Power System Planning 29 October 2009

System requirements concerning the connection of High Voltage Direct Current links to the Fingrid Oyj's AC grid

1 Introduction

The operational reliability of the power system requires that the transmission grid and significant generation and consumption points connected to the grid operate reliably as an entity under all operational situations. The objectives of the system requirements imposed on high-voltage direct current (HVDC) connections are as follows:

- The HVDC connection withstands the voltage and frequency variations caused by the alternating current (AC) system.
- The HVDC connection remains operational also in the event of faults in the AC system and does not promote the expansion of the disturbance.
- The filtering of harmonics caused by the HVDC connection and the compensation of its reactive power are carried out so that the connection does not disturb any other parties connected to or any telecommunication systems close to the AC system.
- The HVDC connection does not cause or amplify subsynchronous torsional interaction related problems in the AC system.

These requirements apply to new HVDC connections to be connected to Fingrid Oyj's (below Fingrid) 400 kV grid. Moreover, Fingrid's **General Connection Terms** must be respected at the connection point. A separate **System Agreement** on operational issues shall also be made between Fingrid and the operator of the HVDC connection.

These requirements do not discuss any emergency power or stabilising controls that can be added to the control system of the HVDC connection. The implementation of such controls is agreed upon separately in each case.

2 Frequency variation

At the substations of the Finnish national grid, the objective is to keep the frequency within the range of 49,9 to 50,1 Hz. However, an HVDC connection must be capable of operating continuously at full power when the frequency is within the range of 49 to 50,3 Hz. The HVDC connection shall also be able to operate in the event of individual disturbances for 30 minutes when the frequency is within the range of 47,5 to 49 or 50,3 to 53 Hz. The active power of the connection may in this case be reduced by 10 %.

It must taking into account that the voltage variations may occur simultaneously with frequency variations.

3 Fault level at the connection point

If the operation of the HVDC connection requires a certain minimum short circuit power from the AC grid, the fulfilment of the value in question must be verified individually at the connection point. Fingrid will specify the minimum short circuit power in the situation which most restricts the short circuit power at the connection point. This is based on the Nordic grid dimensioning rules, according to which no individual fault may lead to an expanding disturbance, in this case to the tripping of the HVDC connection.

4 Properties of the AC voltage at the 400 kV connection points

At the 400 kV substations of the Finnish national grid, the objective is to keep the voltage within the optimum range of 405 to 415 kV. However, an HVDC connection must be capable of operating continuously at full power when the voltage is within the range of 395 to 420 kV. The HVDC connection shall also be able to operate in the event of individual disturbances for 30 minutes when the voltage is within the range of 360 to 395 kV. The active power of the connection may in this case be reduced by 10 %.

The 10 minute average of negative sequence component of voltage in three phase system will be below 1 %, but short time values may exceed this level.

5 Properties of the AC voltage at the 220 kV connection points

At the 220 kV substations of the Finnish national grid, the objective is to keep the voltage within the optimum range of 220 to 235 kV. However, an HVDC connection must be capable of operating continuously at full power when the voltage is within the range of 215 to 245 kV. The HVDC connection shall also be able to operate in the event of individual disturbances for 30 minutes when the voltage is within the range of 205 to 215 kV. The active power of the connection may in this case be reduced by 10%.

The 10 minute average of negative sequence component of voltage in three phase system will be below 1 %, but short time values may exceed this level.

6 Properties of the AC voltage at the 110 kV connection points

At the 110 kV substations of the Finnish national grid, the objective is to keep the voltage within the optimum range of 110 to 122 kV. However, an HVDC connection must be capable of operating continuously at full power when the voltage is within the range of 105 to 123 kV. The HVDC connection shall also be able to operate in the event of individual disturbances for 30 minutes when the voltage is within the range of 100 to 105 kV.

The 10 minute average of negative sequence component of voltage in three phase system will be below 2 %, but short time values may exceed this level.

7 Filtering of harmonics and compensation of reactive power of the link

The harmonic voltages and currents at the connection point shall not exceed the limit values given in Table 1.

However, as the limit values refer to the total value of harmonics in the connection point, possible harmonic injections by other connecting parties shall also be taken into account. This will be done by Fingrid after receiving the preliminary harmonic injection values of the planned HVDC connection. For filtering studies Fingrid will give the harmonic impedance range of the connection point at all relevant harmonic frequencies. Rough estimation for background harmonic levels half of the values of table 1 can be assumed.

MAXIMUM LEVELS OF HARMONIC VOLTAGES AND CURRENTS AT THE TRANSMISSION VOLTAGE LEVEL					
Per cent of the nominal voltage					
Odd				**Even**	
Non multiple of 3		**Multiple of 3**			
n		**n**		**n**	
	%		**%**		**%**
5	**2**	**3**	**2**	**2**	**1.5**
7	**2**	**9**	**1**	**4**	**1**
11	**1.5**	**15**	**0.3**	**6**	**0.5**
13	**1.5**	**21**	**0.2**	**8**	**0.2**
17	**1**	**>21**	**0.2**	**10**	**0.2**
19	**1**			**12**	**0.2**
23	**0.7**			**>12**	**0.2**
25	**0.7**				
>25	**0.1+**				
	12.5/n				
Total harmonic distortion of voltage			**< 3%**		
Psophometric value of phase current			**< 5 A**		

Table 1 Maximum permitted harmonics including existing harmonics

The filtering and reactive power compensation banks required by the HVDC connection shall be realised so that their connection does not cause a voltage change higher than 3 % at the connection point (also see item 5). However, the maximum permitted reactive power generation by a single bank is normally 80 Mvar. Larger units may be used, if the conditions at the connection point it allows. Moreover, the compensation of reactive power at the connection point must be carried out so that the amount of reactive power fed into the AC grid or taken from it under normal operating conditions is reasonable, which may be at the most 8 % of the nominal power of the HVDC connection.

If the HVDC connection can independently regulate its reactive power, the starting point is that part of its reactive power capability is reserved as a disturbance reserve for the AC grid in the manner specified for generators.

8 Subsynchronous torsional interaction

The HVDC connection shall not cause subsynchronous torsional interaction (SSTI) problems in the AC system. If necessary, the control system of the HVDC connection must be capable of damping subsynchronous resonance frequencies characteristic of turbogenerators connected to the connection point or its vicinity.

The control system must also be capable of immediately disconnecting the HVDC connection if the subsynchronous currents exceed the prescribed limits.

9 Other technical requirements

The HVDC connection must be designed so that it remains operational and stays connected to the grid in a stable manner also during disturbances in the AC grid. The power of the connection must be at least 90 % of the value preceding the disturbance when 300 ms have elapsed from the tripping of a single-phase, two-phase or three-phase earth fault or short circuit in the AC grid. Faults in the 400 kV AC grid are normally disconnected in less than 0,1 seconds and within 0,5 s in 110 kV and 220 kV grids. In single-phase high-resistance faults, the fault time may extend to up to 5 seconds.

Voltage stiffness at the connection point may, especially in various outage and fault situations in the AC grid, restrict the maximum permitted stepwise power changes of the HVDC connection. For this reason, it must be possible to restrict the stepwise power changes together with the related switching of filter and compensation banks so that they do not cause a voltage change in excess of 3 % at the connection point. Large filter banks must be connected with synchronised circuit breakers. The power changes must be carried out by ramp speeds agreed with Fingrid. The principles and the practical implementation of the HVDC control shall be agreed in detail individually for each connection point.

The HVDC connection must not essentially increase the short circuit currents at the connection point or cause disturbingly large current and/or voltage transients to the AC grid. The zero sequence impedance of the converter transformer shall be less than 100 % and the transformer must able to operate with neutral point grounded or ungrounded. Moreover the converter transformer shall be connected to grid by synchronised breaker. The HVDC protection system must be designed so that internal faults within the connection are disconnected within 100 ms from the moment when the fault was originated. If the connection trips, it must also be ensured that its filter and compensation banks are disconnected from the AC grid at the same time.

10 Supply and verification of information

Sufficient information on the HVDC connection shall be delivered to Fingrid. This information includes among other things data on the equipment (including filter data) and systems used in the connection, their protection systems and the operation mode of the connection. The information delivered must also include a description of the operation of the HVDC connection during various fault situations in the AC and DC systems as well as its effect on potential subsynchronous resonance conditions.

The correctness of information pertaining to the HVDC connection and the fulfilment of requirements specified for the connection must be verified, as far as possible, through tests carried out in conjunction with the commissioning of the connection. The contents and other arrangements concerning the tests are to be agreed separately with Fingrid.