Embedded HVDC systems – frequency schemes in case of system split

ENTSO-E guidance document for national implementation for network codes on grid connection

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1 DESCRIPTION

1.1 CODE(S) & ARTICLE(S)

COMMISSION REGULATION (EU) 2016/1447 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (NC HVDC), Article 15 and 16.

COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators (NC RfG)

COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (GL SO)

COMMISSION REGULATION (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration (NC ER)

1.2 INTRODUCTION

NC HVDC Article 15 requires that the HVDC systems shall be capable of regulating by means of automatic control their active power as a function of the deviation of frequency from its nominal value measured at its connection point when operating in Frequency Sensitive Mode (FSM), Limited Frequency Sensitive Mode-Underfrequency (LFSM-U) or Limited Frequency Sensitive Mode-Overfrequency (LFSM-O). These requirements were designed consistently to the corresponding requirements for power generating modules by NC RfG with the aim of achieving similar response from power generating modules and HVDC systems in case of system frequency deviations, as well as the same mechanism for reserves sharing.

The interpretation of the FSM, LFSM-O and LFSM-U requirement is obvious for power generating modules that have only one connection point to which the active power frequency response in case of a frequency deviation shall apply. However, in case of HVDC systems the interpretation may not be so clear: the capability to provide active power frequency response is a relevant feature for HVDC systems connecting different synchronous areas, which are not connected to each other by AC lines, and therefore do not share the same frequency. In this situation, the HVDC system can provide support to one synchronous area, which suffers a frequency deviation, by increasing/decreasing the active power infeed/offtake. This active power regulation of the HVDC system providing support to one synchronous area has an immediate impact on the frequency of the other synchronous area, which then needs to be compensated by active power frequency response of generators in that area. This capability of HVDC systems was therefore conceived to be a mean to share frequency reserves across synchronous areas.

However, if an HVDC system is located within a single synchronous area, i.e. the HVDC system is embedded in one control zone or area according to Article 3.1 c) and d) of Regulation (UE) 2016/1447, the FSM and LFSM-O/-U features are not needed in normal operation, without prejudice that these control functions may be useful in case of system splits after which each HVDC terminal resides in a different frequency zone of the split synchronous area.

This IGD aims at clarifying the possible settings of the frequency control functionality for HVDC systems embedded in a synchronous area and recommending its configuration. In addition, the IGD addresses the need for coordination of the frequency control function with additional control functions which aim at guaranteeing the robustness of the control functions and contributing to system security.

KEY DEFINITIONS

The term "embedded HVDC systems" refers to the HVDC systems which are located within a single synchronous area under normal system operating conditions. By other words, frequency at all terminals of an embedded HVDC system is the same under normal system operating conditions.

1.3 NC FRAME

NC HVDC constitutes mandatory requirements for HVDC systems to be capable of FSM, LFSM-O and LFSM-U features. For adequate specification of the requirements, especially in case of having this functionality for embedded HVDC systems in case of system splits, some relevant complementary functions, which have to be specified by the relevant TSOs may be essential to be implemented within the HVDC control system.

However, in this context, in the case of a system split, the coordination between the controllers at all terminals of an HVDC system as well as between other grid users may be complicated to be foreseen. They shall be subject to individual studies as the case may be.

Taking the latter point into account, this IGD focuses on technical capabilities for connection of HVDC systems, rather than operational settings of the control functions, that they shall be subject of further detailed studies.

1.4 FURTHER INFO

[1] IGD on Frequency Sensitive Mode
[2] IGD in limited frequency sensitive mode (LFSM-O/U)

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2 INTERDEPENDENCIES

2.1 BETWEEN THE CNCS

COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators (NC RfG), Article 13(2), Article 15(2)(c) and 15(2)(d)

COMMISSION REGULATION (EU) 2016/1447 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (NC HVDC), Article 15 and 16

2.2 WITH OTHER NCS

COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (GL SO), Articles 118, 137, 146, 147, 148, 156

COMMISSION REGULATION (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration (NC ER), Article 14.

2.3 SYSTEM CHARACTERISTICS

A system split may lead to smaller galvanically separated zones with different frequencies within a synchronous area, having high frequencies in zones with excess of generation and low frequencies in those with generation shortage. At high frequencies, the LFSM-O performance from power generating modules is expected. At low frequencies, LFSM-U performance or even the activation of the low frequency demand disconnection (LFDD) is expected. Depending on the operational conditions (i.e. the capacity allocation, generation distribution, inertia, etc…), a system split may lead to a variety of scenarios, except for some specific cases, with typical patterns of a split. Therefore, in general the possible scenarios are very difficult to be foreseen.

In above described situations - unless a dedicated control function for active power regulation as a function of the frequencies at all HVDC system terminals has been implemented – active power frequency response of an embedded HVDC system shall not be triggered in case of a system split. Instead, HVDC systems shall maintain the active power setpoint until the manual action of an operator.

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2.4 TECHNOLOGY CHARACTERISTICS

HVDC systems have a great capability of modulating its active power without being subject to mechanical or thermal limitations. Therefore the capability to change the active power infeed/offtake at the connection points is much faster than for many power generating modules. Therefore, HVDC systems can provide support to maintaining frequency stability, such as providing reserves across synchronous areas. The same can be applied to providing support in case of a system split. However, it needs to be taken into account, that any active power modulation of an HVDC system always has impact on more than one HVDC system connection point.

Regarding HVDC system technologies, some technology-specific constraints of active power modulation need to be taken into account. The Line Commutated Converter (LCC) technology may have an active power technical minimum for operation, which is not an issue for the Voltage Sourced Converter (VSC) technology. In addition, although fast active power reversal is possible for both technologies, the performance of LCC technology may be slower due to cable limitations in withstanding the voltage reversal, which does not apply to VSC technology.

3 COLLABORATION

3.1 TSO – TSO

If the embedded HVDC system connects two or more control areas, it is important to cooperate between the TSOs of these areas to establish proper settings of the FSM, LFSM-U and LFSM-O functions, as well as other control features of active power frequency response to achieve consistent control at all HVDC system terminals.

3.2 TSO – DSO

N/A

3.3 RNO – GRID USER

N/A

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3.4 METHODOLOGY

Under normal operating conditions frequency is the same at all terminals of an embedded HVDC system and therefore FSM, LFSM-O or LFSM-U control functions shall not be activated. However, NC HVDC constitutes these capabilities to be implemented mandatorily in the HVDC control system. To avoid any undesired activation of these features because of a frequency deviation from its nominal value, it is recommended to disable these functions by parameter settings. Consequently, if an embedded HVDC system is operated with different frequencies at each terminal (e.g. after a system split) no active power modulation and therefore no frequency support shall be expected.

In general, it is very difficult to anticipate a system split pattern and the resulting separated frequency zones to assess the optimal behaviour of an HVDC system in such a situation. However, in some dedicated cases, typical split patterns may still be foreseeable, e.g. if an HVDC system is in parallel to few AC lines that may trip in cascade, or where the AC network nearby one of the HVDC system terminals is not well-meshed and it could be easily isolated in case of an event.

Figures 1, 2 and 3 depict such examples.

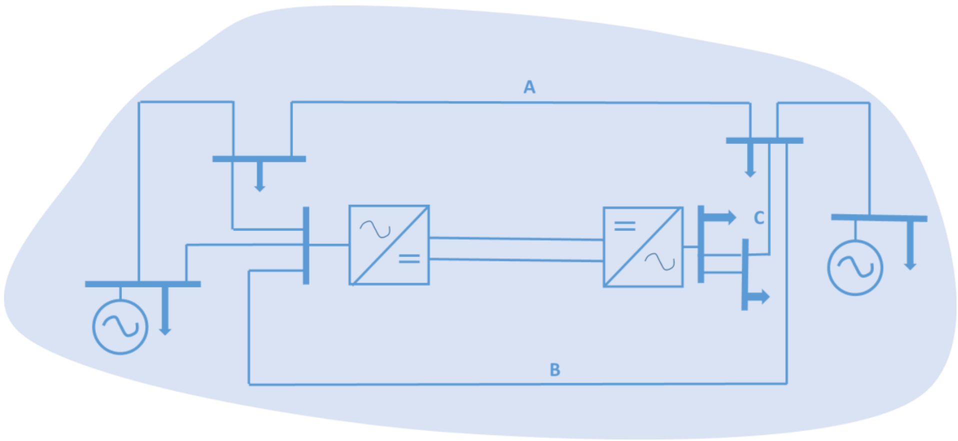

Figure 1. *HVDC system embedded in a synchronous area. In this case, the converters of both extremes measure the same frequency.*

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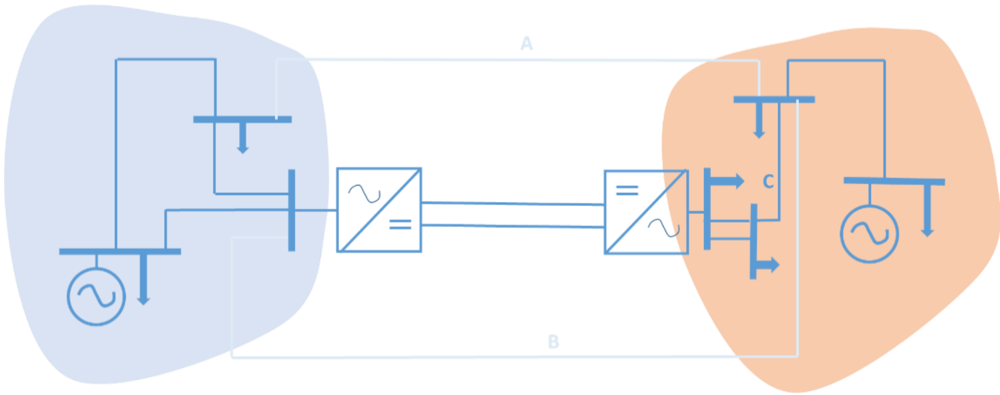

__Figure 2.__ In the same power system depicted in Figure 1, if there is a cascade tripping of lines A and B, the HVDC system will remain connected to the same buses, but they will be part of different frequency zones (one marked as blue and other as orange).

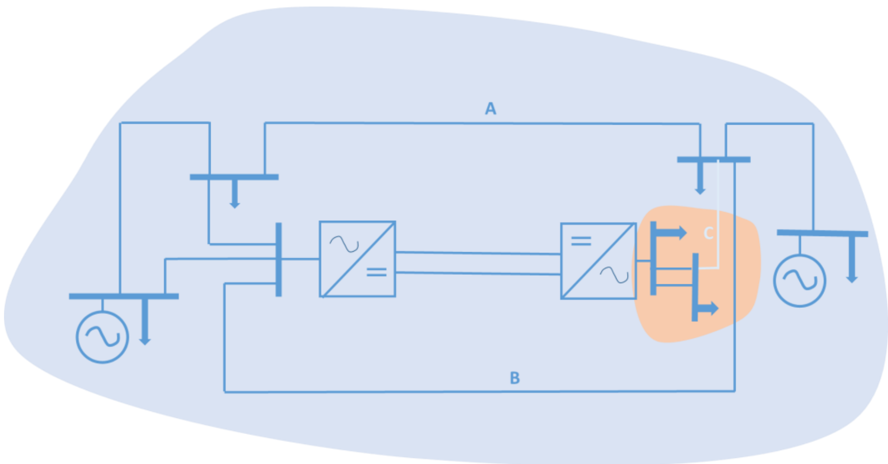

__Figure 3.__ In the same power system depicted in Figure 1, if line C trips, the HVDC system will remain connected to the same buses, but they will be part of different frequency zones (one marked as blue and other as orange).

In cases where some a typical system split pattern can be defined, it may be interesting to implement and enable - although not released under normal operating conditions - to support frequency stability by modulating the active power flow on an HVDC system as a function of the frequency, i.e. by maintaining FSM, LFSM-O and LFSM-U functions or implementing another frequency control according to the provisions of Article 16 of NC HVDC.

In this case, how does the HVDC control system recognize an event causing different frequencies at its terminals?

It may be insufficient to solely rely on frequency measurements to identify that such an event has occurred, because other events (e.g. faults) may cause a transient frequency deviation at one terminal of the HVDC system that shall not trigger the FSM, LFSM-O or LFSM-U control action. Therefore, the control system shall be equipped with a kind of “asynchronous network operation detection” control function that shall filter these transient frequency deviations and be able to detect robustly, if the HVDC system terminals are connected to separated networks.

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This function, for instance shall include a time window for monitoring the frequency, and it may verify that that a measurement sample is coherent with previous and next samples. Furthermore the difference of frequency measurements at the HVDC system terminals should exceed a threshold value before triggering some action. Such measures will lead to a delayed activation of FSM or LFSM-O/-U, but also to a more robust detection of frequency events at the connection points. It is recommended that HVDC system manufacturers, as control experts, propose and test the detailed algorithm of this function. Thus, it is highly recommended that the TSO and later the HVDC system owner mutually specify the design and implementation of this control function at an early stage of a project already.

Once a system split has been detected and the FSM, LFSM-U, LFSM-O, or any other kind of frequency control are triggered, the active power through the HVDC system would be modulated to provide frequency support to the AC system connected to one terminal of the HVDC system by injecting or absorbing active power from the AC system at another terminal.

While the operation in these modes, considering the huge capability of active power regulation of HVDC systems, it is desirable to include a surveillance system in order to ensure that the frequency of the “supporting area” stays within admissible ranges. Therefore, it is recommended to implement a further control functionality in charge of monitoring the frequency of all HVDC system terminals. Some safety margins for each terminal shall be included, allowing the HVDC system to regulate its active power as long as the frequencies at all terminals are within a “healthy range” (parameters to be set by the Relevant TSO), but to freeze FSM, LFSM-U, LFSM-O or any other frequency control function in case any of the frequency exceeding this “healthy range” at any terminal.

As a conclusion, from the connection requirements perspective, it is recommended to the TSOs to complement the abovementioned control functions by both an “asynchronous network operation detection algorithm” and a “frequency surveillance system”, if the active power regulation as a function of the frequency in case of system split functionality is to be implemented within an embedded HVDC system, it is highly recommended.

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