

DOLWIN1 – FURTHER ACHIEVEMENTS IN HVDC OFFSHORE CONNECTIONS

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Summary

With the construction and commissioning of the DolWin1 project ABB and its customer TenneT has taken another big step in the Energiewende by applying state-of-the-art technology in the largest offshore wind connection ever built. ABB is commissioning a link that will transport 800 MW of renewable energy when in full operation. The project has been performed in the context of a new and emerging offshore wind segment with the additional requirements that is linked to that. ABB has built the platform showing that we can live up to the high expectations technologically and in the area of environmental requirement. ABB is also for the first time putting into operation a HVDC system at the record high voltage of +/- 320 kV. The HVDC Light® cables operate at a higher voltage than ever used before and the HVDC Light® converter is introducing ABB's new technology of a two-level cascaded converter. Furthermore this plant will enable TenneT not only to transfer power from offshore but also to use the DolWin1 link to optimize the German transmission grid. Performing an offshore project like this requires a strong organization and ABB's experience provides the foundation for a successful project completion.

With the link in operation we will see that ABB has shown how the HVDC technology plays an important part in the Energiewende and that ABB lives up to its own slogan "Power and productivity for a better world".

Background

The first commercial High Voltage Direct Current (HVDC) link was installed to power the Island of Gotland from shore by a 96 km 100 kV subsea cable in 1954. ABB has participated in the delivery of more than half of the world's around 170 HVDC links. ABB also pioneered the area of VSC (Voltage source converters). For over 15 years, ABB has successfully delivered HVDC Light® systems, based on voltage source converters. Until today, over 24 converter stations using VSC technology have been installed all over the world. HVDC Light® is a key component in the future energy system based on renewables, due to the inherent power quality features. BorWin1 was the first HVDC link to connect offshore wind farms to onshore. In 2010 ABB energized the BorWin1 link connecting wind farms to the German grid. The link has been in operation ever since and has proven the concept of offshore wind farms being connected to onshore grids via HVDC. In July 2010 ABB was awarded the DolWin1 contract in which ABB further develops the technology of offshore wind connections. With DolWin1 ABB is increasing the voltage to 320 kV and the power transmission capability to 800 MW. DolWin1 will be TenneT's second HVDC link for offshore wind farms when it will be put into operation.

Description of the DolWin1 scope

The DolWin1 project was initiated by TenneT Offshore GmbH and awarded to ABB in July 2010. The scope is an 800 MW link operating at +/- 320 kV connecting wind turbines in the North Sea to the German grid at Dörpen West. Three wind farms – Borkum West II, MEG Offshore 1, and Borkum Riffgrund 1 – with a total of 160 wind turbines are connected via AC platforms to DolWin alpha, the offshore converter platform. In DolWin alpha the 155 kV AC from the three AC platforms is converted to +/- 320 kV DC and transferred via two HVDC Light® cables to shore. The cables are terminated at the Dörpen West Converter station where the DC is converted back to AC and supplied to the German 400 kV main grid.

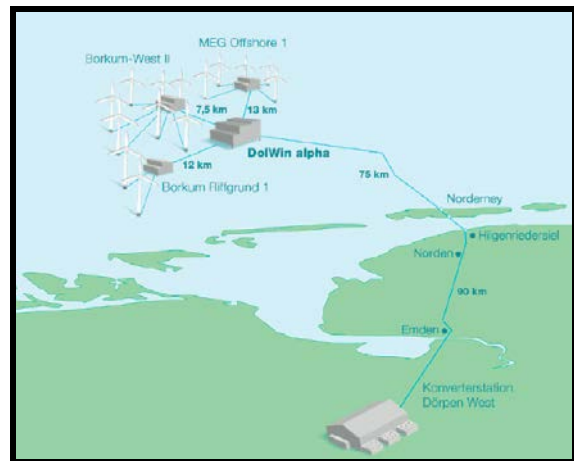


Figure 1 DolWin1 scope

Main changes from BorWin1 to DolWin1

Recognizing the growing market for offshore wind farms and the opportunities therein, ABB formed a new branch within the Grid Systems division called Offshore Wind Connections (OWC). OWC located in Västerås, Sweden, manages the offshore wind projects and is the competence centre for the platform and offshore segment. OWC was founded in 2010 and DolWin1 is one of the projects managed by the new organization. ABB HVDC and ABB HVC are sub-projects in parallel with the platform sub-project that is managed by ABB OWC.

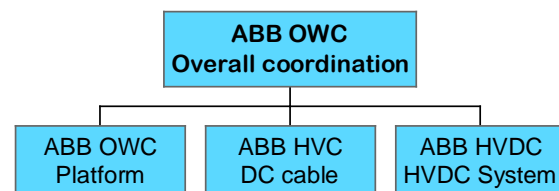


Figure 2 ABB DolWin1 organization

In DolWin1 the transmission capacity is doubled compared to BorWin1. This is made possible by increasing the converter voltage to +/- 320 kV and the voltage in the DC cable to the same level.

Furthermore DolWin1 utilizes the latest generation of HVDC Light® with lower losses, less harmonics and fewer components compared to the technology used in previous projects.

Below sections will further explain the different sub-projects and their deliveries.

Platform DolWin alpha

The DolWin alpha offshore platform was built under supervision of ABB OWC in Västerås, Sweden, by Heerema Fabrication Group (HFG) in the Netherlands. The fabrication took place at two of Heerema's fabrication yards; the topside was built in Zwijndrecht and the jacket in Vlissingen.

The fabrication of the topside started in mid-2011 and was manufactured in two modules. During April 2012 the two modules were "mated" and welded together into one unit. By building the modules in separate fabrication halls the total fabrication time was significantly reduced as the construction and outfitting works as well as the equipment installation could be done in parallel.

The overall dimensions of the topside are: 62 m long, 42 m wide and 42 m high. The total weight of the topside including all electrical equipment is approximately 10.000 metric tons. The picture below illustrates the mating operation of the two topside modules.



Figure 3 DolWin alpha "mating"

The fabrication of the jacket took less than a year and in September 2012, when the required permits for the offshore installation were received, the installation of the jacket at the offshore location in the North Sea could start. The jacket structure measures 50 m high, of which 27 m is below normal sea level. The jacket is secured to the sea bed by 6 piles each 100 m tall and with a diameter of 2.5 m. One of the design challenges was to find a solution to drive down the piles in the sea bed without exceeding the maximum allowed noise level (170 dB) in the water. ABB's Corporate Research Centre in Västerås, Sweden, was involved early in the process and by extensive theoretical calculations and practical scale tests in the lake of Mälaren in Sweden a patent pending concept for noise reduction was developed. During the actual pile driving in the North Sea the method proved to be successful and the noise level stayed below the limits set out by the German Authority BSH (Das Bundesamt für Seeschifffahrt und Hydrographie). The picture below illustrates the offshore installation of the jacket.



Figure 4 DolWin alpha jacket piling

In August 2013 the topside was ready for offshore installation. By then, the next round of permits was released and the topside had been equipped with the electrical components for the HVDC Light® converter. Due to the size and weight of the topside the towing of the barge on which the topside had been loaded onto could only take place at optimal tidal conditions in the river Oude Maas. The below picture illustrates the passing of the Botlek bridge (one of many boundary conditions for the design of the topside). The safety margin around the bridge and to the riverbed was less than one meter.



Figure 5 Passing the Botlek bridge

The offshore installations of both the jacket and the topside were performed by Heerema Marine Contractors (HMC) with the heavy lift vessel Thialf. The below picture illustrates the installed DolWin alpha platform next to the heavy lift vessel Thialf.



Figure 6 DolWin alpha installed

The final installation and commissioning works of the offshore converter station DolWin alpha will continue until energization of the complete HVDC grid connection DolWin1 within the next few months.

Working with projects in the new market for offshore wind connections has shown to be challenging for all involved parties such as customer, supplier, certifying bodies and authorities. Several aspects in offshore projects are not normally part of onshore projects.

The DolWin alpha platform has undergone a thorough certification process, required for receiving the offshore installation permit from the German Authority BSH. The certification process has been clarified during the course of the project. A substantial amount of time and effort has been spent by ABB in order to provide the requested information on design, equipment, concepts and philosophies. The knowledge and lessons learned from this work will be very valuable for ABB in future offshore projects.

Another aspect is the challenge of working in an offshore environment. A missing tool on the platform would initiate a very complex and expensive chain of activities. Equipment can for obvious reasons only be transferred from shore to offshore by either supply vessels or helicopters. With such constraints every work package to be executed on the platform has to be carefully scrutinized, documented and prepared well in advance. Small mistakes in the planning and preparation phase can quickly develop into big costs during the execution phase. From a health and safety point of view a fully mobilized emergency preparedness organization had to be in place from the first day the offshore installation works started. The emergency preparedness organization is triggered in case an accident would occur offshore. TenneT, ABB, ABB's subsuppliers, MRCC (Maritime Rescue Coordination Centre) and a helicopter company are all key players in this organization. ABB is continuously performing emergency drills with the staff onboard DolWin alpha as well as with the emergency preparedness organization to keep everyone reminded and aware of how to react in case the alarm would go off.

DC Cable

The HVDC transmission link is operating at a DC voltage of +/- 320 kV, which is a record high voltage for XLPE-insulated DC cables to be taken into commercial service. The link is connecting the converter station DolWin alpha to the Dörpen West converter station via a pair of HVDC Light® cables. Two sea cable designs are used due to different ambient conditions along the sea route. The thermal resistivity of the ground is higher in Wadden Sea which has to be compensated for with a cable with lower losses. Also two land cable designs are utilised. Extruded cables are, in contrast to paper-lapped cables, electrically insulated by extruded polymer material. This offers many advantages, such as a simpler production process, lower weight, simpler installation process due to easier jointing procedures, no maintenance and environmentally friendly features. The oil-free HVDC Light® cables minimize the environmental impact at sea and on land, which is very important because the DolWin1 cable route passes several environmentally sensitive areas.

Sea cables

Near shore, North Sea:
Copper conductor, 1000 mm²
Diameter ≈ 115 mm
Weight ≈ 34 kg/m
Route length ≈ 68 km



Figure 7 Sea cable North Sea

Wadden Sea:
Copper conductor, 1600 mm²
Diameter ≈ 125 mm
Weight ≈ 44 kg/m
Route length ≈ 5 km



Figure 8 Sea cable Wadden Sea

Land cables

Main land:
Aluminium conductor, 2000 mm²
Diameter ≈ 118 mm
Weight ≈ 14 kg/m
Route length ≈ 92 km



Figure 9 Land cable main land

Norderney, Ems:
Copper conductor, 1600 mm²

Diameter \approx 114 mm
 Weight \approx 33 kg/m
 Route length \approx 4 km



Figure 10 Land cable Norderney, Ems

The HVDC Light® cables for DolWin1 are designed and produced by ABB at its high voltage cables manufacturing facility in Karlskrona, Sweden. The cable production started in early 2011 and was finalized in mid-2012. For the sea cable, flexible factory joints are used to achieve long cable lengths to be delivered directly from the factory to the cable installation vessel. The picture below illustrates the loading of the sea cables onto the installation vessel Lewek Connector at the cable factory in Karlskrona.



Figure 11 Lewek Connector

The prefabricated cable accessories, i.e. cable joints and cable terminations were produced by ABB in Alingsås, Sweden.

The installation of land cables have been executed in close co-operation between ABB and its subcontractor GA Energieanlagenbau Nord. GA performed pegging out of cable route, excavating of cable trench, HDD drilling, cable pulling and backfilling; all under the supervision of ABB. The highly specialized jointing of the cables was handled by ABB. The picture below illustrates the placement of one of the special purpose built jointing containers at jointing site.



Figure 12 Jointing container

The land cable installation was first finalized on the island of Norderney during autumn 2011. The installation activities at main land started in March 2012 and have been performed throughout two installation seasons. The land cable installation was finalized in November 2013. Up to seven installation teams have been working in parallel to speed up the cable installation and jointing work at the over one hundred route sections. A big challenge during the work has been to adopt the installation activities to the very precise installation windows for different sections of the route due to high demands on nature protection in sensitive areas.

The installation of sea cables have been performed in three different installation campaigns under the supervision of ABB. In July 2012 the ABB subcontractor Bohlen & Doyen Bauunternehmung performed sea cable installation and trenching from north beach of Norderney to 14 m water depth in the North Sea. The picture below illustrates the cable pulling at landfall of Norderney.



Figure 13 Cable pulling Norderney

Also the sea cable installation and trenching in the Wadden Sea was performed by BoDo in July 2012 with particular attention to the protection of nature, due to very high demand on environmental care in the National park Niedersächsisches Wattenmeer.

In November 2012, the ABB subcontractor EMAS AMC performed the sea cable installation from 14 m water depth further out in the North Sea to the platform site. The installation vessel Lewek Connector is one of the largest and most advanced subsea installation vessels available. Prefabricated cable joints at 14 m water depth were installed by ABB in July 2013. The installation works at the platform DolWin alpha were finalized during autumn 2013 with cable pulling-in through J-tubes, mounting of cable hang-offs and installation of cable terminations. In order to protect the sea cables they have been buried into the seabed. The normal trenching depths are from 1.5 to 3 meters but even down to 5 m burial exists at shipping lanes. The trenching of sea cables, performed by the vessel Northern Wave, was finalized in August 2013. In general the demands for environmental considerations have been quite high and the process of obtaining the required permits requires a lot of preparations and cooperation between all parties. This has been a challenge in the DC cable subproject. Another challenge has been the limited physical space on the platform as well as the strict planning for the offshore phase. Planning and preparing for the platform works has been complex and is a factor that needs consideration in order to minimize risks.

HVDC System

The DolWin1 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.

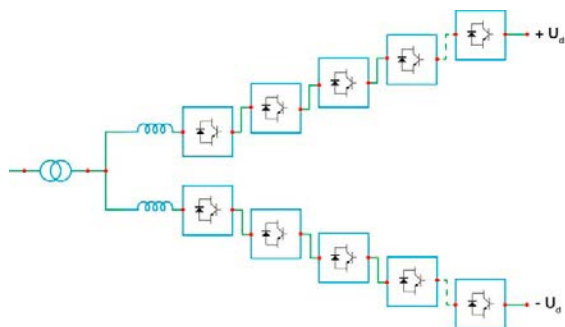


Figure 14 Cascaded two-level converter

This solution consists of several two-level building blocks, as described above, also called cells (see figure 2). By connecting these cells in series the desired voltage level can be reached. In this project the DC voltage level on the DC side is 320 kV which is a record high voltage for VSC systems. The cascaded converter allows us to better emulate a sinusoidal wave. This means that the harmonics generated by the system will be lower. This in turn means lower losses and also fewer components in the system since the need for filters is almost eliminated. In figure 3 the losses in the cascaded two-level converter (CTL) is compared to an ordinary two-level converter showing that the losses are significantly reduced. Reliability and robustness in the HVDC system is crucial for an offshore HVDC link since maintenance and repair works are expensive. In DolWin1 ABB is using IGBTs

with short-circuit failure safe mode. This means that in the case of a failure the IGBT goes into a permanent conducting mode. The system then automatically shifts over voltage to other units enabling the link to continue to operate without disturbance.

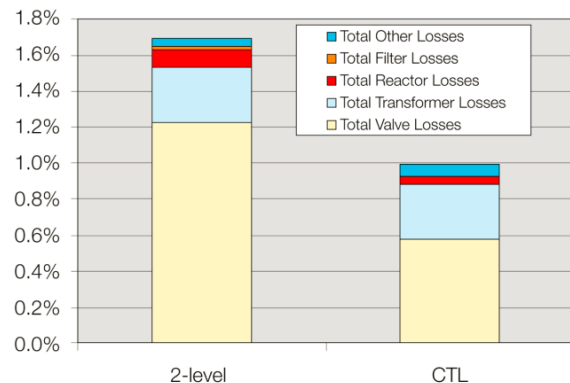


Figure 15 Losses in CTL vs 2-level converter

The DolWin1 land station is located in Dörpen some 120 km West of Bremen in northern Germany. In this location several HVDC links will be connected to the German 400 kV grid. The civil works in Dörpen was planned by ABB HVDC and performed by Matthäi Bauunternehmen GmbH under supervision of ABB. The first foundations were laid in late May 2011 and the converter building was ready for installation in November 2011. The installation works were mainly performed from November 2011 until July 2012 and pre-commissioning and commissioning was completed during the period of August to November 2012.



Figure 16 Dörpen West converter station

In December 2012 the Converter station was ready for energization. On the 13th December the converter was energized bit by bit and on the 16th December 2013 a stable StatCom operation of the Dörpen station was reached. During StatCom operation the DC cable is disconnected and the converter is used to generate or consume reactive power. Following the successful start in Dörpen ABB has performed several measurements and evaluations of the new design. This includes measurement of EMC emissions, AC harmonics, sound levels as well as measurements of voltages, currents etc. to verify the design. Furthermore the Dörpen converter station has run in continuous 24/7 operation to prove the reliability of the plant. These tests and evaluations are on-going until the final energization of the complete link.

During the fabrication of the platform HVDC equipment was lifted onto the platform and for less sensitive parts the installation could start at that time. After the mating of the platform in April 2012 a more focused installation work

could start. The first power transformer was lifted onto the platform in May 2012. Installation, pre-commissioning and commissioning of sub-systems for the HVDC equipment has been done from May 2012 until sail-out in August 2013. Final installation and commissioning of the HVDC equipment is taking place offshore.

There are several factors that make installation on a platform more complex; regulatory, logistics, coordination etc. The offshore industry adds a number of requirements in addition to the requirements for the transmission industry. This has mainly to do with different offshore standards in certain areas e.g. fire fighting on a platform, but also offshore certification for various equipment e.g. lifting devices. Working on a platform with several decks also makes the logistics more complex compared to a normal HVDC station. Large cranes are needed and coordination with other parties is needed. Furthermore the large workforce on the platform has required smooth cooperation between all parties. The size of the platform has been optimized in several ways, this also means that the space on the platform is limited compared to a typical land station for HVDC.



Figure 17 Lift of a power transformer onto DolWin alpha

TenneT has strict regulations on Grid Code Compliance for the connecting HVDC link. This includes harmonics and flicker, behaviour in the event of grid faults, reactive power exchange, static and dynamic stability. Through several studies, reports and field measurements ABB has proved that all grid code requirements can be fulfilled.

As mentioned above the DolWin1 link will have low levels of harmonics and flicker. This is a key part in fulfilling the grid code. Another key part is support in the event of a fault. The DolWin1 link will support the German Grid in the event of a disturbance in the grid. This is achieved by the HVDC control system where the link's behaviour during fault clearance can be determined. E.g. reactive power support is given during short faults to make the voltage recovery after a fault smoother. A VSC system also provides excellent voltage support and hence increased stability for the onshore network

References and further reading

- [1] HVDC Technology for Large Scale Offshore Wind Connections (Nandan Mahimkar, Gunnar Persson, Claes Westerlind, ABB AB) presented at Smartelec 16th April 2013 in Vadodara, India
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- [3] Technology Developments and Plans to Solve Operational Challenges Facilitating the HVDC Offshore Grid (Magnus Callavik, Michael Bahrman, and Peter Sandeberg) presented at 2012 IEEE-PES General Meeting, 22 July, San Diego, USA 2012.