HVDC Technology for Large Scale Offshore Wind Connections

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Summary

The DolWin1 and DolWin2 projects, the first transmission links from the DolWin wind farm cluster in the North Sea, Germany, combines the application of well proven transmission technology and vast project experience with an unmatched realization of offshore wind integration further inland than ever before. Once completed, the 800 MW DolWin1 and the 900 MW Dolwin2 projects will integrate a total amount of 1700 MW of wind power into the German grid using the latest Voltage Source Converter (VSC) technology available, together with state of the art ± 320 kV polymeric cables, thereby reducing the overall losses while maintaining high availability and reliability.

This article elaborates on the DolWin2 project and the latest developments in VSC technology thereby presenting a scalable solution to rightfully harness renewable energy generated by offshore wind farms.

1. Introduction

The DolWin2 project will be one of the largest offshore HVDC grid connections for offshore wind farms worldwide. It uses modern HVDC technology with low losses to integrate the Gode Wind II offshore wind farm and two future wind farms into the German HVAC transmission grid. This 135 km long transmission link is based on voltage sourced converters technology, (VSC), by ABB called HVDC Light©, which use high power transistors for the conversion between AC and DC. The DolWin2 transmission link is planned to be commissioned in 2015.

The predecessors to the DolWin1 & 2 projects are the BorWin1, the Troll A Pre-compression and the Valhall

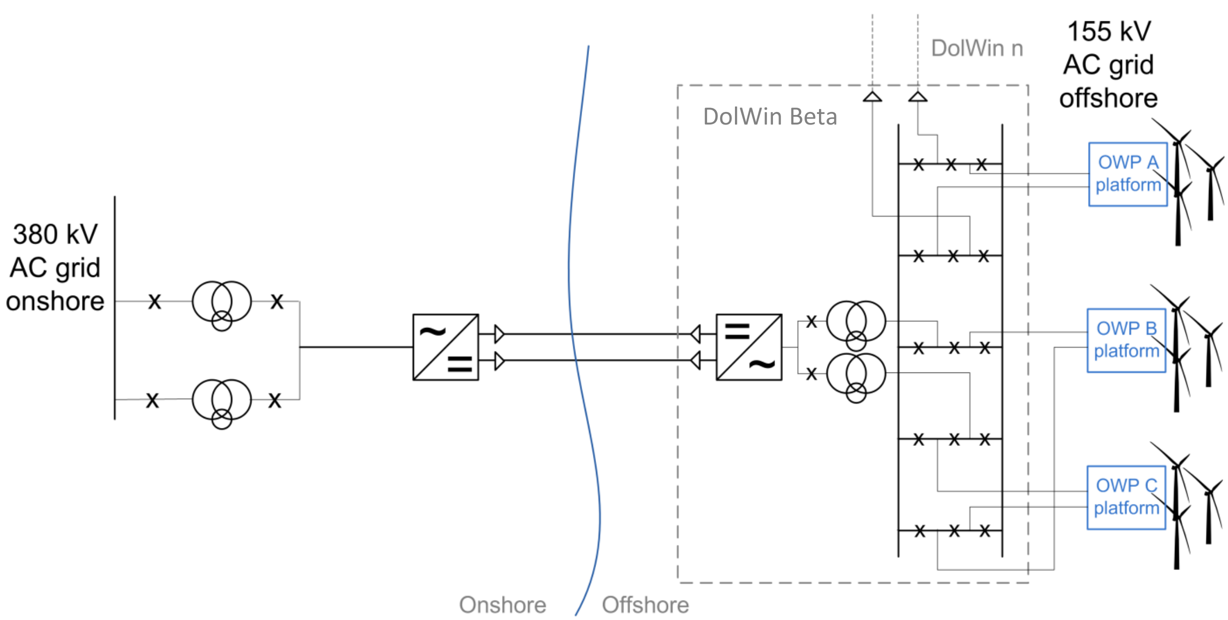

Figure 1: Principle Single Line Diagram of DolWin2

transmission projects, which also employ VSC technology. Throughout these projects, ABB has gained invaluable experience in the field of offshore HVDC installations; something that will become vital in the execution of the DolWin1 and DolWin2 projects.

2. System description and VSC technology

The DolWin2 900 MW transmission link will connect offshore wind farms located in the cluster DolWin (Gode Wind II wind farm, 400 MW, and other wind farms) in the North Sea to the German grid, located 45 km from the German North Sea coast, to the receiving station at Dörpen West, 90 km inland from the sea shore.

Gode Wind will have a total production capacity of 400 MW, and will eventually consist of 80 wind generator units, each with a capacity of 5 MW. These units feed their power into a 33 kV AC cable system, from which it will be transformed to 155 kV for feeding the HVDC VSC offshore converter station. At the receiving station at Dörpen West, the DC power is converted into AC power at 380 kV.

The HVDC VSC transmission link will operate at a DC voltage of ±320 kV, the highest voltage ever used for extruded cables, via a pair of 45 km sea cables followed by a pair of 90 km land cables. One reason for choosing a HVDC VSC link was the possibility to connect the entire transmission system far inland, closer to the German backbone grid on high power cables, without adding overhead lines. In this project, extruded cables are used, simplifying installation on land and on sea, and allowing very short time for cable jointing. The oil-free HVDC VSC cables minimize environmental impact on sea and on land.

Furthermore, the DolWin2 project has an even higher equipment redundancy level than normal HVDC monopole systems: It has parallel transformers, each capable of handling 900 MW. Further, multiple redundant sea water pumps are provided on the offshore platform.

The high-voltage converter equipment weighs around 2000 metric tons, and for the sending station is located on an offshore platform (refer to section 6). All equipment for the offshore station is installed indoors while for the onshore station all DC equipment is installed indoors. These choices ensure safe operation and minimum environmental impact.

3. Important benefits of using HVDC VSC technology for offshore transmission

The HVDC technology makes the creation and connection of remote wind farms feasible, as there are no technical limitations to the length of the cables that can be used for transporting the energy. In AC transmission, the charging current of the cables takes a significant portion of the current capability, which worsens with increasing cable length. In HVDC there is no charging current in the cables, since the voltage polarity is not changing continuously.

As the cables for HVDC are lighter than other cables, their installation onshore is more effective. Their lower weight per unit length allows the transport of longer sections in lorries, which translates into fewer cable joints. In addition, as the cables are less complex, the joints are also less complex and can be executed faster, thereby reducing the installation time and hence the visual impact on the surroundings and eventual safety issues.

An indirect but decisive advantage of HVDC cables being less complex is that their cost per MW and km will be lower than for an equivalent AC solution; partly because of the cables themselves, and partly on account of of the easier laying and jointing.

HVDC VSC converters have the inherent capability of independent control of active and reactive power flow, with total control of power from zero to full power without filter switching. This enables and supports the smooth and reliable operation of the offshore wind farm.

The HVDC links for wind farm applications have an additional feature. As is known, during AC system faults onshore, the electrical power goes to zero or close to, because the voltage collapses. To decouple such incidents from the wind farms, independently of the operation mode, fast energy absorption capability is added into the HVDC VSC system, by a device named DC chopper. The purpose of the chopper is to temporarily absorb the excess energy from the wind park which cannot be transmitted to the AC system during temporary disturbances.

The DC link decouples the wind park from faults, electrical transients and oscillations that may occur in the main grid, thereby reducing the mechanical stresses on the equipment in the wind turbines.

The DolWin2 project features a refined type of VSC technology based on many years of experience where two level converters are cascaded (see figure 2) with the aim of maintaining robustness while decreasing losses (see figure 3) and stresses on equipment.

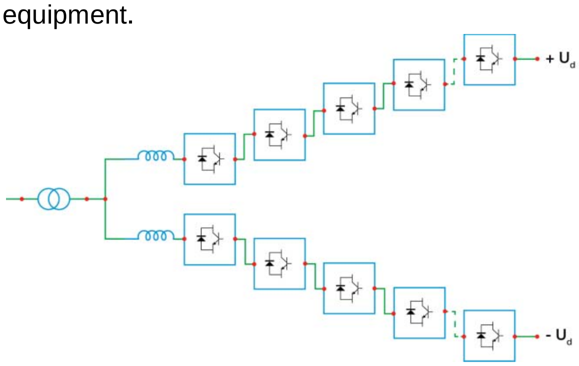

Figure 2: Cascaded two-level converter

The original two-level converter valve, together with series-connected press-pack insulated-gate bipolar transistors (IGBTs), have been the base for the development of ABB's cascaded two-level (CTL) converters. This solution consists of several two-level building blocks, as described above, also called cells (see figure 2). The creation of a nearly sinusoidal output voltage from the converter is thus enabled.

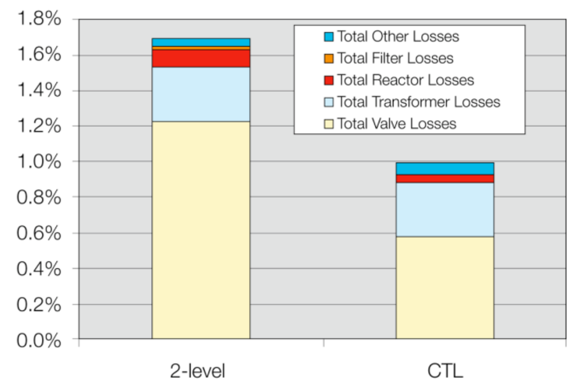

Figure 3: Losses in VSC systems [1]

While high availability and reliability are key requirements on all power transmission systems this becomes even more evident in offshore systems given the high costs of maintenance and full transmission redundancy. To achieve the best possible reliability, it is therefore vital that the key components, such as the valves, are of a robust design, with built-in redundancy, and with a minimal number of mechanically active components. Failure of one or even more of the IGBTs should not impose any limitation in the operation of the system. In the solution above, this is achieved by basic redundancy in the number of components in each cell together with short-circuit failure safe mode of the IGBT which, upon failure, safely goes into a permanent conducting mode. This results in the remaining units in the cell needing to accept a slightly higher voltage, for which they are designed, with undisturbed operation as result.

4. Expansion possibilities and VSC modularity

The plan is to gradually expand the transmission with additional HVDC links as the DolWin cluster is populated with future wind farms.

Each wind farm has its own AC transformer platform, on which the 33 kV cables arriving from the wind turbines are connected together. Using short high-voltage three phase cables, this platform is in turn connected to the converter platform, where AC power is rectified to DC. At the same time, the converter station is able to cover the reactive power requirements of the offshore network, and to regulate its frequency.

Several of the converter platforms and hence HVDC VSC systems can be connected at sea using three-phase bus bars and cables, which enable additional transmission systems to be successively integrated in parallel to the present one as the grid connection is in need of expansion in the future. Of course, integrating several platforms and HVDC VSC systems in a new AC system offshore requires advanced controls, but the present technology can handle this challenge.

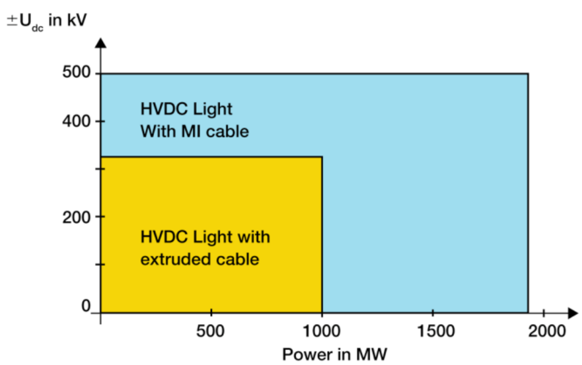

Figure 4: Rating modularity

In terms of modularity the VSC solution presented in this article is fully scalable in order to align with the specific needs of the project. With cascaded two-level converters, the DC voltage will be dependent on the number of cells used. Currently; ±80, ±150 and ±320 kV are foreseen using extruded cables making the solution reach from 100 MW to above 1000 MW in power capability (see figure 4). With mass impregnated cables, even higher ratings are possible, since their present voltage capabilities are higher than those of extruded cables.

5. Offshore transmission systems

The BorWin1 project conclusively proved that HVDC VSC is very suitable to meet offshore operating demands. The platform effectively protects the high-voltage equipment from salt and humid air and due to the modular station design is very flexible and adaptable to different platform designs as well as to future expansion.

The high-voltage equipment for offshore is standard equipment, which means that it is designed for outdoor placement. However, on the DolWin2 platform all main circuit equipment including the transformers is located indoors.

The control system is advanced in its nature, but is standard with no need for a special version for the subjected application; applications such as a special fire protection and detection system, due to strict offshore regulations, are easily integrated into the standard control system.

The HVDC VSC converter stations have "black-start" capability – they can generate a voltage with amplitude and phase controlled as desired. This feature is especially useful when it comes to starting up an offshore network. The offshore station can initially act as a generator operating in voltage and frequency control mode. It creates an AC voltage with the desired amplitude and frequency, which is ramped up smoothly to prevent transient over-voltages and inrush currents. As wind farms come on line, they are synchronized into this voltage source.

Additionally to the benefits for the offshore network described above, a VSC system also provides excellent voltage support and hence increased stability for the onshore network.

6. Platform design and installation

The high-voltage equipment, support systems and safety systems are designed for long periods of maintenance-free operation. In addition, the converter station is designed for easy access to the equipment. Housings for staff and access points for vessels are necessary parts of the overall design. Transportation paths on the platform must enable access to all equipment in a safe way and, as safety is a key issue in offshore environments, this has top priority when designing the platform and its support systems.

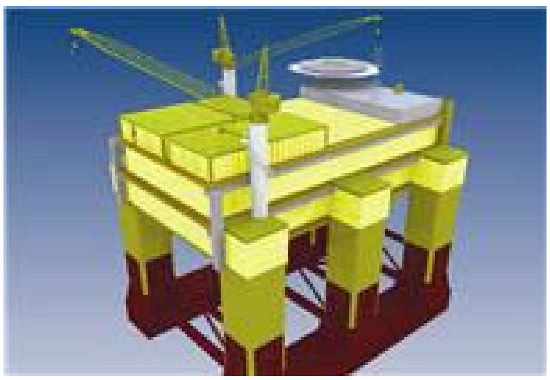

Figure 5: Offshore HVDC VSC platform

The offshore converter equipment is installed on the platform, while it is still in the construction yard. The modular concept of equipment and modules increases installation speed and minimizes construction time offshore. The platform for the DolWin beta station will have a gravity based structure, hence the installation of the platform will done without any need of listing cranes etc. The offshore parts of the construction activities are limited to the connection of AC and DC power cables. All support systems running on auxiliary diesel power are instantly operational after installation.

7. Operation and Maintenance

Offshore platforms are difficult and expensive to access. Operation and maintenance must therefore be easy and efficient, and support systems must have high reliability, automation and possibilities of remote control.

HVDC converters have always been designed with redundancy in mind. This applies to all parts - valves, cooling systems and control systems, but in the DolWin projects, this extends even to converter transformers.

The valves allow continued operation despite failure in one or several IGBT's, as described earlier. The cooling system and the control systems are duplicated as a minimum, with automatic switch-over to the stand-by system in case of malfunction. In such cases, the supervisory system is notified of the need for maintenance.

Components that can be avoided on the platform converter should be omitted, if their functions can be replaced by other means. One example of this is the transformer on-load tap changer. This mechanical device can be replaced by the extended converter voltage range, and the voltage can also be controlled by the land-based converter station.

Safety systems run continuously, including fire detection and man-over-board detection. Multiple cameras enable continuous monitoring from shore. Strict safety and security regulations, as well as awareness, are of vital importance, for example routines for helicopter landing.

The organization on land must support the offshore activities. Harsh environment puts requirements on staff to handle extreme situations, which is why staff members must have thorough knowledge of the system design and behavior when in operation.

References

[1] Björn Jacobson et al, “VSC-HVDC Transmission with Cascaded Two-Level Converters”, *B4-110 Cigré 2010*