in the Transmission System to provide

transmission capacity. The operational criteria are met either via investing in the Transmission System to provide additional capacity or via ensuring that enough operational measures are available for NGET to use.

- 4.53 The actual level of investment may differ from the level required to meet the criteria of the NETS SQSS. This difference may be driven by Transmission Licensees based on an economic justification. It may also be driven by a Transmission System User requesting a Design Variation in accordance with the relevant criteria of the NETS SQSS.
- 4.54 The NETS SQSS is applied by the Transmission Licensees when designing and operating the electricity transmission network. Whilst Generators would not typically apply the NETS SQSS, the standards will still have a significant effect on them as it determines the scope of works required to connect them to the electricity transmission network and the terms and conditions of their connection agreements (i.e. restrictions on availability, inter-trips...etc...)
- 4.55 The NETS SQSS is used in design timescales to assess Connection Applications, Modification Applications, changes in conditions at a connection site (i.e. demand) and for ongoing compliance assessments by the Transmission Owners (TO) and System Operator (SO). In addition, the NETS SQSS is also used in operational timescales to assess outage plans (long term to day ahead) and real time system operation.
- 4.56 Occasionally, works required to meet the NETS SQSS criteria affect a Transmission System User other than the User whose application has triggered these works. In these instances, the Affected User will be informed of any potential works via a Modification Notification and will be requested to submit a Modification Application, free of charge, in accordance with the Connection and Use of System Code (CUSC).

#### Discussions Framework

- 4.57 The Workgroup agreed to use a template for a typical Clause of the NETS SQSS as a basis of the discussion. This typical Clause had the form:

*For the background condition X, following the secured event Y, the criterion Z should be met.*

On this basis, the Workgroup will need to agree a set of background conditions, a set of secured events and some criteria.

- 4.58 The Workgroup also agreed to start with the assumption that the criteria that Transmission Licensees are required to meet in relation to System Instability is sufficient to ensure that the Transmission System will not be adversely affected by SSO. The Workgroup will then debate the implications of this assumption and propose a change if required.

#### Secured Events

- 4.59 The NETS SQSS defines a “secured event” as a contingency which would be considered for the purpose of assessing system security and which must not result in the remaining NETS being in breach of the security criteria.
- 4.60 The Workgroup considers that, in respect of the System Instability criteria, the existing set of secured events strikes the right balance between the probability of these events taking place, the cost associated with securing the system against them and the consequences of a contingency that causes System Instability. That is the risks associated with System Instability when not securing the system against



these events outweighs the cost saving resulting from not securing the system against them. Also, the costs resulting from securing the system for more-onerous, less-probable contingencies outweighs the risks mitigated by ensuring that the system remains stable following such events.

- 4.61 The Workgroup also considers that the consequences of an event leading to Unacceptable SSO are in the same order of magnitude of an event leading to pole slipping of a synchronous machine.
- 4.62 Hence, the Workgroup recommends that the Transmission System should be planned and operated such that the system should be secured against Unacceptable SSO for the same set of secured events that are considered when securing the system against System Instability.

#### Background Conditions

- 4.63 Background conditions define the set of operating points of the Transmission System, prior to any secured event taking place, that need to be considered in design timescales. They usually comprise three elements. These are:
  - 4.63.1 The output of the power station under consideration, where there is one;
  - 4.63.2 The output of other power stations and demand levels at Grid Supply Points; and
  - 4.63.3 pre-fault outages.
- 4.64 Background conditions are only required to be defined for the planning criteria defined in Sections 2, 4, and 7 of the NETS SQSS. The operational criteria defined in Sections 5 and 9 are required to be met under prevailing system conditions.
- 4.65 For Generation Connection Capacity Requirements, the background conditions are defined in Paragraphs 2.8 for onshore generation connections and 7.14 for offshore generation connections. For the power station under consideration, 2.8.1 and 7.14.1 specify that the MW output shall be set to its registered capacity. Conditions on the rest of the system, according to 2.8.5 and 7.14.3 are set to those which ought reasonably to be expected to arise in the course of a year of operation. Hence, Transmission Licensees are required to consider all credible scenarios that are likely to occur when the power station under consideration is running at full output. However, in practice, Transmission Licensees will usually consider additional scenarios when the plant under consideration is running at different levels of output.
- 4.66 For the Minimum Transmission Capacity Requirements, Section 4 requires Transmission Licensees to consider several scenarios. These are:
  - 4.66.1 a peak demand scenario with an intact Transmission System and generation despatched according to the Security Background defined in Appendix C of the NETS SQSS;
  - 4.66.2 a peak demand scenario with an intact Transmission System and generation despatched according to the Economy Background defined in Appendix E of the NETS SQSS; and
  - 4.66.3 a representative set of scenarios with the background conditions that ought reasonably to be expected to arise in the course of a year of operation as described in Clause 4.7 of the NETS SQSS.



- 4.67 The Workgroup noted that the background conditions will affect the damping of SSO in the following ways:
- 4.67.1 The mechanical damping associated with a particular (mechanical) torsional mode increases with turbine load (generator power output). Therefore, the damping margin at low generator load is reduced and could even become negative (unstable system), depending on the characteristics of the electrical network.
  - 4.67.2 When several machines are in close electrical proximity to each other, unless they share the same torsional modes, they are likely to have a positive contribution to the SSO damping of each other. That means that more onerous SSO may take place during planned outages of some Generating Units.
  - 4.67.3 The potential of Unacceptable SSO increases when there is a credible contingency leaving a machine connected radially to the system through a series compensated overhead line.
- 4.68 The onerous SSO conditions associated with Transmission System outages and planned Generating Unit outages will be taken account of under Clauses 2.8.5, 4.7, and 7.4.3.
- 4.69 The onerous SSO conditions associated with the machine under consideration, running at an output level below its rated output is only covered by Transmission Licensees practice to consider such conditions although such operating conditions are not covered by the letter of the NETS SQSS.
- 4.70 The Workgroup proposes that Clauses 2.8.1 and 7.4.1 be modified to clarify that Transmission Licensees need to study SSO at the loading condition that corresponds to the most onerous SSO risk.

#### Definitions and Criteria

- 4.71 The NETS SQSS definition for System Instability does not differentiate between modes arising from rotor swings and those associated with SSO. However, the extent it should be met to the letter is largely dependent on how the definition was originally developed and how compliance against it has been assessed up to date.
- 4.72 In order to meet the System Instability criteria defined within the NETS SQSS, all electromechanical oscillations need to have sufficient damping such that, the magnitude of rotor angle and / or speed oscillations, 20 seconds following a disturbance should drop to less than 15% of the peak deviations. In other words, the time constant of the slowest mode should be less than 15 seconds. These values are likely to have been defined using the models that are typically used to study transient stability. These models will have the shaft systems of generating units represented by a single mass and the network modelled by its steady state equations. Compliance against these criteria has always been assessed using the same models. There has been no evidence that suggests that this practice should be revised.
- 4.73 On the other hand, in order to study SSO, the models need to have the shaft systems of generating units modelled as a multi-mass system and the network modelled by its differential equations. These models will show modes of oscillation that would not appear when using the models typically used for transient stability studies with some of these additional modes, i.e. torsional modes, having time constants in excess of the 15 seconds specified within the System Stability definition even without any series compensation or HVDC converters. It is expected that

reducing the time constant of these modes to less than 15 seconds is technically challenging and adds very little value to the system.

- 4.74 Based on paragraphs 4.72 and 4.73 the Workgroup concluded that, although the principles of the System Instability criteria apply, the letter of the definition is almost impossible to be met. Consequently, there is a need to have Sub-Synchronous Oscillations and Unacceptable Sub-Synchronous Oscillations defined explicitly in the NETS SQSS.
- 4.75 The NETS SQSS definition for SSO should be a generic and high level definition such that it covers all well-established phenomena that might result in Unacceptable SSO and it does not restrict Transmission Licensees from investigating any other potential interactions that might arise due to new generation and transmission technologies.
- 4.76 The option to have a definition for Unacceptable SSO that specifies a maximum electrical undamping at the frequencies where Unacceptable SSO might arise is in line with the practice followed by SPT and NGET when the Series Capacitors were specified. This option allows Generators to expect the level of electrical undamping they are going to be exposed to and take that level when specifying their Generating Unit. However, this criterion was based on the Synchronous Generating Units that are already connected to the system and might not be suitable for other types of Synchronous Generating Units or Power Park Modules.
- 4.77 A generic definition that refers to the consequences of Unacceptable SSO that is mechanical failure of Generating Unit shaft systems due to fatigue or electrical failure of Generating Units due to high voltages or currents, with no specific values leaves Transmission Licensees exposed if a Generator procures Generating Units of sub-standard design. However, it has the advantage that it can be made general and independent of generation, HVDC, or Series Compensation technology. It also provides sufficient assurance for Generators that their plant will not fail due to Unacceptable SSO.
- 4.78 The definition for Unacceptable SSO should be such that it is required to be met at frequencies where there is a potential risk. It should also not rule out that positive electrical undamping may coincide with a modal mechanical frequency provided that the overall damping is positive. This is illustrated by point 'a' and point 'b' in Figure 1. However, it should prevent situations where the high positive electrical undamping coincides with a mechanical mode of low mechanical damping as illustrated by point 'c' in Figure 1.
- 4.79 In practice, Generating Units are designed to cope with the high Sub-Synchronous transient torques that may arise following a large disturbance on the system and that, provided that these are positively damped, they will not be of any material risk to the machine. This means that having positive damping is sufficient to ensure that there will be no risk of machine failure due to Unacceptable SSO and that any references to fatigue or damage of equipment is a secondary element of the definition with no actual implications on the design.
- 4.80 The workgroup discussed the use of the term "insufficient damping" in addition to "negative damping" as this will ensure that there will be a discussion between the User(s) and Transmission Licensees to establish what level of damping is sufficient. It was noted that word "insufficient" is not specific which might undermine Transmissions Licensees' ability to ensure compliance.
- 4.81 It was agreed to seek feedback from the industry, through the Industry Consultation in order to confirm that compliance against the definition, in its current form, can be demonstrated.

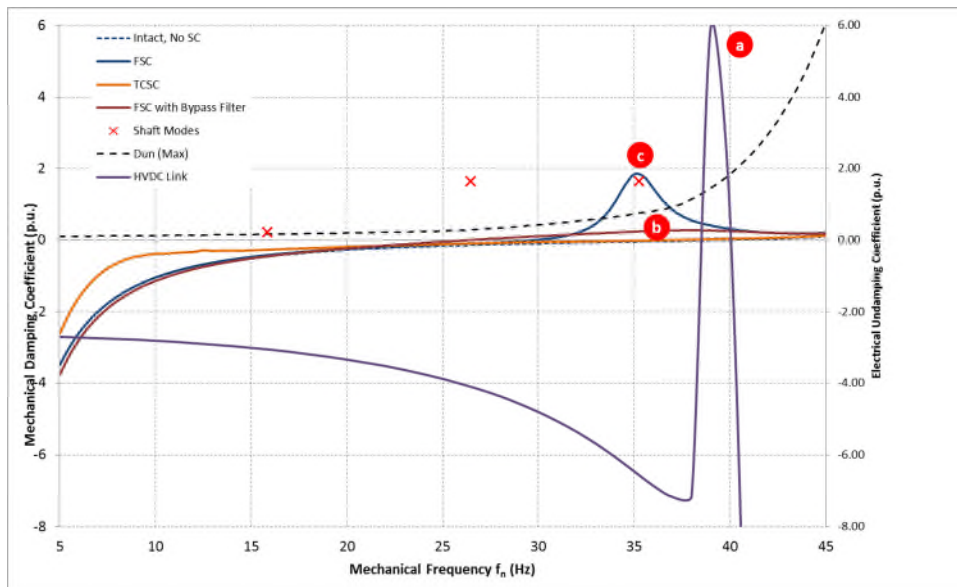


Figure 1: Acceptable characteristics for modal electrical undamping. This figure is for illustrative purposes only and does not completely reflect the characteristics of any of the projects in progress.

## Grid Code

- 4.82 The Grid Code Modification Proposal “GC0077: *Suppression Of Sub-Synchronous Resonance From Series Compensators*” was published for Industry Consultation in July 2014. This proposal aimed to clarify accountabilities related to managing SSO arising from interactions between Users’ plant and transmission plant. Under CC.6.1.9 of this proposal, NGET would be made responsible for ensuring that User’s Plant and Apparatus will not be subject to Unacceptable SSO conditions. Other Transmission Licensees would be required to ensure their Transmission System complies with these requirements in accordance with Section D, Paragraph 2.2.6 of the STC. Where necessary, CC.6.1.10 would require NGET to specify any SSO related site specific conditions applicable at a User’s Connection Site in the Bilateral Agreement between NGET and the User.
- 4.83 The proposed CC.6.1.9 specified that NGET shall ensure that Users’ Plant and Apparatus will not be subject to unacceptable Sub-Synchronous Oscillation conditions as specified in the relevant Licence Standards. So far, Licence Standards have not referred explicitly to requirements related to SSO. This issue has been addressed via this NETS SQSS Modification Proposal.
- 4.84 This obligation would require NGET to operate the system such that under prevailing system conditions and following any of the secured events defined in Section 5 of the NETS SQSS, the system shall not be subject to Unacceptable SSO. If the pre-fault network configuration has been considered in design timescales, the system will be secure against Unacceptable SSO by virtue of design. If the pre-fault network configuration has not been considered in design timescales, NGET will need to manage generation, via the Balancing Mechanism, in order to allow bypassing the Series Capacitors and / or switching the HVDC Link out of service.

- 4.85 Although events that are more onerous than the secured events defined within the NETS SQSS might take place, the probability of these events is very low to the extent that it is not economic to invest or constrain generation to secure for such events. That is the level of risk that Users are exposed to due to SSO and is comparable to that due to pole-slip.
- 4.86 Due to the nature of SSO phenomena, there is no single generic solution that would apply for all cases. Requirements Users have to meet in relation to SSO will be assessed on a case by case basis with Transmission Licensees liaising with Users in order to identify the most cost effective solution. This liaison will take place as a part of the Connection Application or Modification Application processes.
- 4.87 In order to allow Transmission Licensees to monitor the performance of their plant, they may choose to require some Users to install monitoring equipment and provide signals to Transmission Licensees.
- 4.88 In general the Grid Code and NETS SQSS criteria are met via investing in transmission capacity or via provision of operational measures. The operational measures include rearrangement of transmission outages, appropriate reselection of Generating Units from those expected to be available, operational intertripping schemes and auto-closure schemes. Operational measures do not include protection relays and hence these will not be used to mitigate SSO risks.
- 4.89 The requirements will equally apply to all Users. However, the complexity and the cost of retrofitting existing plant to meet additional requirements are likely to limit the scope of these requirements.

### **Practical Application of the Criteria Proposed**

- 4.90 The details of the works required to meet the criteria proposed mitigate SSO risks and the technical requirements that a new User's plant needs to meet will be developed over the lifetime of the User's Construction Agreement from the pre-application stages up to the Completion Date.
- 4.91 At the early stages of application, with no certainty about the connection site, the parameters of any new transmission plant, and the electrical and mechanical parameters of the User's plant, there will be some generic User Works in the Construction Agreement and some generic requirements in the Bilateral Agreement to ensure that the User is aware of the potential requirements.
- 4.92 As the relevant electrical parameters become available, and with certainty about connection site, Transmission Licensees will be able to calculate the impedance characteristics as seen by the Generating Unit and, in case of Synchronous Generating Units, the electrical damping characteristics. These characteristics will be shared with the User who will be required to ensure that their plant is designed such that it will not cause Unacceptable SSO and that it will withstand sub-synchronous torques, voltages, and currents that may arise during transient periods.
- 4.93 As the initial designs of the User's plant, and the mechanical parameters of the shaft system of Synchronous Generating Unit, become available the User will be expected to submit the relevant Grid Code data to NGET and flag any risks that couldn't be mitigated by this initial design. Transmission Licensees will then be able to re-assess the SSO risks, identify potential Transmission Reinforcement Works and/or User Works required to mitigate these risks, and revise the agreements as required. Consequently, the User may need to revise their designs to account for any changes in the requirements.
- 4.94 This is potentially an iterative process with both the User and Transmission Licensees having to modify their designs several times.

## Relevant Commercial Processes

### General

- 4.95 For simplicity, the discussion below uses terminology that is more relevant to Users that are connected directly to the Transmission System. However, the same logic applies for all Generators or, where applicable, for Network Operators on behalf of Generators,
- 4.96 In general, all liaisons between Transmission Licensees and Users will take place through NGET in its capacity as the System Operator.

### General Background

- 4.97 Transmission System Users are not required to directly comply with the NETS SQSS. However, they are impacted by its criteria. This impact is identified through the Connection Application or the Modification Application processes defined within the Connection and Use of System Code (CUSC). The effect is reflected in the site specific conditions specified in the Bilateral Agreement between NGET and the User; and Construction Works, User Works, Third Party Works, Completion Date and User Commitment specified in the Construction Agreement between NGET and the User.
- 4.98 Once a Transmission System User submits a Connection Application or a Modification Application, pursuant to 2.13.1 or 6.9.2 of the CUSC, Transmission Licensees will check for compliance against the relevant criteria of the NETS SQSS and identify any transmission reinforcements and Third Party Works required to achieve compliance. Compliance with the NETS SQSS criteria may also trigger some site specific requirements such as Operational Intertripping Schemes, fault clearance times or automatic excitation system control parameters. This information will be reflected in the Construction Agreement and the Bilateral Agreement offered to the User.
- 4.99 From time to time, Transmission Licensees identify that an upgrade to existing transmission plant is necessary to meet the criteria of the NETS SQSS. This upgrade may either be triggered by a specific Connection Application or by a general change of generation and demand backgrounds.
- 4.100 If an upgrade to existing transmission plant is required, Transmission Licensees will identify the Users affected by this upgrade. NGET will then send a Modification Notification to these Users in accordance with 6.9.3.1 of the CUSC and the Users will be invited to submit a Modification Application, free of charge in accordance with 6.9.3.3 of the CUSC, requesting that Transmission Licensees identify the impact on the User's plant and any User Works necessary. The details of any works required to be completed by the User will be specified within the Construction Agreement. Any changes to the site specific requirements will be specified in the Bilateral Agreement.
- 4.101 Once an offer is made to the User, the User will have a chance to discuss and negotiate the contents of this offer with NGET. Where an agreement cannot be reached between NGET and the User, the User is able to refer the issue to the Authority in accordance with Standard Licence Condition C9 of the Transmission Licence.
- 4.102 NGET will provide all advice and assistance reasonably requested by that User to enable that User adequately to assess the implications (including the feasibility) of making a Modification to the User's Equipment in accordance with 6.10.1 of the CUSC.

## SSO Interactions

- 4.103 Any works required to comply with the requirements related to SSO that are proposed to be included within the NETS SQSS and / or the Grid Code will be treated in line with the provisions and mechanisms already established under the CUSC.
- 4.104 Works required to manage potential SSO interactions between a new generation connection and an HVDC Interconnector are likely to be identified as Third Party Works within the Construction Agreement of the new generation plant. In this case, the Generator will be expected to liaise with the HVDC Converter Owner, who has the obligation to mitigate the risks of SSO under CC.6.3.16 of the Grid Code, to identify the necessary SSO mitigation measures. The HVDC Converter Owner will have to implement these measures.
- 4.105 The need to assess SSO interactions between new transmission plant and an existing Generating Unit will be identified as a part of the transmission reinforcement project. NGET will issue a Modification Notification to the relevant Users who will need to submit a Modification Application. Transmission Licensees will then, in liaison with the Users, identify the scope of any User Works and any SSO related requirements. User Works will be specified within the Construction Agreement and SSO related requirements will be specified in the Bilateral Agreement.
- 4.106 The works required to mitigate SSO risks arising from interactions between new User connections and existing transmission plant will be identified through the Connection Application or Modification Application process. As a part of these processes, Transmission Licensees will, in liaison with the relevant User, identify the scope of any User Works and any SSO related requirements. User Works will be specified within the Construction Agreement and SSO related requirements will be specified in the Bilateral Agreement.
- 4.107 The modification process also allows for any necessary feedback to be provided to Users affected by another party's modification, including where necessary, changes to Bilateral Agreements. This could include the agreement of any mitigation measures should these be determined to be necessary.

## **Connect & Manage**

- 4.108 Connect and Manage was introduced to allow Generators access to the Transmission System ahead of to the completion of some of the transmission reinforcements that would have otherwise been required to complete ahead of their connection date.
- 4.109 According to Section 13 of the CUSC and the relevant sections of the STC, following a Connection Application or a Modification Application, in relation to a Generator, Transmission Licensees will identify all the work required to connect this Generator to the National Electricity Transmission System. Thereafter, Transmission Licensees will apply the Connect and Manage Derogation Criteria to classify the works identified into Enabling Works and Wider Transmission Reinforcement Works. The Generator will be allowed access to the Transmission System once all the Enabling Works are completed. Wider Transmission Reinforcement Works completing after the completion date will be covered by a Connect and Manage Derogation.
- 4.110 The Workgroup discussed the potential interactions between CUSC Section 13, Enabling Works and the NETS SQSS criteria proposed. The potential combinations of these interactions are summarised in Figure 2. There should be no Unacceptable

SSO resulting from interactions between existing Transmission Plant and existing User Plant as these would have already been taken care of. Unacceptable SSO resulting from interactions between new Transmission Plant and Users' plant, whether the Users' plant is already connected or due to connect, will be addressed in line with the programme of the relevant transmission project. Where interactions between new Users' plant and existing transmission plant may result in Unacceptable SSO, these interactions will be assessed by Transmission Licensees who will need to identify the works required to meet the NETS SQSS criteria and then classify the works identified into either Enabling Works or Wider Transmission Reinforcement Works.

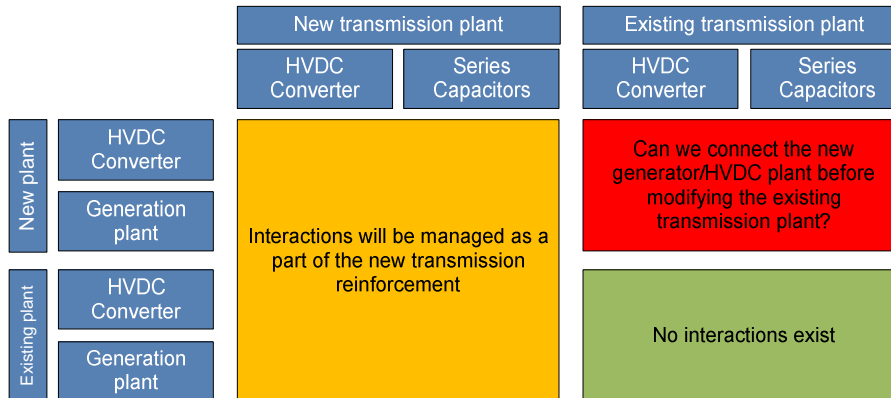


Figure 2: Potential interactions between the proposal and CUSC Section 13.

- 4.111 Transmission reinforcement works required to meet the NETS SQSS Section 2 pre-fault SSO criteria will be automatically classified as Enabling Works in line with Clause 13.2.4.1 of the CUSC, whereas works required to meet the NETS SQSS Section 2 post-fault criteria would need another qualifier if these were to be classified as Enabling Works. This additional qualifier could be that these works are required to enable NGET to operate the NETS in a safe manner (13.2.4.3), comply with the Grid Code criteria (13.2.4.5) or avoid any adverse impacts on other Users (13.2.4.7).
- 4.112 If a User were to connect to the system prior to the completion of all the works required to mitigate Unacceptable SSO, NGET would have to either switch the transmission plant interacting with the User's plant permanently out of service or continuously manage the User's plant interacting with the transmission plant via the Balancing Mechanism. Switching the transmission plant interacting with the User's plant permanently out of service would artificially reduce the transmission capacity available and consequently result in additional transmission constraints. Continuously managing the User's plant interacting with the transmission plant via the Balancing Mechanism would have to be done at the bid price set by the User who would be, due to the nature of SSO, the only User who is able to provide this service. Both options are deemed to be neither economic nor efficient.
- 4.113 In accordance with its Licence Obligations, NGET has to operate the NETS in an economic, efficient, and coordinated manner. While doing so, NGET needs to ensure safety, comply with the additional Grid Code criteria proposed by this Workgroup and avoid adverse impacts on other Users. In order to achieve this, all transmission works required to mitigate Unacceptable SSO have to be classified as Enabling Works in accordance with Clause 13.2.4.3, 13.2.4.5 and 13.2.4.7 of the CUSC.
- 4.114 It is expected that this classification, in the majority of cases, would not result in any delays in connection dates due to the limited scope of the works required to mitigate Unacceptable SSO.



## 5. Impact & Assessment

### Impact on the NETS SQSS

- 5.1 The Workgroup recommends amendments to the following parts of the NETS SQSS:
  - 5.1.1 Background conditions for Generation Connection Capacity Requirements in both Section 2 and Section 7.
  - 5.1.2 Pre-fault and Post-fault criteria defined under Section 2, Section 4, Section 5 and Section 7.
  - 5.1.3 The terms “Sub-Synchronous Oscillations” and “Unacceptable Sub-Synchronous Oscillations” need to be defined within Section 11.
- 5.2 The text required to give effect to this proposal is contained in Annex 2 of this document.

### Impact on the Grid Code

- 5.3 The Workgroup recommends amendments to the following parts of the Grid Code:
  - 5.3.1 Connection Conditions (CC).
- 5.4 The text required to give effect to this proposal is contained in Annex 3 of this document.

### Impact on the National Electricity Transmission System (NETS)

- 5.5 The modification proposed formulates requirements that are implicitly defined within the Transmission Licence, the NETS SQSS System Instability criteria and good industry practice. Hence the proposal should have no material impact on the National Electricity Transmission System.

### Impact on Transmission Licensees

- 5.6 The modification proposed clarifies the accountabilities related to Sub-Synchronous Oscillations. This clarification ensures that Transmission Licensees will continue to design and operate the Transmission System in a way that does not expose User's equipment to Unacceptable Sub-Synchronous Oscillations.
- 5.7 The modification also allows NGET to place some site specific requirements on the relevant Users in order to facilitate meeting the NETS SQSS and the Grid Code criteria related to Sub-Synchronous Oscillations.

### Impact on Transmission System Users

- 5.8 The modification proposed gives Users comfort that their plant will not be subjected to Unacceptable Sub-Synchronous Oscillations.
- 5.9 The modification places an obligation on Users to meet certain site specific requirements related to Sub-Synchronous Oscillations. These requirements will be specified by NGET on a case by case basis and will be discussed with the Users in line with the relevant commercial processes.

### Impact on Greenhouse Gas Emissions

- 5.10 This modification has a neutral impact on greenhouse gas emissions.



## Assessment Against NETS SQSS Objectives

5.11 The Workgroup considers that the proposed amendments would better facilitate the NETS SQSS objectives:

- (i) **facilitate the planning, development and maintenance of an efficient, coordinated and economical system of electricity transmission, and the operation of that system in an efficient, economic and coordinated manner;**

The modification proposal clarifies the criteria that Transmission Licensees will need to meet when securing the system against Sub-Synchronous Oscillations. It also clarifies the scenarios that will be considered in both design and operational timescales. This will ensure that no excessive costs are incurred when investing in transmission plant or when operating the system to secure the system against events of significantly low probability.

- (ii) **ensure an appropriate level of security and quality of supply and safe operation of the National Electricity Transmission System;**

The modification proposal stipulates that the system will be secured against Unacceptable Sub-Synchronous Oscillations for the same events that it is secured against for System Instability. This ensures that no User's equipment will be exposed to Sub-Synchronous Oscillation risks for all secured events.

- (iii) **facilitate effective competition in the generation and supply of electricity, and (so far as consistent therewith) facilitating such competition in the distribution of electricity; and**

The modification proposal has no impact on this NETS SQSS objective.

- (iv) **facilitate electricity Transmission Licensees to comply with their obligations under EU law.**

The modification proposal has no impact on this NETS SQSS objective.

## Assessment Against Grid Code Objectives

5.12 The Workgroup considers that the proposed amendments would better facilitate the Grid Code objectives:

- (i) **to permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity;**

The modification proposal clarifies the accountabilities in terms of management of Sub-Synchronous Oscillations on the Transmission System. Whilst doing so,

it provides NGET with a tool to enforce, where necessary and where economic to do so, reasonable SSO-related site specific requirements on Transmission System Users. This ensures that the risks are managed using the most coordinated, economic, and efficient means.

- (ii) to facilitate 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);**

By clarifying that Transmission Licensees will develop and that NGET will operate a Transmission System that is free from Unacceptable Sub-Synchronous Oscillations, under all credible scenarios, Users will have enough assurance to invest in new plant and to continue to operate their existing plant that are connected in close proximity to the series capacitors and/or the HVDC links.

- (iii) 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; and**

The modification proposal clarifies the accountabilities related to management risks of Sub-Synchronous Oscillations. This gives comfort to Transmission System Users that their plant will not be exposed to material risks. While doing so, the modification proposal provides means to ensure that the most appropriate and cost effective countermeasure against Sub-Synchronous Oscillations has been implemented. This is by clarifying that NGET may specify some site specific conditions on some Users to ensure that the Transmission System is not exposed to any Sub-Synchronous Oscillation risks.

- (iv) 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.**

The modification proposal has no impact on this Grid Code objective.

### **Impact on Core Industry Documents**

5.13 The proposed modification does not impact on any core industry documents.

### **Impact on Other Industry Documents**

5.14 The proposed modification does not impact on any other industry documents.

### **Implementation**

5.15 The Workgroup proposes that, should the proposals be taken forward, the proposed changes be implemented 10 business days after an Authority decision.

## 6. Workgroup Recommendations

- 6.1 The Workgroup proposes a modification to the NETS SQSS to include:
  - 6.1.1 a definition of Sub-Synchronous Oscillations and Unacceptable Sub-Synchronous Oscillations;
  - 6.1.2 place a requirement on Transmission Licensees to secure the system against Unacceptable Sub-Synchronous Oscillations for the same set of secured events that are used when securing the system against System Instability; and
  - 6.1.3 clarifying that, when securing the system against Unacceptable Sub-Synchronous Oscillations in design timescales, Transmission Licensees have to take into account the most onerous loading condition of the Generating Unit under consideration.
- 6.2 The Workgroup endorses the Grid Code Modification Proposal GC0077 after having addressed and / or clarified all the points that were raised by the responses to the Industry Consultation. This proposal:
  - 6.2.1 places a requirement on NGET to ensure that no User's plant are subject to Unacceptable Sub-Synchronous Oscillations; and
  - 6.2.2 gives NGET a tool to specify some site specific requirements on Users.
- 6.3 The Workgroup believes that the Terms of Reference has been discharged and invites the NETS SQSS Review Panel to approve this Workgroup Report.

**National Electricity Transmission System  
Security and Quality of Supply Standards  
Sub-Synchronous Oscillations (SSO) Workgroup  
TERMS OF REFERENCE**

### Governance

The Sub-Synchronous Oscillations (SSO) Workgroup was established by the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) Review Panel at the 02 April 2014 NETS SQSS Review Panel meeting.

The Workgroup shall formally report to the NETS SQSS Review Panel.

### Membership

The Workgroup shall comprise a suitable and appropriate cross-section of experience and expertise from across the industry, which shall include:

Name	Role	Representing
Graham Stein	Chair	-
Nick Martin	Technical Secretary	-
Bieshoy Awad	National Grid SO Representative	National Grid
Andrew Dixon	National Grid SO Representative	National Grid
Danson Joseph	National Grid TO Representative	National Grid
Cornel Brozio	Industry Representative	SPT
David Adam	Industry Representative	SPT
Yash Audichya	Industry Representative	SHE Transmission
Alastair Frew	Industry Representative	Scottish Power
Lorna Short	Industry Representative	RWE
Ankit Patel	Industry Representative	SSE
John Reilly	Industry Representative	EDF
Mayure Daby	Authority Representative	Ofgem

### Meeting Administration

The frequency of Workgroup meetings shall be defined as necessary by the Workgroup chair to meet the scope and objectives of the work being undertaken at that time.

National Grid shall provide technical secretary resource to the Workgroup and handle administrative arrangements such as venue, agenda and minutes.

The Workgroup will have a dedicated section on the National Grid website to enable information such as minutes, papers and presentations to be available to a wider audience.

## Scope

The Workgroup shall consider and report on the following:

- The need to include SSO related provisions within the NETS SQSS;
- The SSO phenomena that needs to be considered;
- The definition of Acceptable or Unacceptable SSO conditions;
- The operating conditions and secured events for which Acceptable or Unacceptable SSO conditions should be assessed; and
- The requirement for changes to the Grid Code arising from the Workgroup's proposals.

## Deliverables

The Workgroup shall provide verbal updates and a Workgroup Report to the NETS SQSS Review Panel which will:

- Detail the findings of the Workgroup;
- Draft, prioritise and recommend changes to the NETS SQSS and any associated documents in order to implement the findings of the Workgroup; and
- Highlight any consequential changes which are or may be required.

## Timescales

It is anticipated that this Workgroup shall provide a verbal update to each NETS SQSS Review Panel meeting and present a Workgroup Report to the April 2015 NETS SQSS Review Panel meeting.

The Workgroup will provide a written progress update to the October 2014 NETS SQSS Review Panel meeting including details of the programme of work remaining required to meet its target Workgroup Report date.

If the Workgroup is in existence for more than one year, there is a responsibility for the Workgroup to produce a yearly update report, including but not limited to; current progress, reasons for any delays, next steps and likely conclusion dates.

This section contains the proposed legal text to give effect to the Workgroup proposals. The proposed new text is in red and is based on NETS SQSS Version 2.2, Dated March 5 2012.

### Section 2

#### Generation Connection Capacity Requirements

##### Background conditions

2.8.1 the active power output of the *power station* shall be set equal to its *registered capacity* or, for the purpose of *Sub-Synchronous Oscillations* studies, that which provides the lowest level of damping for the sub-synchronous mode under consideration;

##### Pre-fault criteria

2.9 The *transmission capacity* for the connection of a *power station* shall be planned such that, for the background conditions described in paragraph 2.8, prior to any fault there shall not be any of the following:

2.9.1 equipment loadings exceeding the *pre-fault rating*;

2.9.2 voltages outside the pre-fault planning voltage limits or insufficient voltage performance margins; ~~or~~

2.9.3 system instability; or

2.9.4 *Unacceptable Sub-Synchronous Oscillations.*

##### Post-fault criteria – background condition of no *local system outage*

2.10 The *transmission capacity* for the connection of a *power station* shall also be planned such that for the background conditions described in paragraph 2.8 with no *local system outage* and for the *secured event* of a *fault outage* on the *onshore transmission system* of any of the following:

2.10.1 a single *transmission circuit*, a reactive compensator or other reactive power provider;

2.10.2 a *double circuit overhead line* on the supergrid;

2.10.3 a *double circuit overhead line* where any part of either circuit is in *NGET's transmission system* or *SHETL's transmission system*;

2.10.4 a single *transmission circuit* with the prior outage of another *transmission circuit*;

2.10.5 a section of *busbar* or mesh corner; or

2.10.6 a single *transmission circuit* with the prior outage of a *generating unit*, a reactive compensator or other reactive power provider;

there shall not be any of the following:

2.10.7 a *loss of supply capacity* except as permitted by the demand connection criteria detailed in Section 3;

2.10.8 unacceptable overloading of any primary transmission equipment;

2.10.9 unacceptable voltage conditions or insufficient voltage performance margins; ~~or~~

2.10.10 System Instability; or

2.10.11 *Unacceptable Sub-Synchronous Oscillations.*

## Section 4

### Minimum Transmission Capacity Requirements

#### At ACS peak demand with an intact system

4.5 The minimum *transmission capacity* of the *MITS* shall be planned such that, for the background conditions described in paragraph 4.4, prior to any fault there shall not be:

4.5.1 equipment loadings exceeding the *pre-fault rating*;

4.5.2 voltages outside the pre-fault planning voltage limits or insufficient voltage performance margins; ~~or~~

4.5.3 system instability; **or**

**4.5.4 *Unacceptable Sub-Synchronous Oscillations.***

4.6 The minimum *transmission capacity* of the *MITS* shall also be planned such that for the conditions described in paragraph 4.4 and for the *secured event of a fault outage* of any of the following:

4.6.1 a single *transmission circuit*, a reactive compensator or other reactive power provider;

4.6.2 a *double circuit overhead line* on the supergrid;

4.6.3 a *double circuit overhead line* where any part of either circuit is in *NGET's transmission system* or *SHETL's transmission system*;

4.6.4 a section of *busbar* or mesh corner; or

4.6.5 provided both the *fault outage* and prior outage involve plant in *NGET's transmission system*, any single *transmission circuit* with the prior outage of another *transmission circuit*, or a *generating unit*, reactive compensator or other reactive power provider,

there shall not be any of the following:

4.6.6 *loss of supply capacity* (except as permitted by the demand connection criteria detailed in Section 3 and Section 8);

4.6.7 unacceptable overloading of any primary transmission equipment;

4.6.8 unacceptable voltage conditions or insufficient voltage performance margins; ~~or~~

4.6.9 system instability; **or**

**4.6.10 *Unacceptable Sub-Synchronous Oscillations.***

#### Under conditions in the course of a year of operation

4.8 The minimum *transmission capacity* of the *MITS* shall be planned such that, for the background conditions described in paragraph 4.7, prior to any fault there shall not be:

4.8.1 equipment loadings exceeding the *pre-fault rating*;

4.8.2 voltages outside the pre-fault planning voltage limits or insufficient voltage performance margins; ~~or~~

4.8.3 system instability; or

4.8.4 *Unacceptable Sub-Synchronous Oscillations.*

## Section 5

### Normal Operational Criteria

5.1 The onshore transmission system shall be operated under prevailing system conditions so that for the secured event of a fault outage on the onshore transmission system of any of the following:

5.1.1 a single *transmission circuit*, a reactive compensator or other reactive power provider; ~~or~~

5.1.2 the most onerous *loss of power infeed*; or

5.1.3 where the system is designed to be secure against a *fault outage* of a section of *busbar* or mesh corner under *planned outage* conditions, a section of *busbar* or mesh corner,

there shall not be any of the following:

5.1.4 a *loss of supply capacity* except as specified in Table 5.1;

5.1.5 unacceptable frequency conditions;

5.1.6 unacceptable overloading of any primary transmission equipment;

5.1.7 unacceptable voltage conditions; ~~or~~

5.1.8 system instability; or

5.1.9 *Unacceptable Sub-Synchronous Oscillations.*

5.3 The *onshore transmission system* shall be operated under prevailing system conditions so that for the *secured event* on the *onshore transmission system* of a *fault outage* of:

5.3.1 a double circuit overhead line; or

5.3.2 a section of *busbar* or mesh corner,

there shall not be any of the following:

5.3.3 a *loss of supply capacity* greater than 1500 MW;

5.3.4 unacceptable frequency conditions; ~~or~~

5.3.5 *unacceptable voltage conditions* affecting one or more *Grid Supply Points* for which the total *group demand* is greater than 1500 MW; ~~or~~

5.3.6 system instability of one or more Generating Units connected to the supergrid;  
or

5.3.7 *Unacceptable Sub-Synchronous Oscillations.*



## Conditional Further Operational Criteria

- 5.5 If:
- 5.5.1 there are *adverse conditions* such that the likelihood of a *double circuit overhead line* fault is significantly higher than normal; or
- 5.5.2 there is no significant economic justification for failing to secure the *onshore transmission system* to this criterion and the probability of *loss of supply capacity* is not increased by following this criterion,
- the onshore transmission system shall be operated under prevailing system conditions so that for the secured event of
- 5.5.3 a fault outage on the supergrid of a double circuit overhead line there shall not be:
- 5.5.4 where possible and there is no significant economic penalty, any *loss of supply capacity* greater than 300 MW;
- 5.5.5 unacceptable overloading of any primary transmission equipment;
- 5.5.6 unacceptable voltage conditions; ~~or~~
- 5.5.7 system instability; ~~or~~
- 5.5.8 *Unacceptable Sub-Synchronous Oscillations.*

## Section 7

### Generation Connection Capacity Requirements

#### Background conditions

- 7.14.1 the active power output of the *offshore power station* shall be set to deliver active power at the offshore *grid entry point* equal to its registered capacity ~~or~~, *for the purpose of Sub-Synchronous Oscillations studies, that which provides the lowest level of damping for the sub-synchronous mode under consideration;*

#### Pre-Fault Criteria – background conditions of no *local system outage*

- 7.15 The *transmission capacity* of the *offshore transmission circuits* for the connection of one or more *offshore power stations* shall be planned such that, for the background conditions described in paragraph 7.14, with *no local system outage* and prior to any fault, there shall not be any of the following:
- 7.15.1 Equipment loadings exceeding the *pre-fault rating*;
- 7.15.2 Voltages outside the *pre-fault planning voltage limits* or *insufficient voltage performance margins*; ~~or~~
- 7.15.3 *system instability*; ~~or~~

#### 7.15.4 *Unacceptable Sub-Synchronous Oscillations.*

##### Post-Fault Criteria – background conditions of no *local system outage*

7.16 The *transmission capacity* of the *offshore transmission circuits* for the connection of one or more *offshore power stations* shall also be planned such that for the background conditions described in paragraph 7.14 with *no local system outage* and for the *secured event* on the *offshore transmission system* of any of the following:

7.16.1 In the case of an *offshore power park module* connection with an *OffGEP capacity* of 90MW or more, with the *OffGEP capacity* reduced by 50%, a *fault outage* or *planned outage* of a single AC *offshore transmission circuit* on the *offshore platform*;

7.16.2 In the case of an *offshore power park module* connection with an *OffGEP capacity* of 120MW or more, with the *OffGEP capacity* reduced to 50%, a *fault outage* or a *planned outage* of a single AC *offshore transmission circuit* at the onshore transformation facilities

And in all cases other than specified in 7.16.1 and 7.16.2 above:

7.16.3 a *fault outage* or a *planned outage* of a single *offshore transmission circuit*;

And in all cases:

7.16.4 a *fault outage* or a *planned outage* of a single reactive compensator or other reactive provider;

7.16.5 a *fault outage* of a single *offshore transmission circuit* during a *planned outage* of another *offshore transmission circuit*;

7.16.6 a *fault outage* or a *planned outage* of a single section of *busbar* or mesh corner;

There shall not be any of the following:

7.16.7 a *loss of supply capacity* except as permitted by the demand connection criteria detailed in Section 8;

7.16.8 *Unacceptable overloading* of any *primary transmission equipment*;

7.16.9 *Unacceptable voltage conditions* or *insufficient voltage performance margins*; ~~or~~

7.16.10 system instability; ~~or~~

7.16.11 *Unacceptable Sub-Synchronous Oscillations.*

## Section 11 Terms and Definitions

### Sub-Synchronous Oscillations

Power system oscillations at frequencies that are less than the power frequency. They arise from modes of oscillation associated with interactions between certain elements on the system such as generator rotor circuits, generator shaft systems, series compensated lines, excitation system controllers, power system stabilisers, converter controllers of power park modules and converter controllers of DC interconnectors and links.

### Unacceptable Sub-Synchronous Oscillations

Unacceptable Sub-Synchronous Oscillations are Sub-Synchronous Oscillations with the relevant modes of oscillation having negative or insufficient net damping. Unacceptable Sub-Synchronous Oscillations may have a significant effect on generating units including a significant reduction in the lifetime of the machine shaft system due to fatigue or the failure of some of its electrical components due to high voltages and / or currents.

## Annex 3 - Proposed Legal Text for the Grid Code

This section contains the proposed legal text to give effect to the Workgroup proposals. The proposed new text is in red and is based on Grid Code Issue 5, Revision 13, and Dated 22 January 2015.

### Grid Code Connection Conditions

#### Sub-Synchronous Resonance and Sub-Synchronous Torsional Interaction

CC.6.1.9 **NGET** shall ensure that **Users' Plant and Apparatus** will not be subject to unacceptable Sub-Synchronous Oscillation conditions as specified in the relevant **Licence Standards**.

CC.6.1.10 **NGET** shall ensure where necessary, and in consultation with **Transmission Licensees** where required, that any relevant site specific conditions applicable at a **User's Connection Site**, including a description of the Sub-Synchronous Oscillation conditions considered in the application of the relevant **License Standards**, are set out in the **User's Bilateral Agreement**.