IEC TR 63411

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TECHNICAL REPORT

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Grid connection of offshore wind via VSC-HVDC systems

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GRID CONNECTION OF OFFSHORE WIND VIA VSC-HVDC SYSTEMS

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The text of this Technical Report is based on the following documents:

Draft	Report on voting
8A/177/DTR	8A/184/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

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INTRODUCTION

New technical solutions to meet the engineering development of grid integration of offshore wind generation via HVDC are the content of this document. The new solutions include new technologies, methods and practices to provide more flexibility and improve the efficiency of power systems, constantly balancing generation and load.

The development of offshore wind is progressing steadily, and VSC-HVDC systems are commonly adopted to link long distance offshore wind farms with the onshore bulk power grid. According to this fact, the purpose of this Technical Report (TR) specifically focuses on the planning, interaction and coordinated control between offshore wind farms and VSC-HVDC systems.

For various stakeholders, including transmission system operators, offshore wind farm owners, research institutes and so on, this Technical Report is to collect information from regulatory contents including relevant issues in different countries and regions, and work out a TR for offshore wind farm Integration via DC Technology, which mainly addresses the technology development tendency, best practices, and the future standardization activities.

The aim of this document is to draft a strategic, but nevertheless technically oriented and referenced TR, which represents the core and key issues of offshore wind integration via VSC-HVDC systems. Offshore wind farm developers and owners, transmission system operators have a common understanding about the key issues based on practices and challenges between offshore wind farms and VSC-HVDC systems.

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GRID CONNECTION OF OFFSHORE WIND VIA VSC-HVDC SYSTEMS

1 Scope

The voltage source converter based on high-voltage direct current (VSC-HVDC) transmission technology has attracted increasing attention because of its advantages such as flexible control, supply to passive systems, and black start capability, which has been widely used in offshore wind farm integration. Although offshore wind farms generate electricity just like any other power plants on a system-wide level, such offshore wind generation has quite distinctive characteristics to be considered in terms of capacity optimization, voltage and power control, fault response, multi-frequency oscillation, power DC collection, etc., when compared to conventional generation integration via HVDC. Understanding these distinctive characteristics and their interaction with the other parts of the power system is the basis for integrating large-scale offshore wind farms via VSC-HVDC.

This document discusses the challenges of connecting offshore wind farms via VSC-HVDC, key technical issues and emerging technologies. The potential solutions include new technologies, methods and practices to provide more flexibility and improve the efficiency of power systems. The primary objective of this document is to provide a comprehensive overview of challenges, potential solutions, and emerging technologies for grid integration of large-scale offshore wind farms via VSC-HVDC. It is expected that this document can also provide guidance for further standardization on relevant issues. The purpose of this document is not intended to hinder any further development of state-of-art technologies in this field.

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This Technical report is not an exhaustive document in itself to specify any scope of work or similar, between a purchaser and a supplier, for any contractual delivery of a HVDC project/equipment. It is expected that this document is used for pre-study and then to make studies, specification for delivery of specific HVDC project, as applicable.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TR 62001-5, *High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters – Part 5: AC side harmonics and appropriate harmonic limits for HVDC systems with voltage sourced converters (VSC)*

IEC 62747, *Terminology for voltage-sourced converters (VSC) for high-voltage direct current (HVDC) systems*

IEC 62934, *Grid integration of renewable energy generation – Terms and definitions*

IEC TR 63401-1, *Dynamic characteristics of inverter-based resources in bulk power systems – Part 1: Interconnecting inverter-based resources to low short circuit ratio AC networks*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TR 62001-5, IEC 62747, IEC 62934, IEC TR 63401-1 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

4 Practices and challenges

4.1 Practices

4.1.1 General

The number of projects using HVDC to integrate renewable energy (RE) is growing, mainly due to the significant acceleration of offshore wind development. These projects are, to date, mainly based on point-to-point HVDC systems.

4.1.2 Projects in North Sea, Germany

BorWin1 is the world's first HVDC system connecting an offshore wind farm. It connects the BARD Offshore 1 wind farm and other offshore wind farms near Borkum, Germany to the European power grid by VSC-HVDC. The project started in 2007 and was put into operation in 2009.

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The BARD Offshore 1 wind farm includes eighty 5 MW wind turbines located in the North Sea that are 130 km away from the coast. The rated capacity of the converter station is 400 MW, the DC voltage level is ±150 kV, and the total length of the DC connection is 200 km, including 125 km of submarine cables and 75 km of underground cables.

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Since the BorWin1 project, Germany has developed a series of offshore wind farm projects based on VSC-HVDC systems in the North Sea, as shown in Table 1. The VSC-HVDC transmissions of these systems, except that of BorWin1, are based on modular multi-level technology, and the highest voltage level reaches ±320 kV.

Table 1 – VSC-HVDC-based offshore wind projects in Germany

Project	Transmission Capability	Length	Operation Time
BorWin1	±150 kV,400 MW	200 km	2010
BorWin2	±300 kV,800 MW	200 km	2015
BorWin3	±320 kV,900 MW	160 km	2019
DolWin1	±320 kV,800 MW	165 km	2015
DolWin2	±320 kV,900 MW	135 km	2016
DolWin3	±320 kV,900 MW	160 km	2018
HelWin1	±250 kV,576 MW	130 km	2015
HelWin2	±320 kV,690 MW	130 km	2015
SylWin1	±320 kV,864 MW	205 km	2015
DolWin6	±320 kV,900 MW	90 km	2023
DolWin5	±320 kV,900 MW	130 km	2024

These projects have strongly supported the development of VSC-HVDC-based offshore wind farm grid connections. The renewable power generation farms and VSC-HVDC systems achieve power conversion and transmission based on the fast controllability of power electronic converters. Under operating conditions, in case some oscillation phenomenon occurs when the two systems are jointly operated, the relevant suppression measures for these phenomena focus on designing additional damping control systems for the generation units and improving the control strategy of the VSC-HVDC converters.

4.1.3 Nan’ao project, China

Nan'ao is located in the eastern sea of Guangdong Province in China. This project is the world’s first multi-terminal HVDC system for offshore wind farms. It involves a three-terminal VSC-HVDC transmission system including two sending terminals and one receiving terminal. The sending end converter stations are the Qing'ao Station and Jinniu Station, and the receiving end converter station is the Sucheng Station. The capacities are 50 MVA, 100 MVA, and 200 MVA, respectively, and the DC voltage level is ±160 kV. The Tayu converter station was planned, but hasn’t been constructed yet.

Modular multilevel converter (MMC) technology was used in this project. This project was formally put into operation at the end of 2013 and is the world's first demonstration multi-terminal VSC-HVDC project. Figure 1 shows the schematic diagram of this multi-terminal VSC-HVDC demonstration project. The Nan’ao multi-terminal VSC-HVDC has three main operation modes: an AC feeder and DC feeder in parallel, DC feeder only, and STATCOM. However, the lack of DC circuit breakers poses risks to the operation of the DC-feeder-only mode.

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Before the project was put into operation, the power grid in the Nan’ao area was very weak, and the fluctuations of the grid-connected wind power system had a large impact on the local power grid. After this project was put into operation, the flexible control capabilities of VSC-HVDC were used to provide not only support for the wind power integration, but also effective support for the stability of the local power grid.

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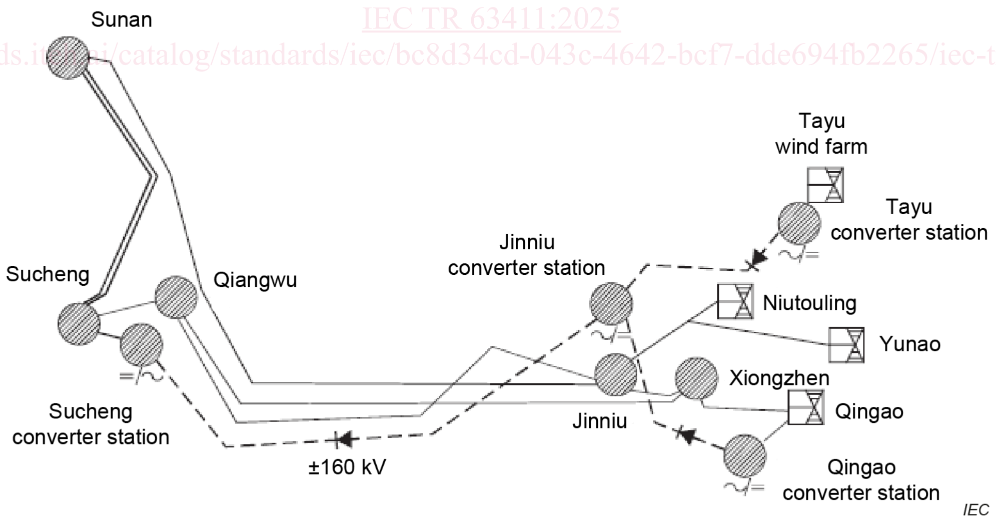

Figure 1 – Schematic structure of the Nan’ao VSC-MTDC project

4.1.4 Hybrid Interconnector project, Belgium and Denmark

European Electricity Transmission System operators Elia (Belgium) and Energinet (Denmark) have announced in February 2021 to set up a working group to examine the feasibility of a subsea cable between Belgium and Denmark that links the high-voltage grids of both countries over a distance of more than 600 km. A 'hybrid' design, which means that it brings wind energy from offshore wind farms to onshore power grids and can also be used as an interconnector between different electricity grids, is being examined. On the Danish side, the interconnector connects to a new 'energy island' to be built 80 km off the Danish coast and to which a large 10 GW wind farm is eventually connected.

When the interconnector between Belgium and Denmark is completed, the cable run through the territorial waters of four countries: Belgium, the Netherlands, Germany and Denmark. This gives Belgium direct integration to the renewable bulk generation in order to decarbonizes its energy-intensive industry and achieve the European climate targets. The start of the feasibility study follows the political cooperation agreement signed by the Belgian and Danish Energy Ministers. The project dovetails with the implementation of the European Green Deal, which aims for Europe to become the first carbon-neutral continent by 2050 by increasing the current capacity of offshore wind from 25 GW to 300 GW.

It is the first time Belgium is connected to a new electricity market that is further away than neighbouring countries. Hybrid technology also enables Belgium to gain direct integration to large wind farms in the far northern part of the North Sea where the meteorological conditions are different from those off the coast of Belgium. This provides greater security of supply and helps the Belgian energy-intensive industry to continue decarbonising.

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4.2 Challenges

When large-scale offshore wind farms are connected to the VSC-HVDC system over long-distance transmission, the operation characteristics of offshore wind farms and the VSC-HVDC system affect each other. The adaptability of offshore wind farms connected to the VSC-HVDC system becomes an important issue affecting grid operation. In particular, the complex interaction between offshore wind farms and the power grid brings new challenges to the offshore wind farms and VSC-HVDC system.

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1) Planning optimization. The planning of offshore wind farms and its integration is significantly important considering the relatively high investment of offshore wind farms and the VSC-HVDC system. When the capacity of offshore wind farms is larger than the VSC-HVDC capacity, wind curtailment is inevitable. Also, if the VSC-HVDC capacity is larger than offshore, the overall investment becomes excessive.
2) Voltage control. At present, the study on hierarchical voltage control for aggregated wind farms focuses on the AC grid. As the islanded aggregated offshore wind farms connected via VSC-HVDC are decoupled from the AC network, the optimization target and mode of which is quite different from the traditional connection. New voltage control strategies combined with its characteristics are developed.
3) Active power control. As the utilization of offshore wind farm in the power grid increases, synchronous power generation units are gradually decommissioned, causing the inertia and active power reserve capacity of the entire system to be reduced. This brings challenges to the frequency stability of the power grid. Developments of enhanced frequency regulation methods are required.
4) Fault control. When large-scale offshore wind farms are connected to a VSC-HVDC system, the operational characteristics of offshore wind farms and VSC-HVDC grid interact with each other. Various methods of fault ride-through inevitably have a certain impact on the offshore wind turbine, and even have impacts on the regulations and standards for offshore wind farms with interconnection to power system via DC.