Design, Control and Application of Modular Multilevel Converters for HVDC Transmission Systems
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Introduction

• In recent years several offshore HVDC transmission projects for export of offshore wind energy to shore have been realized.
• The experience from German offshore HVDC projects indicates that housing the HVDC converters in an offshore platform is more challenging than anticipated. Installing the HVDC converter equipment on a platform for use in offshore environments imposes new requirements and restrictions, affecting project execution and design as well as the manufacturing,
• installation, commissioning, operation, and maintenance of that equipment.
• Different European regulatory frameworks impact the design optimization and ownership of HVDC schemes used for the export of offshore wind energy to the mainland.
• Main components of the offshore and onshore MMC-HVDC converters are presented.
• Minimum set of system studies that are required for the design, development, and manufacture of these HVDC schemes system is presented in this chapter.
The Influence of Regulatory Frameworks on the Development Strategies for Offshore HVDC Schemes

- National regulatory frameworks impact the development strategies and ownership of offshore HVDC assets.
- In UK offshore wind project developer can construct the offshore transmission assets themselves (generator build), after the integration and trial test period, the HVDC scheme, including any offshore assets above 132 kV ac, must be transferred to an OFTO (Offshore Transmission Operator), according to strict regulatory frameworks.
- The UK’s regulatory framework opens up for optimizing the radial connections of export links from offshore wind farms to the mainland. Existing frameworks provide no incentives for the optimization of offshore platforms.
The Influence of Regulatory Frameworks on the Development Strategies for Offshore HVDC Schemes (2)

- Based on the enforced regulations, when an offshore WPP project receives the necessary permits for construction, and the grid connection agreement from the TSO, the required offshore transmission link to shore must be in place according to the agreement between the stakeholders. The German grid code for the connection of offshore wind does not differentiate between ac- or dc-connected wind farms.

- The UK regulation requires that the offshore transmission assets of 132 kV and above are defined as offshore transmission assets and must comply with the GB grid code at the connection point between the offshore and onshore transmission system. However, German regulation defines the technical requirements for offshore WPPs at the point of connection offshore for both ac and dc export assets.

- ENTSO-E has published new sets of grid codes. It is expected that these set of new grid codes will harmonize the requirements across the European countries, and will be implemented in the internal electricity market of EU member countries by 2017.
Components of an Offshore MMC-HVDC Converter

- Offshore HVDC Converter Transformer
- Phase Reactors and DC Pole Reactors
- Converter Valve Hall
- Control and Protection Systems
- AC and DC Switchyards
- Auxiliary Systems
Offshore HVDC Converter Transformer

- The offshore HVDC station adapts its converter voltage according to the varying power flow and reactive power supply/absorption requirements. The basic principle for the voltage control at the islanded offshore power system is to keep the ac network voltage constant.

- The converter transformer provides galvanic isolation between the converter and the offshore ac network.
Converter Phase and Starpoint Reactors

- Phase reactors for MMCs in HVDC applications are typically dry-type air-core reactors.
- The converter reactors suppress the converter circulating currents and limit the rate of rise of possible fault currents.
- The star-point reactor provides the zero potential point for the dc side of the converter. This device consists of three star-connected inductors with their neutral connected to the ground, This reactor provides a low impedance path to the ground for dc from the ac side of the converter without requiring dc current flowing through the transformer windings.
Converter Valve Hall

• The MMC HVDC terminal consists of two separated valve halls.
• Each valve hall accommodates the submodule structures corresponding to three arms of the converters. The converter arms are physically made of stacking the submodules to a tower construction, which can be shaped in different manners, regarding height and length without affecting its functionality.

A 24-MW demonstrator facility valve and valve reactor hall (Courtesy of Alstom Grid – © Alstom Grid UK Ltd).
Auxiliary Systems

- The offshore HVDC platforms are normally equipped with a secondary source of auxiliary power, such as diesel power generators. The diesel generator is necessary to provide the back-up power in the event of a loss of power, during the maintenance intervals.
- Uninterruptible power supplies (UPSs) with a dc battery system are required for protection, control, and communication systems. A backup power supply with UPS is essential for the reliable operation of the HVDC terminal.
- Seawater cooling and closed heat exchangers are required for the forced cooling of de-ionized water and ventilation of the platform rooms.
- National regulations define the minimum firefighting requirements for the platforms.
Offshore Platform Concepts

• There are several different types of platforms and jackets that can be utilized for housing the offshore HVDC equipment:
  • conventional jackets (with lift- or float-over topside installation)
  • gravity-based substructures (with lift-over or integrated topsides)
  • self-installing platforms

Gravity-based platform DolWin Beta (photo courtesy of Aibel AS)
DC choppers or Dynamic Brakers

• In order to limit the propagation of onshore ac faults to the other side of the dc system, and offshore ac collector grid, a dedicated dc chopper is installed between the dc plus and minus pole at the onshore converter station.

• DBS dissipates the rated power from the wind farm for a short period, normally longer than the onshore auto-recloser dead-time. This period should be long enough to clear the fault on the ac network connected to the HVDC inverter.
Inrush Current Limiter Resistors

• In order to limit the inrush current and avoid undesired dynamic voltage sag during the energizing process of HVDC converters, normally the converters are equipped with a pre-insertion resistor bank between the converter transformer secondary side and the ac side of converter.

• The resistor limits the impact of the potential voltage distortion caused by the charging process of the dc side capacitors from the ac side.

• The resistor is only in service for 0.5–1.0 s during the initial energizing process of the scheme and thereafter is shorted out by a bypass-switch.
Recommended System Studies for the Development and Integration of an Offshore HVDC Link to a WPP

- Feasibility studies (pre-project studies);
- Technical pre-specification studies for the tendering process;
- Detailed design studies for manufacturing, front-end engineering design (FEED), including equipment rating studies (main circuit parameters);
- System integration studies;
- Steady-state load flow studies;
- Grid code compliance studies (required by the grid operators or TSO);
- Dynamic load flow studies;
- Transient stability studies;
- Harmonic analysis studies;
- Insulation coordination studies.
Ferroresonance

• Ferroresonance is a special case of resonance involving nonlinear inductances that mainly affects the functionality of transformers. Ferroresonance is characterized by high sustained overvoltages and overcurrents with maintained levels of current and voltage waveform distortion causing irreversible damage to a converter’s components.

• When the magnetic flux in a core (e.g. transformer) exceeds a certain value, resonance conditions may occur. The phenomenon occurs when the magnetic core of an inductive device is saturated, making its current-flux characteristic nonlinear. Because of this nonlinearity, resonance can occur at various frequencies. In practice, ferroresonant oscillations are initiated by momentary saturation of the core of the inductive element as a result of switching operations.

• Ferroresonance can also be initiated in other situations, such as capacitive coupling between parallel lines, ferroresonance between the VT and the power transformer’s internal capacitance, Ferroresonance can occur when an unloaded 3-phase system consisting mainly of inductive and capacitive components is interrupted by single phase means.