NETS SQSS

Offshore Infeed Loss Working Group (GSR013)

Working Group Report

July 2012

1 Introduction

The National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS) “SQSS”, sets out a coordinated set of criteria and methodologies that transmission licensees shall use in the planning, development and operation of the National Electricity Transmission System (NETS).

The SQSS was initially developed across 1990 to 2005 for application to the onshore system of England, Wales and Scotland. In June 2009, additional criteria (namely SQSS sections 7, 8, 9 and 10) were introduced for offshore transmission systems. (Revision June 2009). The initial drafting of these offshore criteria took into account offshore generation capacities of less than 1500 MW, with radial connections to shore of less than 100km.

Subsequent reviews of the maximum infeed loss criteria relating to the whole GB system (GSR007/7a) resulted in changes to increase the normal infeed loss to 1320MW and infrequent infeed loss risk to 1800MW from April 2014[1]. A consequence of these changes is that the offshore criteria have also become modified, such that offshore generation with a capacity up to 1800MW can be radially connected via a single cable.

In June 2008, The Crown Estate made available further significant tranches of seabed around GB for the development of renewable generation. These tranches are referred to as Round 3 sites. The Round 3 sites are much further from shore (some sites go up to 300km) and have far greater potential generation capacities (up to 13 GW in one area). The economic connection of generation in these zones is most likely to involve the use of HVDC circuits.

With more and more future offshore wind generation are likely to connect to the system through HVDC, an issue has been raised on how existing infeed loss risk criteria should be applied to the HVDC system: whether particular events leading to an infeed loss, such as a converter fault and a cable fault, should be considered as infrequent risk or normal risk, and whether the current infeed loss limits are appropriate.

Another issue is to investigate the likelihood of multiple cable faults within a short time, and whether this leads to requirements for cable separation. Whilst offshore cable faults are relatively rare (in order of 1 in 10 years), there is a possibility of several cables suffering faults at similar times due to an anchor dragging. Such an event may cause a loss of generation above the Infrequent Infeed Loss within a short period time and trigger the system defence mechanism like low frequency load shedding.

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[1]Loss of Power Infeed – The output of a generating unit or a group of generating units or the import from external systems disconnected from the system by a secured event, less the demand disconnected from the system by the same secured event. In the case of offshore generation, the offshore grid entry point is classified as the interface to the system. In the case of external interconnector the interface point is typically at the onshore substation at which it connects to the NET.

The review has addressed issues relating to:

- Current views on what is “normal”, and what is “infrequent”
- HVDC converter fault rates from around the world
- Infeed loss risk associated different HVDC configurations
- HVDC converter fault mitigation measures
- Offshore cable fault rates and multiple cable fault rates due to anchor dragging from around the world
- Multiple cable fault mitigation measures

This report describes each of the issues considered, and makes recommendations on NETS SQSS amendments to offshore infeed loss risk.

The terms of reference and working group membership can be found in appendix A and B respectively.

2 Related SQSS Reviews

Several reviews of the NETS SQSS have recently been undertaken. Of these, two are particularly relevant for this review. These reviews considered the largest permitted infeed loss; and the criteria to design and operate the offshore transmission network

2.1 Infeed Loss Review (GSR007/7a)

In view of the potential future onshore connection of larger generating units than those currently connected in GB, a review of the NETS SQSS was initiated in 2007 to ensure that its criteria in relation to infeed losses were appropriate. This review proposed amendments to the SQSS to accommodate single generating units up to 1800 MW, with an implementation date to be determined by the first such connection. Subsequently the proposals were modified to fix the implementation date to 1st April 2014, and to allow the radial connection of 1800MW of offshore generation. The standard was amended to reflect these proposals in March 2011. The reports are available at:

http://www.nationalgrid.com/NR/rdonlyres/EEEB8EDB-6AA5-4D44-BFDC-763ECE251E73/31739/SQSS1320Reportfinalv10_040209_.pdf

http://www.nationalgrid.com/NR/rdonlyres/749C9FD8-1651-4059-8219-564940C4678C/44473/ReporttoAuthorityfinal.pdf

2.2 Offshore Review (GSR011)

A parallel on-going review is to investigate the design criteria for offshore networks on how to connect large amounts of offshore generation in the most economic and efficient way. One of the conclusions related to this review is that the short duration of losses of an offshore DC link slightly greater than infrequent loss limit can be tolerated, provided that parallel offshore routes can increase their flows near-instantaneously to keep the system frequency within the statutory limits.

The report is available at:

http://www.nationalgrid.com/NR/rdonlyres/6F14407D-EDAE-4F0A-901A-FC3375D28740/55379/SQSSWGReportFinal.pdf

3 Summary of Current Criteria for Infeed Loss Risk

3.1 Statutory Frequency Requirements

The Electricity Safety, Quality and Continuity (Amendment) Regulations 2006, Part IV, Clause 27 (commonly referred to as the ESQCR) requires that system frequency shall not vary more than one percent above or below the declared frequency of 50Hz save in 'exceptional circumstances'.

For many years the former CEGB took the phrase 'exceptional circumstances' to mean that the system frequency shall not transgress outside the statutory limits of 50Hz +/- 0.5Hz (i.e. 49.5Hz to 50.5Hz) more than four times a year.

Whilst National Grid has continued to use the CEGB interpretation, there is no absolute mandate to maintain this precise number of transgressions as a limit.

Nevertheless, it is considered reasonable to use this frequency of occurrence as a general indicator as to what may be considered frequent and what may be considered infrequent.

The current SQSS definition of "unacceptable frequency conditions" is:

These are conditions where:
the steady state frequency falls outside the statutory limits of 49.5Hz to 50.5Hz; or

a transient frequency deviation on the MITS persists outside the above statutory limits and does not recover to within 49.5Hz to 50.5Hz within 60 seconds.

Transient frequency deviations outside the limits of 49.5Hz and 50.5Hz shall only occur at intervals which ought reasonably be considered as infrequent. It is not possible to be prescriptive with regard to the type of secured event which could lead to transient deviations since this will depend on the extant frequency response characteristics of the system which NGC shall adjust from time to time to meet the security and quality requirements of this Standard.

3.2 NGET's Frequency Containment Policy

The statutory requirements relating to system frequency are included in NGET's frequency containment policy. The frequency containment policy is such that:

a) For a 'significant loss' of generation or demand up to 1000MW (from 14th April 2014 this will be 1320MW), the maximum change of frequency shall not be greater than +/- 0.5Hz;

b) For an 'abnormal loss' of generation up to 1320MW (from 14th April 2014 this will be 1800MW), the maximum change of frequency shall not be greater than -0.8Hz;

c) If the system frequency is 49.8Hz (i.e. the lower operational limit) prior to an ‘abnormal loss’ of 1320MW (from 14th April 2014 this will be 1800 MW), then the frequency shall not fall below 49Hz. This is to maintain a margin of 0.2Hz above the first stage of emergency low frequency demand disconnection at 48.8Hz;

d) Any frequency deviation outside the 50.5Hz to 49.5Hz shall not exceed one minute.

The frequency containment policy equates a ‘significant loss’ (under normal circumstances) with the normal infeed loss risk and an ‘abnormal loss’ (under exceptional circumstances) with the infrequent infeed loss risk. The reason for the different terminology is that the Normal and Infrequent criteria apply to the System Planner (SQSS section 2. to 4.). From time-to-time, the System Operator may for a few hours operate the system to different levels of infeed risk, and so the criteria of operational policy (reflecting SQSS section 5.) are termed 'significant loss' and 'normal loss'.

The current GB SQSS definitions of normal and infrequent infeed loss risk are referenced below:

Infrequent Infeed Loss Risk:

That level of loss of power infeed risk which is covered over long periods operationally by frequency response to avoid a deviation of system frequency outside the range 49.5Hz to 50.5Hz for more than 60 seconds..

Normal Infeed Loss Risk:
That level of loss of power infeed risk which is covered over long periods operationally by frequency response to avoid a deviation of system frequency by more than 0.5Hz.

The current values of 1320MW and 1800MW are also a function of NGET’s obligations to contain costs. An increase in either of these values or their frequency of occurrence would lead to the need for more frequency response and reserve holding and incur higher operational cost although, it may be argued, reduced investment in some circumstances[2].

For instantaneous losses greater than 1800MW, or for situations where there are a series of smaller losses in short timescales, National Grid may have to rely on emergency defence measures such as the initiation of low frequency relays leading to demand shedding. Fortunately this is a rare occurrence (the last event happening in May 2008).

Great Britain has never implemented automated reserve restoration services (such Automatic Generation Control), and manual actions are required to restore primary

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[2] It could be argued that, given sufficient response to keep the system frequency above 49.2Hz for a 1800MW loss, the system could accept a loss somewhat greater than 1320MW and still keep the frequency within 49.5Hz. Hence the normal infeed loss risk could be modified to reflect this. This is not within the scope of this review, and a separate review could be raised to investigate this issue.

and secondary response following an initial loss. At present it can take up to 20 minutes to fully restore response levels.

The current definitions of the two terms (i.e. normal and infrequent infeed loss risk) leave scope for reviewing the thresholds, should the need arise in an event such as an increased frequency of occurrence of a loss of power infeed more than 1320MW such that it could no longer be reasonably considered ‘infrequent’ or ‘exceptional’ (e.g. due to the introduction of external HVDC importing more than 1320MW subject to interruption materially more than in the region of up to four times per year).

4 Issues Considered by This Review

Since the first commercial installation in 1954, a large number of HVDC transmission systems have been installed around the world; it is considered to be more desirable technology to connect the large offshore generation which is far from the shore for the following reasons[3]:

- Losses and voltage drop in the DC link are low
- Virtually no limit on connection distance beyond practical constraints of cable manufacturing and cable laying
- Offshore wind generators do not contribute significant short circuit currents to the main grids with DC link
- DC link provides fast control of active and reactive power

With the increase of HVDC circuits in offshore applications, it is necessary to understand how the infeed loss risk criteria should be applied to the HVDC systems and also the overall system performance with respect to increase of large infeed loss events.

This review addresses two main issues:

- The failure rate and infeed loss risk of the HVDC converter for different HVDC configurations, whether the fault should be considered as infrequent risk or normal risk, and what are the mitigation measures

- The failure rate and infeed loss risk for HVDC offshore cables, especially multiple cable failure due to the anchor dragging, and what are the mitigation measures

4.1 HVDC converter failure rate and the infeed loss risk

4.1.1 HVDC Configurations

HVDC systems can be arranged in a number of configurations, which have different availability following outage of one of the key components, i.e. converter or cable. Two main types of HVDC systems are Monopole and Bipole connections. This section presents the different configurations of HVDC circuit in Monopole and Bipole types.

Main HVDC Configurations are:
- Monopole with ground return path
- Monopole with metallic return path
- Symmetrical monopole

[3] http://www.ownersguidepdf.com/download-manual-ebook/hvdc-connection-of-offshore-wind-farms-to-the-transmission-system-pdf.pdf

- Bipole with ground return path
- Bipole with metallic return path
- Bipole without ground return path

Monopole HVDC System

Figure 1 shows a monopole configuration with ground or sea electrode return path. With a ground return, the system requires only one cable and earth is used as the return path.

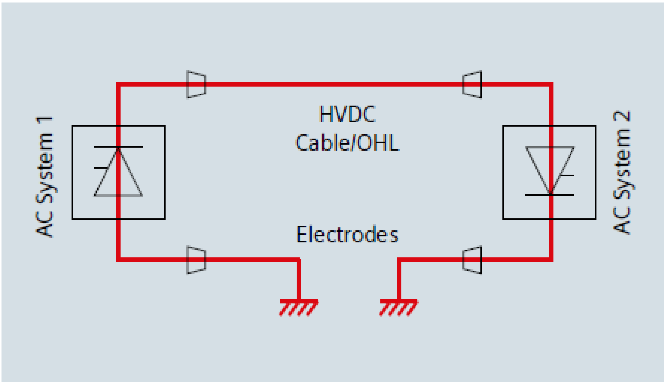

Figure 1 Monopole with Ground Return Path[4]

Figure 2 represents the same monopole configuration but with a metallic return. A metallic return path is preferred instead of through the ground when the ground resistance is too high or the underground/undersea metallic components may cause some interference. The return conductor is connected to earth at one end of the system. The metallic return conductor carries the return current between converters.

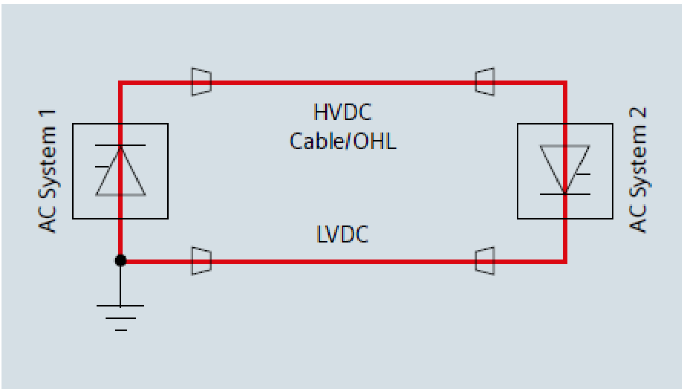

Figure 2 Monopole with Metallic Return Path

In the case of symmetrical monopole configuration two HV cables are used as shown in Figure 3[5]. In symmetrical monopole configuration, one cable carries a positive

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[4] "High Voltage Direct Transmission System – Proven Technology for Power Exchange" , available at http://www.energy.siemens.com/hq/pool/hq/power-transmission/HVDC/HVDC_Proven_Technology_.pdf

[5] http://www.sari-energy.org/PageFiles/What_We_Do/activities/HVDC_Workshop_Sep_2011/presentations/HV

voltage the other a negative voltage and the earth point is at the mid point of the two equal series connected capacitors. For ground return path either sea electrode or metallic return path can be used. The main benefit of symmetrical monopole system with metallic return path is that if one cable faults the system can be reconfigured and one circuit can carry 50% of the system capacity. The symmetrical monopole configuration uses Voltage Source Converter (VSC) technologies, explained in section 4.1.2.

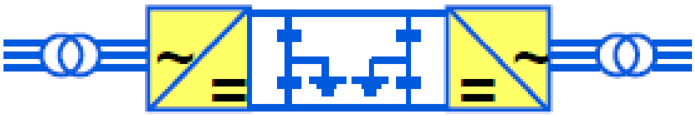

Figure 3 Symmetrical Monopole Configuration

Bipole HVDC System

A bipole system consists of two poles, one positive polarity and the other negative polarity and with / without ground return. Figure 3 shows a Bipole arrangement with ground or sea electrode return.

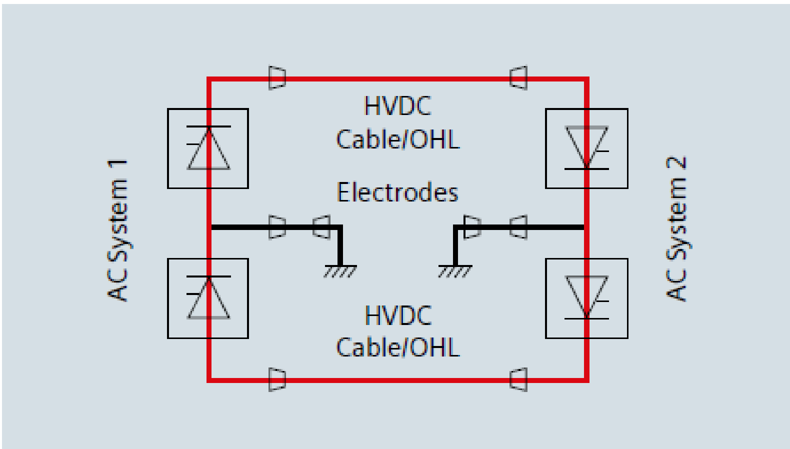

Figure 4 Bipole with Ground Return Path

Under normal operation, the current flow in each pole is the same and hence no current flows through the grounded return. If either pole is on outage, then the other pole can transmit power by itself with ground return as shown in Figure 4.

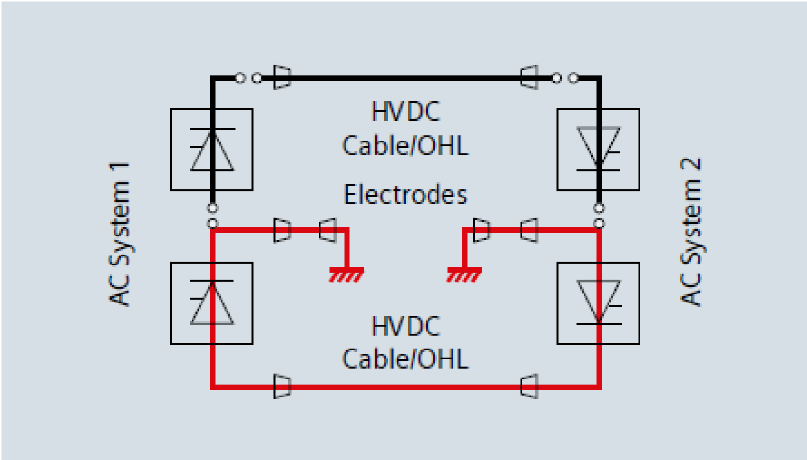

Figure 5 Operation of Bipole with Ground Return during One Pole Outage

This type of HVDC configuration may have by-pass arrangements to transfer return path from sea electrode to HVDC conductor of the faulty pole. Following a pole outage caused by converter fault, for a shorter time, the other pole can transmit power with sea electrode. Then by-pass switches will transfer the return path to the HVDC conductor of the faulty pole as shown in Figure 5. Thus, for a converter fault, there will be a power loss of only 50% of the system capacity. However, it should be noted that the direct current flow in sea electrode could result in corrosion of metallic structures and also there are environmental concerns for the wellbeing of organism and creature in the vicinity of electrodes. It is unclear to Working Group whether a sea electrode return would be permitted in UK waters.

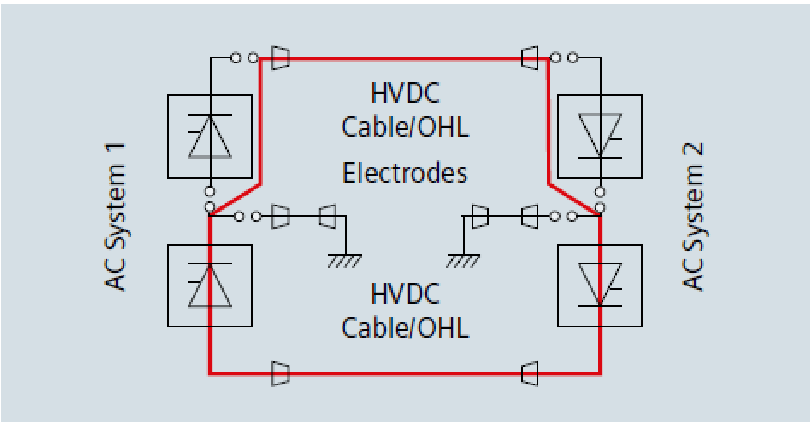

Figure 6 Operation of Bipole HVDC Configuration with By-pass Switch

When ground currents are not tolerable or when a ground electrode is not feasible for any reason such as high earth resistivity, a third conductor to give a Bipole metallic return can be installed. Figure 6 shows a Bipole arrangement with metallic return. The metallic return conductor carries imbalance currents during Bipole operation. It also serves as the return path when one pole is out of service / on outage. In other words, when one pole becomes unavailable, the system can be operated in monopole metallic return mode by utilising the other pole.

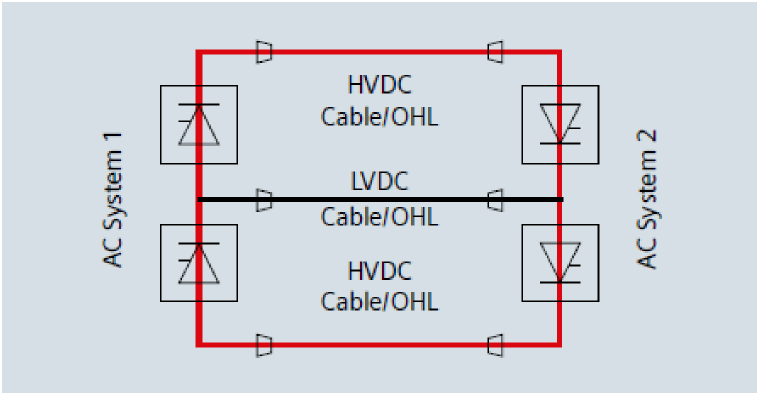

Figure 7 Bipole With Metallic Return Path

Bipole arrangement without metallic return or ground return is also possible as shown in Figure 7. Bipole without ground return configuration may have by-pass switches that can be used to reconfigure the system during a converter fault as shown in Figure 8. For a pole outage caused by converter fault, the whole system will be shut down. Then by-pass switches can reconfigure the system to isolate the faulty pole and utilise the HVDC conductor of the faulty pole for return path. Hence, until the reconfiguration completes the system power flow will be lost. Following the reconfiguration, 50% of the system capacity can be recovered.

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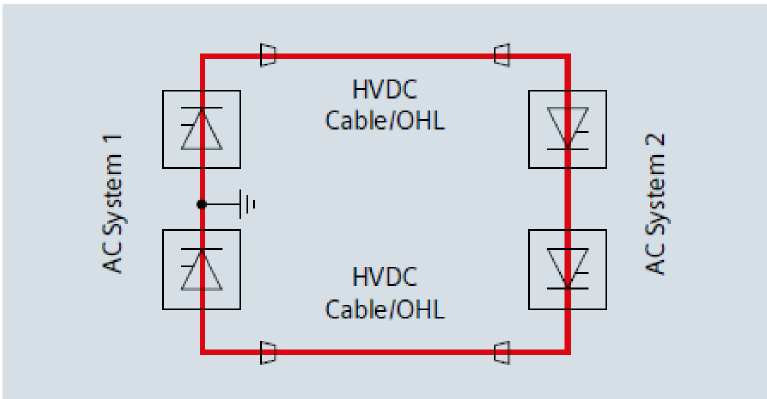

Figure 8 Bipole without Ground Return

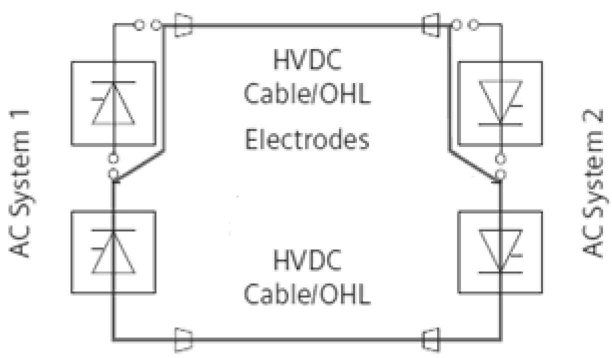

Figure 9 Bipole without Ground Return Configuration with By-Pass Switch

4.1.2 HVDC converter failure rate

There are two different types of HVDC technologies: Current Source Converter (CSC) and Voltage Source Converter (VSC). CSC uses thyristors as switches/valves, whereas in the case of VSC Insulated Gate Bipole Transistors (IGBT) or Gate Turn-off Thyristors (GTO) are used as switches / valves.

The majority of HVDC installations world-wide have CSC type dated as early as 1940, and have developed increased capacity over time to well over 2000MW at present. The VSC type converters have been in existence since 1992 but have lower ratings up to 800MW (a 1000MW rating is not site proven yet). It is generally agreed that VSC are more suitable for offshore wind connections compared to CSC due to their technical advantages such as immunity towards commutation failure, and ability to control real and reactive power and power reversal without changing the voltage polarity.

Voltage Source Converters (VSCs) can be realised in two different topologies named as half-bridge and full bridge. Both of these arrangements are shown in Figure 9. There is only one phase leg in the half-bridge topology. The output voltage is made between the midpoint of the phase leg and midpoint of the two equal series connected DC capacitors. The full-bridge arrangement has two phase legs and the output terminal is formed between the midpoints of these legs.

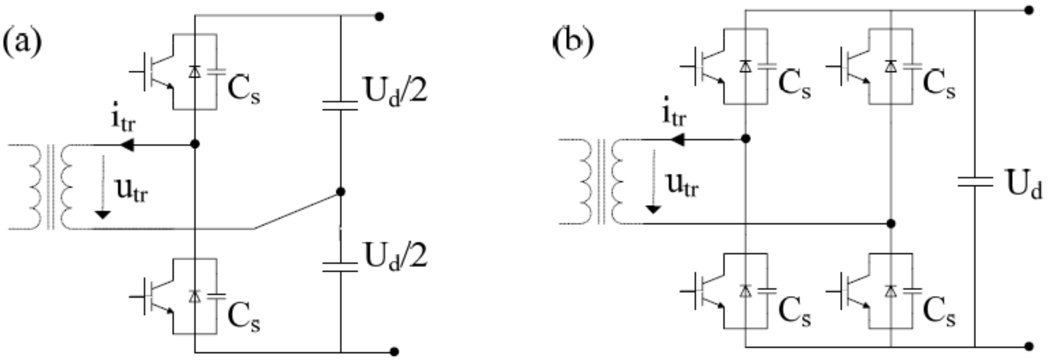

Figure 10 VSC Converter Arrangements (a) Half-bridge (b) Full-bridge

Currently VSC converters have only been developed as half-bridges and full-bridge VSC converter arrangement is an emerging technology. Bipole configurations with ground return or metallic return path, for a converter fault, half-bridge VSC converters will not automatically commutate to the metallic return and hence 100% of system capacity will be lost. Whereas full-bridge VSC type can automatically commutate and hence a converter fault could lead to only 50% of system capacity lost. However, full-bridge converter has disadvantage of increase in converter losses (about 30%) as well as the capital cost.

Historical performance data and failure rates for HVDC system are periodically published by CIGRE as the benchmark for industry to carry out the investigation of reliability studies for HVDC systems.

The statistics data of HVDC system failure rate so far in CIGRE is based on the CSC technology. As an emerging technology, there is very limited information on VSC technology failure rates.

This review will use failure rate values based on actual data from CSC technology in CIGRE report as estimated failure rate for VSC technology; however, it is recognized within the review group that VSC technology might have different fault characteristics and additional review works should be carried out if further failure rate data for VSC technology becomes available in the future.

Three key HVDC reliability documents used in this report are:

- Vancers et al, "A Survey of the Reliability of HVDC Systems Throughout the World During 2005-2006", CIGRE 2008 Report, B4-119.

- M.G. Bennett at al, "A Survey of the Reliability of HVDC Systems Throughout the World During 2009-2010", CIGRE 2010 Report, B4-113.

- K. Linden et al, "Reliability Study Methodology for HVDC Grids", CIGRE 2010 Report, B4-108, Paris.

The CIGRE reports are a summary of the reliability performance of HVDC systems in operation throughout the world. These reports provide HVDC system performance data on energy availability, energy utilisation, forced and scheduled outages. The current report is based on 700 system-years data on thyristor valve systems.

The main findings in the two reports related to this review are summarised in the table below:

Table 1: HVDC converter fault rate

HVDC Component	Failure Rate / year
Converter	1.4
Converter Common-mode Control & Protection	0.063
Converter common-mode DC equipment	0.015

The CIGRE reports suggest that the converter failure rate as 1.4 per converter per year; considering the frequency of the occurrence of converter fault, this would be treated as normal event hence the normal infeed loss risk criteria of the SQSS would apply.

There are some low probability events that may lead a Bipole HVDC system to lose its full transfer capacity:

- Both poles are unavailable due to overlapping outage, for example one transformer and one line in the other pole
- Both poles are unavailable due to a fault affecting both poles

- Both poles are unavailable due to a common-mode failure in the control and protection of the converter
- Both poles are unavailable due to a common-mode failure in the DC equipment

Amongst all the events causing the loss of total capacity, the rate of common-mode failures due to “control and protection” and “DC equipment” are 0.063/year and 0.015/year respectively as indicated in CIGRE report. Unavailability of both poles due to overlapping outage or a fault affecting both poles is considered to be a very rare event although the exact data is not available in the report. Considering the frequency of the occurrence of events causing the loss of both poles, they are treated as an infrequent event hence the infrequent infeed loss risk criteria of the SQSS would apply.

4.1.3 Infeed Loss risk for different HVDC configurations

According to the SQSS, the normal infeed loss risk limit is 1320 MW and the infrequent infeed loss risk limit is 1800 MW[6]. As explained in the previous section, only converter failure is considered as normal infeed loss risk, and other faults which may lead to bipole outage are considered as infrequent fault risks. In this section the instantaneous loss due to converter failure, for different HVDC configurations are discussed.

In monopole HVDC configurations, for a converter failure the HVDC system will lose 100% of system capacity. Most of the existing monopole systems ratings are less than 1320 MW, however this may be increased to more than 1320 MW in the future. Hence, for a converter fault in monopole configuration the instantaneous power infeed loss could be greater than 1320 MW.

In a bipole HVDC system without ground return, for a converter fault all other converters also need to be disconnected instantaneously. Hence the instantaneous infeed loss will be 100% of system capacity. The system can be reconfigured to bring one pole to operation and the pole with faulty converter can be isolated.

Analysis work (detailed in Appendix C) has demonstrated that the reconfiguration to recover the half capacity will need to be completed within 1.35 seconds to ensure that the system frequency will remain within 49.5 to 50.5 Hz for an instantaneous 1800 MW loss. This analysis is based on the assumption that the offshore wind system will be stable during this period. It is considered to be very challenging, based on current technology, to reconfigure HVDC system within 1.35 seconds and also to maintain the stability for the offshore wind system during and after the HVDC reconfiguration.

In bipole configurations with a return path (ground or metallic), for a converter fault only one pole will be lost. The other pole will be in operation and hence the instantaneous power loss will be only 50% of the system capacity for a converter fault. As explained in the previous section, for certain faults such as common-mode

[6] After 2014

faults, these configurations will lose 100% of the system capacity instantaneously. However these faults are considered as infrequent fault risks.

It should be noted that bipole with ground return or metallic return path, for a converter fault one pole will be lost and another pole will be in operation is based on the CSC HVDC technology and half-bridge VSC converters will not automatically commutate to the metallic return and hence 100% of system capacity will be lost. However, in future emerging full bridge VSC technology can automatically commutate to a metallic return like CSC systems. Hence for full bridge VSC technology, for a converter fault there could lead to only 50% of system capacity lost.

Assuming the radial connection of 1800MW through HVDC system, the instantaneous power infeed loss for each HVDC configuration, for different technology, is provided in Table 2.

Table 2 Instantaneous power infeed loss for a converter fault

Configuration	HVDC Technology	Power infeed loss
Monopole		100% (1800 MW)
Bipole without ground return		100% (1800 MW)
Bipole with ground return	CSC	50% (900 MW)
	VSC – Half Bridge	100% (1800 MW)
	VSC – Full Bridge	50% (900 MW)
Bipole with metallic return	CSC	50% (900 MW)
	VSC – Half Bridge	100% (1800 MW)
	VSC – Full Bridge	50% (900 MW)

4.1.4 Discussion

SQSS clause 7.8.2.1 states that
“Following a planned outage or a fault outage of a single DC converter on the offshore platform, the loss of power infeed shall not exceed the normal infeed loss risk”

SQSS clause 7.13.2.1 states that
“Following a planned outage or a fault outage of a single DC converter at the onshore DC conversion facilities, the loss of power infeed shall not exceed the normal infeed loss risk”

The Working Group conclusions on HVDC system configurations for radial offshore wind farm connection of greater than 1320MW are as follows:

Monopole and Symmetrical monopole configuration designs are certain to lose greater than 1320MW of generation (when running) for any converter fault. Thus this design is non-compliant with SQSS clauses 7.8.2.1 and 7.13.2.1.

In a bipole system with no ground return configuration, it is considered highly unlikely that HVDC can be re-configured within some 1½seconds, to return the other converter following one converter fault, and that the offshore wind farm can stay stable for this 1½ seconds of islanding, which would be required for this design to be compliant. Thus it is near-certain that this design is also non-compliant with SQSS clauses 7.8.2.1 and 7.13.2.1.

For this configuration, an alternative mitigation to achieve compliance, is to hold sufficient additional Response to cover the converter risk to a change of frequency of < 0.5Hz. In effect, this increases the normal infeed loss risk to the infrequent infeed loss risk of 1800MW. A full cost-benefit of this alternative is beyond the scope of this review. But the outline cost-benefit of Appendix D indicates costs of order £40m pa of Response for this mitigation. For up to at least ten instances of loss of 1800MW radial offshore connection, the capital costs of bipole with metallic return design would be cheaper overall than £40m pa of additional Response cost.

The Working Group consensus that bipole configurations with metallic return design can meet the current SQSS requirement. For the majority of converter faults, only one pole of the system will be lost and another pole will remain in service. This can provide loss of infeed of less than ½ × 1800 = 900MW. Thus this design is compliant with clauses 7.8.2.1 and 7.13.2.1.

The Working Group consensus that bipole configurations with ground return design can meet the current SQSS requirement. For the majority of converter faults, only one pole of the system will be lost and another pole will remain in service. This can provide loss of infeed of less than ½ × 1800 = 900MW. Bipole with neutral return via sea electrodes design requires clearance by Marine authorities, that the magnetic field disturbances consequent on sea return are acceptable, for a few instances of 0-5 minutes pa of single converter fault. If so, this design is also compliant with clauses 7.8.2.1 and 7.13.2.1[7].

Each individual design proposed has to be assessed for SQSS compliance on its own merits; the above deliberations only act as generic guidance, of how the Working Group believe the SQSS should be interpreted in this area.

4.1.5 Recommendations

The conclusion of the above discussion is that SQSS clauses 7.8.2.1 and 7.13.2.1 remain valid: the converter fault remains at a frequency which should be covered down to the Normal Infeed Loss Risk. Accordingly, no drafting changes to SQSS are proposed in this area.

[7] This review only considered the power infeed loss associated with converter fault, the rest of SQSS and Grid Code requirements (stability requirements etc) for the offshore generation connection through HVDC system should also be met.

4.2 Offshore cable failure rate and the infeed loss risk

4.2.1 Offshore cable failure rate

Historical performance data and cable failure rates are required to estimate the impacts, severity, and consequences of a cable failure. Submarine cable failures do occur and are measurable. However, the difficulty is that good historical information is not readily available.

Two key documents used in this report are:

Cigre TB379, "Update of Service Experience of HV Underground and Cable Systems", April 2009. Working Group B1.10

Cigre TB398, "Third-Party Damage to Underground and Submarine Cables", December 2009, Working Group B1.21.

Cigre WG B1.10 study was done to collect and analyse data relating to the installed underground and submarine cable systems rated at 60 kV and above between 1990 and 2005. More than 33,000 km of underground land cables and approximately 7000 circuit km of submarine cable systems were identified as being in service at the end of 2005. The data that was collected was indicative of the reliability performance based on trends in technology, design and service experience.

The key findings for offshore cable circuit failure rate are shown in Table 3 (TB379 Table 30):

Table 3: Failure rate of submarine cable system

		AC - HPOF cables			***AC - SCOF cables***			***AC - XLPE cables***			***DC - MI cables***			***DC - SCOF cables***		
A. Failure Rate - Internal Origin Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	NA	0.0000	0.0000	0.0000	0.0000	NA	0.0346	0.0346
B. Failure Rate - External Origin Failures or unknown		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	1.9183	0.0000	0.7954	0.1277	0.0738	0.1061	0.0705	NA	0.0705	0.1336	0.0998	0.1114	NA	0.0000	0.0000
C. Failure Rate - All Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	1.9183	0.0000	0.7954	0.1277	0.0738	0.1061	0.0705	NA	0.0705	0.1336	0.0998	0.1114	NA	0.0346	0.0346

Note: NA – not available

As can be seen in the table, for offshore DC cable the failure rate is of order 0.1 pa, that is to say once in every ten years and this is to be treated as an infrequent event. It is recognized that high voltage XLPE potentially might be used in future HVDC systems, but the failure rate of that is assumed to be in the similar range of 1 in every ten years.

4.2.2 Offshore cable failure due to Anchor dragging

Failure statistics showed that the risk of third-party mechanical damage is one of the key factors contributing to the failure of cable systems. This includes damage by ship anchors and trawling and fishing gear.

Anchors weighing a few tons can penetrate deep into the seabed so it is not economical to bury every cable beyond the reach of anchors. However in areas such as the English Channel where there is high maritime activity, burial is the best option as risk of damage is very high. Soil hardness is a factor as anchors can penetrate depths of over 5m in soft soils. The figure below shows anchor penetration with respect to soil conditions.

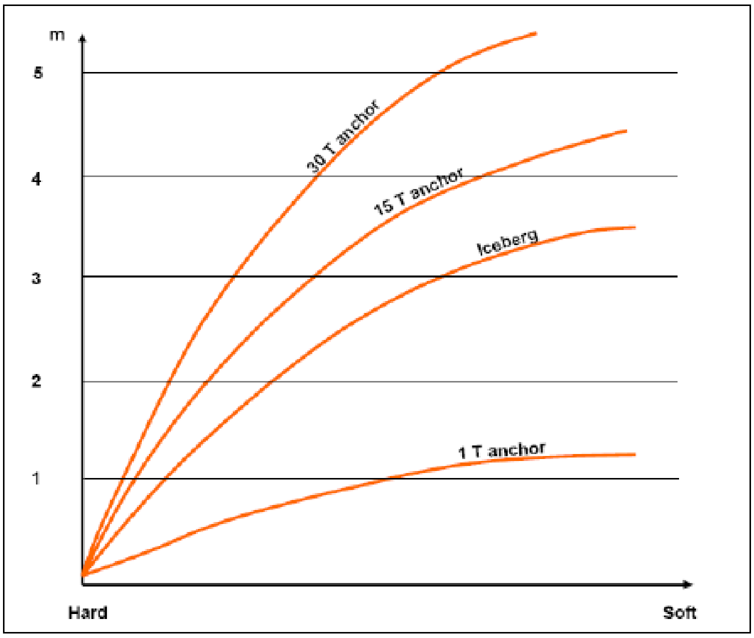

Figure 10 Anchor penetration with respect to soil conditions

The length of the chains of the anchors is taken into account as most of them can be 400m or more, so cables laid with the previous assumption of chains being 100m would now be at risk.

It is indicated in TB379 that 85% of “26 defined” faults (fault cause has been identified) were due to external influences and almost 50% of damage was known to be caused by anchors. It is clearly shown that significant cause of cable failure is anchor dragging, but the exact cable failure rate for this reason is not available.

4.2.3 Mitigation for cable failure due to anchor dragging

Many protection methods have been explored when installing cables subsea, in areas of high risk to external damage. These protection methods include burial at various depths, mechanical protection (pipes and ducts), mattressing and rock dumping. The latter techniques are employed to deflect anchors from cables.

Geo-physical studies must be done in good detail to know soil conditions to determine which protection is appropriate. Burial seems to be the best option in areas at high risk, with cables being buried by a plough simultaneously whilst a vessel lays it.

Water jetting, controlled by a driver or remotely operated vehicle (ROV) is another option of burial. In hard soils, a cable can be laid in a pre-excavated trench.

Burial depth does need to be analysed as the deeper one buries the cable the more thermal resistivity it will have, and this will decrease the transmission capacity. Further armouring of the cable will also provide mechanical protection.

4.2.4 Separation of cables to avoid multiple anchor dragging

There is a risk of losing more than one offshore circuit due to anchor dragging, and depending on the offshore generation output, it could potentially lead to a power loss of more than infrequent infeed loss risk (1800MW) within a few minutes.

The Working Group identified two varieties of risk to subsea cables from ships' anchors:

- 'Ship Dropping Anchor' risk: this is the risk that a ship inadvertently and mistakenly drops anchor while it proceeding at full speed.
- 'Storm Dragging Anchor' risk: this is the risk that a ship attempts to anchor during a storm, but breaks away from the anchored position, and is dragging its anchor at the mercy of the storm.

If those risks were mitigated by separating the circuits[8] by sufficient distance such that National Grid as System Operator could recover the system response and reverse before the second fault; that would require:

- For 'Ship Dropping Anchor' risk: the ship is likely to be travelling at 10-20 knots, and in order to ensure that two circuits would not be faulted within a 10-15 minute interval, the circuits would need to be separated by 10-20 knots × 0.17-0.25 hr = 3.1 to 9.3 km.

[8] Each offshore circuit may comprise one (eg monopole with sea return) or two (eg bipole) cables. This section is considering the risk of loss of two separate offshore circuits, irrespective of the number of constituent cables, and so the section is drafted in terms of 'circuit separation' rather than 'cable separation'.

- For 'Storm Dragging Anchor' risk: the ship is likely to be travelling at 0.5 knots, and in order to ensure that two circuits would not be faulted within a 10-15 minute interval, the circuits would need to be separated by 0.5 knots × 0.17-0.25 hr = 150-250m.

There are no clear statistics on the likelihood of each risk. What statistics there are, mainly relate to telecoms cables, and it is surmised that these cables are lighter, such that they are both more easily damaged by an anchor, and are likely to be less deeply buried than electricity cables.

National Grid suggested a target frequency of less than 1 in 100 years, for an event of loss of two independent circuits leading to a loss of infeed of >1800MW within 10-15 minutes.

For the 'Ship Dropping Anchor' risk, the group noted that if this risk were of order 1 in 28 years per cable-route, then times a 0.35 chance that the windfarm is generating above 50% output would yield that target frequency of 1 in 100 years for the >1800MW loss event. The group thought that the 'Ship Dropping Anchor' risk must be much lower than this 1 in 28 year criterion; and in any event, the mitigation of a 3 – 9 km cable separation is clearly utterly impractical.

For the 'Storm Dragging Anchor' risk, the group noted again that if this risk were of order 1 in 28 years per cable-route, then times a 0.35 chance that the windfarm is generating above 50% output would also yield that target frequency of 1 in 100 years for the >1800MW loss event. The group was less confident that the 'Storm Dragging Anchor' risk could be assured to be less than this 1 in 28 year criterion.

The group considered drafting an SQSS requirement, of the form that such offshore circuits should be separated by at least 250m. The majority conclusion was not to propose any such SQSS modification, for the following reasons:

a. There are already a number of >1800MW risks identified on the GB power system, which have risks variously estimated at 1-in-20 or 1-in-200 years. A few extra such risks cannot be said to give an overwhelming case for mitigation.

b. Designers are already under incentives to minimise downtime of valuable wind connection assets. It is not clear that an SQSS requirement would add much to what designers will strive towards anyway.

c. Good practice on laying offshore cables already typically leaves a separation of 100-200m, in order to gain unfettered access to a cable in case of fault. Hence a requirement of 250m separation would add little.

d. Circumstances along individual cable routes will vary. Difficult seabed conditions may naturally drive a section of route towards close cable separation. When crossing other cables, it can help to minimise cross-over disruption to have the crossings close. A blanket requirement for 250m separation does not respect such individual considerations.

On the other hand, a minority of the Working group supported drafting a separation requirement, of order 250m, on the grounds that such a requirement would add clarity to what is a very unclear area for both developers and regulators at present.

4.2.5 Recommendations

Based on the above discussion, the majority working group recommendation is for no SQSS change in this area.

4.3 Overall Performance of the System

It is appropriate to consider the overall performance of the power system, with respect to large infeed losses, following the above conclusions on converter and offshore cable faults.

Assume the following generation sources on the GB power system. (The following assumptions are approximately those of National Grid's 'Gone Green' scenario for 2030.)

- Six new EPR nuclear reactors connected, of TEC 1650MW and posing an infeed loss risk of 1800MW. Each reactor experiences an instantaneous full-load trip once every nine years (this is a value indicated or targeted by EdF).
- Amongst 35GW of offshore windfarms, half of the volume is connected by radial 10 x1800MW HVDC connections. (The rest are connected by lower rated cables; or else are connected in an Integrated way with sufficient redundancy not to pose an 1800MW infeed loss risk.) As per the rest of this report, the cables see a fault of 1-in-10 years each; and the converters (two on each end) cause an half infeed loss (biople with return configuration) 5.6 times per year each.
- There are also five instances on the onshore system, of 1800MW of generation connected behind a double circuit, which faults 1-in-20 years each.

This system will then experience the following average rates of large infeed losses:

- The radial DC converters will cause a loss of 900MW of infeed some 10x5.6 times per year, which is high. However, 900MW is well within the Normal Infeed Loss Risk, and frequency performance will be within all standards.
- The rate of 1800MW infeed losses will be:
  - 6 x 1/9 pa = 0.7 pa from EPR reactors
  - 10 x 1/10 x 0.35 (assumed chance of wind farm generating above 50%) = 0.35pa from offshore cables
  - 5 x 1/20 = 0.25 pa from onshore double-circuit connections

This gives a total of 0.7 + 0.35 + 0.25 = 1.35 1800MW infeed loss events pa; which is comfortably within the criterion of less than four times of such loss events pa.

Thus this section concludes that, although relatively extensive development of both EPR reactors and large radial offshore connections will increase the current rate of Infrequent Infeed Loss events, it will not do so to an unacceptable level.

5 Conclusion

This review has investigated two issues associated with the offshore infeed loss risk, the main conclusions are:

- The HVDC converter fault remains at a frequency which should be covered down to the Normal Infeed Loss Risk and current SQSS remain valid. Accordingly, no drafting changes to SQSS are proposed in this area.[9]

- It is also noted (see 4.1.4) that the monopole configurations of greater than 1320 MW is not expected to be complaint with SQSS clauses 7.8.2.1 and 7.13.2.1.

- There is no significant value for SQSS to specify the offshore cable separation to mitigate the risk of multiple cable failure due to anchor damage. Hence no drafting changes to SQSS are proposed in this area.

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[9] This review only considered the power infeed loss associated with converter fault, the rest of SQSS and Grid Code requirements (stability requirements etc) for the offshore generation connection through HVDC system should also be met.

Appendix A - Terms of Reference

Offshore connections – loss of infeed risks

NETS SQSS working group

Terms of reference

Background

The NETS SQSS criteria for the connection of offshore generation allow for generation capacities up to the defined Infrequent Infeed Loss Limit[10] by a single radial cable. Consideration is currently being given to extending the offshore criteria so that they are applicable to an offshore interconnected network, with the standard allowing for losses up to the Infrequent Infeed Loss Limit for the loss of any offshore cable. The combined probability of losing a large onshore generator, and the probability of losing offshore generation due to a cable fault, may increase the frequency of losses up to the Infrequent Limit such that they become "normal" events.

Whilst offshore cable faults are relatively rare, there is a possibility of several cables suffering faults at similar times, for example due to an anchor being dragged across parallel cables. Such an event may cause a loss of generation above the Infrequent Infeed Loss Limit, leading to widespread defensive load shedding.

Scope

The aim of this working group is to determine, and make recommendations on:

- Are future losses of generation between the Normal and Infrequent Loss Limits likely to be sufficiently frequent to be "normal"?
- If so, what are the implications of this, and how should these implications be managed?
- What is the likelihood of a multi-cable loss, and what are the impacts of this?
- Should mitigation measures against multi-cable losses be required, and if so what are they?

The group should consider:

- HVDC converter fault rates from around the world
- Offshore cable fault rates from around the world

[10] The Infrequent Infeed Loss Limit will increase from 1320MW to 1800MW from April 1st 2014; Normal Infeed Loss limit will increase from 1000MW to 1320MW from April 1st 2014; this review will only consider the increased limits.

- Current views on what is “normal”, and what is “infrequent”
- The impacts on security and costs of a higher number of infrequent losses
- The impacts on security and costs of losses greater than the infrequent limit
- Cable fault mitigation measures – their costs and benefits
- HVDC converter fault mitigation measures – their costs and benefits

Group constitution

Invitations for group membership will be made to all TOs and OFTOs, the SO, the Crown Estates, major manufactures, Ofgem, offshore generation developers

Timescales

The group will make recommendations to the NETS SQSS Review Group by end July 2012

Appendix B Working group membership

Name	Organization
Xiaoyao Zhou (Chair)	National Grid, Network Operation
Jay Ramachandran (Secretary)	National Grid, Network Operation
Paul Plumptre	National Grid, Asset Management
Manjinder Dhesi	National Grid, Asset Management
Bernie Dolan	National Grid, Network Operation
David Carson	Scottish Power Energy Network
Sarah Graham	Scottish Power renewables
David Flood	Forewind
David Gray	OFGEM
Fiona Irwin	SSE renewables
Graeme Dean	SSE
Bless Kuri	SSE
Sean Kelly	Transmission Capital
Chuan Zhang	The Crown Estate
Tomasz Sulawa	RWE
Gareth Parker	Dong Energy
Guy Nicholson	Renewable uk
Peter Stratford	Centrica
Richard Tyreman	Centrica

Appendix C Frequency response after single pole power recovery

The study was carried out in power factory with a single bus model (equivalent shown in Fig). The size of generation-demand system under study is 27 GW. A low demand system is considered as this presents the most onerous condition for frequency control. The model has a higher wind proportion as compared to the other generating sources. Frequency response is provided such that for a loss of 1800MW the minimum system frequency will be 49.2Hz, ie the system is on the limit of compliance with the SO's licence requirements. The model also takes into account a contractual load shedding of 200 MW. This same model has been previously used by National Grid in the both studies of 1800 MW loss for Frequency Response Technical Sub group within Grid Code CUSC working group and SQSS offshore working group.

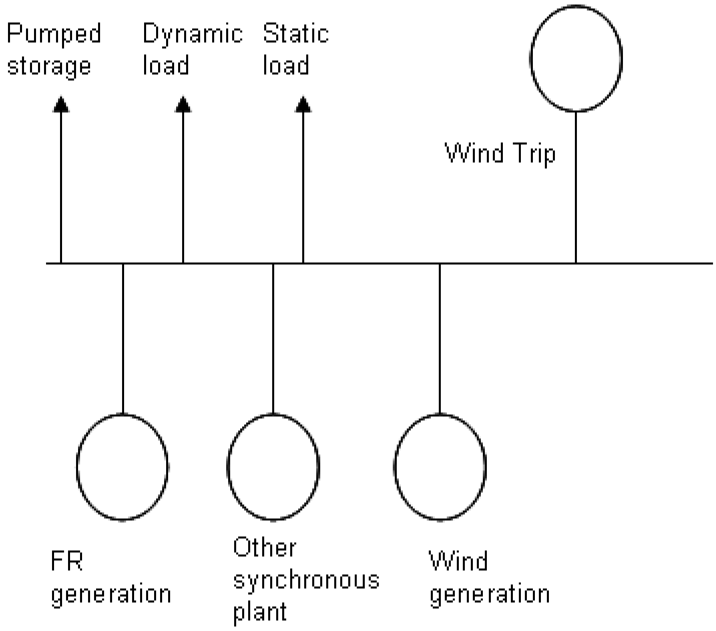

Figure 10: Study model

The figure below show the system frequency following 1800MW loss and the post fault restoration of half capacity of 900MW. The graph shows the system frequency response for different recovery time. It is demonstrated the restoration time is required to be less than 1.35s to ensure the system frequency compliance with statutory limits ie: for normal event, the frequency should be limited with in 49.5Hz to 50.5Hz.

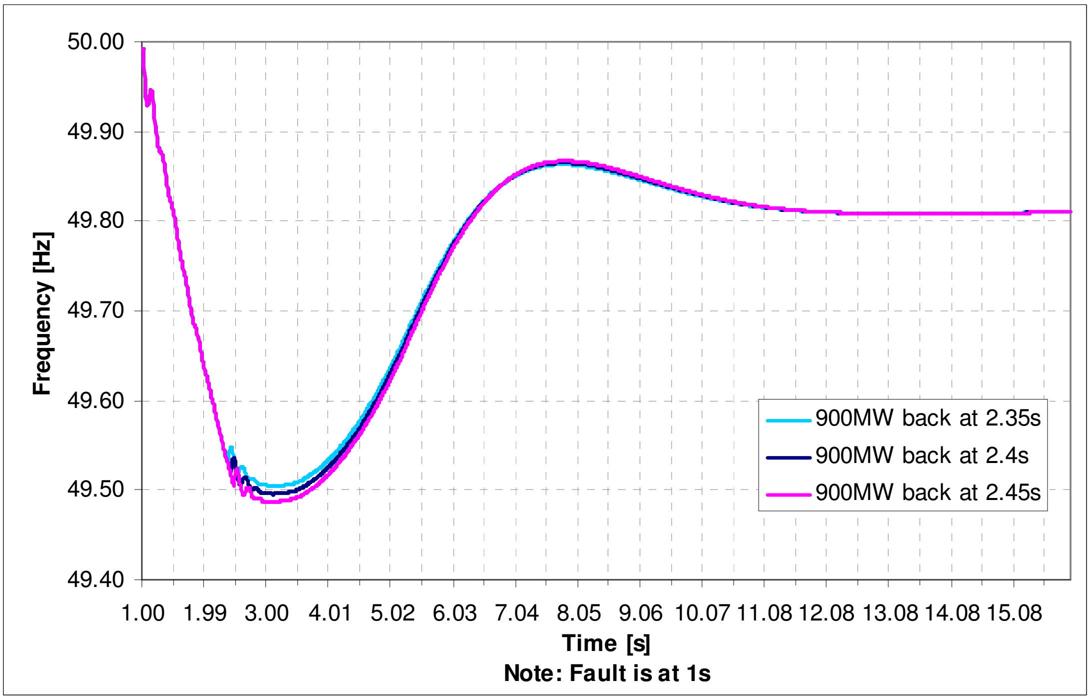

Figure 11: System frequency response after power recovery

Appendix D Outline Cost-Benefit of raising Normal Infeed Loss risk

The costs of holding extra Response, such that a converter loss of 1800MW infeed leads to a change of frequency of < 0.5Hz, are not easily assessed accurately. Response requirements should be derived from system dynamic studies of the change of system frequency second-by-second following the loss of infeed; such studies should be carried out for a variety of system demand levels and qualities of Generator Response being held. Some such studies are documented in Appendix 6 of the GSR007 report.

An outline of such a cost-benefit, which should be accurate to within a factor of two, runs as follows:

- Assume that the extra Response requirement is one-for-one on the extra MW of infeed; thus to cover from 1320MW normal infeed (at present) to 1800MW requires 480MW of extra Response (the extra requirement is probably a little higher than this; Response requirements get non-linear with infeed risk level at values >1000MW)
- Assume that the extra Response requirement is all primary Response, and there is no offset against requirements for Secondary Response
- Assume the historic average Response holding price of £20 per MW.hour of Response ('£/MWh_resp'). (As derived in Appendix 4 of the GSR007 report)
- Assume that at least one of a fleet of some 4-10 offshore windfarms connected radially via 1800MW converters is generating >1320MW output for some half of the year (4380hours), such that one has to hold this extra Response for 4380hours pa.

Then cost of extra Response holding = 480MW x 4380hours x 20 £/MWh_resp = £40m pa.

This cost of Response is compared against a cost of metallic returns in section 4.1.4 above.