Deep Water Cable Solutions - Cable System Development and Installation

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SUMMARY

The need for new renewable power production, electrification of offshore platforms and interconnections for exchange of energy between countries has increased the market for HVDC cable systems. In addition the development of Voltage Source Converters (VSC) has opened a new market for HVDC cable systems because of the ability of the VSC converter to feed power to remote islands and offshore platforms as well as to provide reactive load to a network for stabilization purposes. The power requirement for HVDC links varies a lot from 78 MW for the interconnection to the Valhall platform in the North Sea to 1000 MW at 500 kV for the Sardinia to Italy interconnection. The large laying depth for major projects has influenced cable design and laying and repair technologies.

The paper will present the development and qualification testing that has been performed in some of the latest projects. It will also discuss the need for advanced laying and repair procedures of HVDC power cables for large water depths.

KEYWORDS

HVDC mass-impregnated cables, HVDC oil filled cables, deep water cable systems, installation.

1 Introduction

HVDC cable links with Line Commutated Converters (LCC) has been in operation for more than 50 years and have been very important for making connections between separated, but relatively strong AC grids. During the 90'ies a new type of converter, Voltage Source Converter, was introduced to the market. This converter does not need local power supply for commutation and can be used in links to offshore platforms and isolated, remote islands. The market for HVDC cables have therefore increased significantly over the last years.
The first large HVDC cable link was installed in 1954 between the island of Gotland and the Swedish mainland, Gotland 1. The cable used for this interconnection was of the mass-impregnated paper insulated type and had an operating voltage of 100 kV and a power capacity of 20 MW. This cable type has been further developed over the years and is now available for voltage levels of 500 kV and power capacity of more than 800 MW per cable.
Paper insulated cables impregnated with low viscosity oil have also proven to have good properties as HVDC cables and can be used for HVDC links at more than 500 kV. This cable technology can be used for land cables or for short submarine crossings due to the need for hydraulic systems.
Over the last decade HVDC cables with extruded insulation has been introduced in links using VSC technology. These cables were first introduced at relatively low voltage levels as for the Visby system at 80 kV, but the voltage level has increased over the years and cable systems have been reported tested at voltage levels up to 320 kV [5].

The development of the cable technology has not only been in the direction of higher voltages and higher power transfer capacity. Challenges have also been related to installation at deeper waters and in challenging sea current conditions. This paper will present the development and qualification testing that has been performed in some major projects. It will also discuss the need for advanced laying and repair procedures of HVDC power cables for large water depths.

2 Low pressure oil filed cables as HVDC cables

Paper insulated oil filled cables are very good for HVDC transmission. The insulation system in these cables is constantly under oil pressure to avoid formation of cavities when the cables are cooled down and the oil contracts. We have qualified and installed two cable systems for use in AC and DC operation, the Aqaba project and the Spain-Morocco project. Both projects were challenging because of the large installation depth and the sea current conditions.

2.1 The crossing of the gulf of Aqaba

In May – June 1997 four oil filled cables were installed across the Gulf of Aqaba. The Cables were installed to a record water depth for this kind of cables of 850m. The cables were qualified for 420 kV as AC cables and for 400 kV voltage level in DC operation. The cables are operated as AC cables, but the power transfer capacity of the 4 cables can be increased from 550 MW to 2000 MW by switching to DC operation. More details about the project can be found in [3].

2.2 The Spain - Morocco interconnection

The first interconnection between Spain and Morocco was installed in 1997. This interconnection consisted of 4 cables that were installed at a maximum water depth of 615m.

A contract for 3 new cables was awarded in 2003. The cables were qualified for operation at 420 kV AC and for 450 kV DC. The power transmission in AC operation is 700 MW and can be upgraded to 2000MW by switching to DC operation. More details about the cable link can be found in [4].

3 Mass-impregnated HVDC cables

Mass-impregnated cables do not need oil feeding from the ends and has as such no limitation in length. The compact design is also an advantage for deep water applications.

3.1 The Spain – Mallorca project (Cometa project)

A 400 MW HVDC link is being constructed between the Spanish mainland and the island of Mallorca. The link will be operated as a bipole with two HVDC mass-impregnated cables at 250 kV voltage level and with a separate XLPE insulated metallic return conductor.
The main challenge in this project is the large depth of the route. Figure 1 shows the route profile. The figure shows that approximately 50% of the route is at a water dept below 1000m and that there are several rather steep slopes along the route.

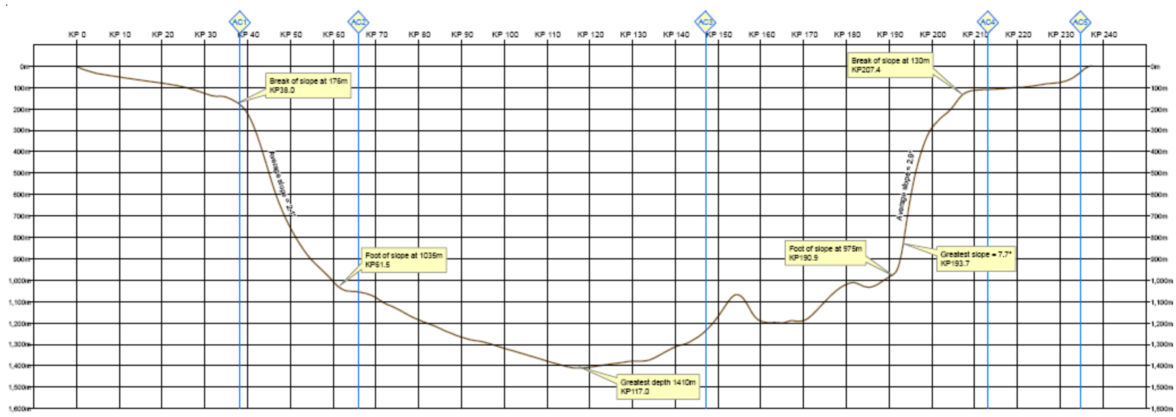

Figure 1. Cable route profile for the Spain-Mallorca HVDC project.

3.1.1 Cable designs

The cable designs have been optimised to be able to install the whole length in one laying campaign. The HVDC cables have a copper cross section of 750 mm2. A design with a single layer of flat armour wires was chosen for the shallow part of the route close to both shore ends. This design will be used to approx. 200 m water depth where a second layer of flat wires will be added to the cable. Figure 2 shows the cross section of the deep water cable.

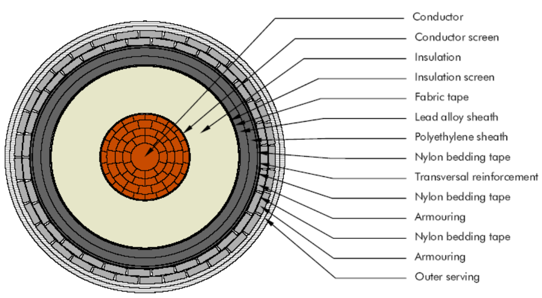

Figure 2. Design of deep water cable.

3.1.2 Qualification testing

The installation depth for this project is beyond previous experience so a rather extensive qualification program was part of the contract.
Type testing was performed according to the Cigre recommendations published in Electra No. 171 "Recommendations for Mechanical tests on Sub-Marine Cables" [1] and Electra No.189 "Recommendations for Tests of Power Transmission DC Cables for a Rated Voltage up to 800 kV" [2].
The single wire armoured shallow water cable including a flexible repair joint was subjected to a mechanical tension of 64 kN during the tensile bending test. This test was designed to cover installation down to 200 meters.
The deep water double armoured cable including a flexible repair joint was subjected to a tension of 440 kN during the tensile bending test. The test was designed to cover a repair at the deepest part of the cable route, i.e. at 1485 meter water depth.

After the mechanical tests both cables including joints was subjected to electrical type testing according to [2]. Only testing to maximum conductor temperature was performed because of the relatively warm sea bed in the Mediterranean Sea.
Both cable systems passed the tests in the type tests.

3.1.3 Sea trial

The qualification test program also included a full sea trial on the shallow water cable including a flexible repair joint and the deep water cable including a flexible repair joint.
The sea trials were performed in the Pacific Ocean approximately 15 nautical miles from Japan as this was the location of the Nexans Skagerrak vessel at that time. The shallow water cable was laid at approximately 260 m water depth and the deep water cable was laid at approximately 1500 m water depth.

After the sea trials the cables were subjected to a HVDC test at 1.4 Uo according to [1]. Both cable lengths including joints passed the test.

3.1.4 Installation and protection

The Nexans HVDC cable will be installed with Nexans Skagerrak and the cables will be buried in the sea floor to a water depth of 800m. Protection will be performed with the Capjet water jetting system.

The cables for the Cometa project are currently under production and the cable system is scheduled to be completed in 2011.

3.2 The NorNed project

The NorNed project is the world's largest cable project and the total cable length is approximately 1160 km. Nexans Norway has manufactured the deep water cable system designed for a maximum water depth of 420m and the land cable system in Norway. The deep water cable system consisted of two lengths of 156 km and the land cable system was two lengths of 1,5 km, transition joints and terminations. The voltage level for the NorNed cable was 450 kV and the conductor cross section of the deep water cable was 700mm^2. The cross section of the land cable was 760mm^2.
No qualification testing of the deep water cable system was performed in this project because the designs were covered by previous type tests.
The link went into operation in May 2008.

3.3 The Sardinia – Italy project

A very large HVDC link is under construction between the island of Sardinia and the Italian main land. The rating of the system in 1000MW and the voltage level for the bipole is 500 kV. The total length of cable is approximately 840 km out of which Nexans Norway is supplying 241 km. This cable is designed for installation down to 400 m water depth.
The cross section of the copper conductor is 1000mm^2 and the insulation thickness is 20 mm.

3.3.1 Qualification testing

Type testing was performed according to the Cigre recommendations published in Electra No. 171 “Recommendations for Mechanical tests on Sub-Marine Cables” [1] and Electra No.189 “Recommendations for Tests of Power Transmission DC Cables for a Rated Voltage up to 800 kV” [2] plus project specific test requirements.
The mechanical test was performed for an installation depth of 400m. The electrical test was performed in warm conditions in order to reach the maximum conductor temperature during load cycling. There was no test at low ambient temperature because of the relatively warm conditions in the Mediterranean Sea.

The electrical tests were extended after the Cigre test with additional polarity reversals. A total of 1000 polarity reversals (60 polarity reversals specified for the Cigre test) were performed on the cable system after the normal type test program. All polarity reversals were performed at the voltage specified in the CIGRE test (1.4 Uo) and the test was completed by superimposed impulse testing.
The cable system withstood all the tests.

4 Installation of HVDC cables at deep waters

4.1 The Skagerrak installation vessel

The Cable laying vessel Nexans Skagerrak has been extensively used for installation of the world largest submarine cable systems the past years. With a cable carrying capacity of 7000ton on a rotating turntable, and laying machinery capable of 50 ton tension, the dynamically positioned vessel is one of two vessels in the world for installing long HVDC cables. For deep cable laying, the cable capstan with a diameter of 10m is used. This ensures control of the laying tension without exerting high sidewall loads on the cable. Likewise, the cable exits the vessel over a continuously revolving wheel to minimise abrasive forces.
Five powerful thrusters ensure the dynamic positioning of the vessel is upheld in severe weather conditions. The system is also mandatory for precision laying required when cable is to be installed in congested areas, crossing pipelines etc.
The vessel is a versatile installation tool, and has equipment for installing FO cable strapped to the main cable or simultaneously laid at a distance apart. With its 40 ton capacity A-frame and supporting winches it is also used for installation of oil and gas field cable systems.
With advanced sensors the as-laid data and tension are logged continuously during the laying operation. Monitoring of the cable touch down on the sea bed is performed by a remote operated vehicle (ROV) equipped with TV cameras.
For cable installation in deep water with high currents, the precision laying tool “CapTrack” can be used. The Captrack is a remotely operated guide weight system, which is attached onto the cable and which can move along the cable at a certain distance above the sea bed during laying. With a comprehensive suite of cameras, sonar’s, lights and thrusters, it can be used for exact touchdown monitoring and precision cable guidance. On the Spain-Marocco project with currents up to 5 knots, this system greatly reduced the freespans during laying, in turn

reducing the risks for Vortex Induced Vibrations (VIV) problems and expensive rectification work. The CapTrack was a successful part of the Spain-Mallorca sea trial down to 1500m and will be used on this project.

Integration of precision laying equipment and burial tools on one vessel has proved to be a cost efficient solution when system locations are as far between as Canada and New Zealand. Figure 3 shows a picture of the Nexans Skagerrak.

Figure 3. The Nexans Skagerrak installation vessel

4.2 Protection of cables by water jetting

The protection level required for cables on the seabed is usually expressed as the BPI (Burial Protection Index). The BPI expresses the relative protection burial affords in soils of different stiffnesses against certain types of dangers. Figure 4 shows the required burial depth to protect the cables from different objects as function of composition of the sea floor. The table is taken from [6].

Threat	Hard ground (clay >72kPa, rock)	Soft-firm soils (sand, gravel, clay 18-72kPa)	Very soft-soft soils (mud, silt, clay 2-18kPa)
Trawl boards, beam trawls, scallop dredges	<0.4m	0.5m	>0.5m
Hydraulic dredges	<0.4m	0.6m	N/a
Stow net fishing anchors	N/A	2.0m	>2.0m
Ships' anchors up to 10,000t DWT (50% of world fleet)	<1.5m	2.1m	7.3m
Ships' anchors up to 100,000t DWT (95% of world fleet)	<2.2m	2.9m	9.2m

Table 1. Nominal required burial depths to place cable below threat line for different threats and soils (these figures include a 33% safety factor on actual threat penetration)

Figure 4. Required burial depth for protection as function of soil composition, from [6].

Thus it is necessary to both assess the seabed conditions and the activities that constitute the threat of external damage to the cable in order to specify the burial depths and methods. A consequence is that the BPI will remain constant for the same threat but the burial depth requirement will vary with the soil type along the route. The Burial Assessment Survey

should not only give answers to the soil type, stiffness and layers along the route, but also decide through a desktop study the threats existing along the route.
For deep water applications, the threats from fishing gear and anchors are non-existing and consequently a burial operation can be largely omitted. However, for many cable systems in more shallow waters, burial is mandatory due to the existing threats for mechanical damage along the route.
Burial using jetting techniques is a fast and efficient way of achieving burial depths of up to 3 meters in soft clay and sand. By means of water jetting swords that is lowered on each side of the cable, the seabed material is fluidised and the cable is sinking into the trench. This is also an environmentally friendly solution as the disturbance of the seabed material is minimal. The natural movements of the sediments quickly restore the seabed to a natural state. The CapJet system has been offering fast, and safe, remotely operated jetting of cables since 1988. Fully integrated with heave compensated launch and recovery system, state of the art control room and rated to operate at depths to 1500m the CapJet system is easily mobilised on a variety of DP vessels. When recovery of cables is required, the CapJet is easily reconfigured to perform dredging tasks.

Figure 5. CapJet 1 MW ready for deployment with its launch and recovery system.

4.3 Repair of deep water cable links

Cable repairs are relatively infrequent and are almost always due to an external mechanical damage to the cable. A complete repair consists of fault location, cutting, recovering, inline joint, laying spare cable, joint to the second cable end and laying a hair pin loop.
For deep water cable systems there are certain aspects to consider when engineering a repair operation:

1. Cable recovery: ROV operated cutting devises and clamps for pulling the cable from the sea bed is required. This cable clamp can be allowed to sacrifice cable integrity. By initiating the recovery process in moderate water depths (<300m) existing tools can be used.
2. Mechanical stresses in connection with hairpin lowering of the second joint will be too large for ordinary cable repair vessels in very deep waters, for example 1500m for the Cometa project. A possible solution is to cut the cable in rather shallow waters, recover the cable to the fault area, perform an in-line joint, relay from in-line joint in deep water and to perform hairpin loop joint in moderate water depth (<300m). Most of the existing cable is being reused for this laying operation. This means that there will be a second in-line joint before the hairpin loop joint in order to add extra length of cable.

The Cometa project sea trial gave valuable insight into the limits of the existing repair scenarios, and forms the basis for developments in the above mentioned areas. Figure 6 shows the principle for a repair of a fault at very deep water.

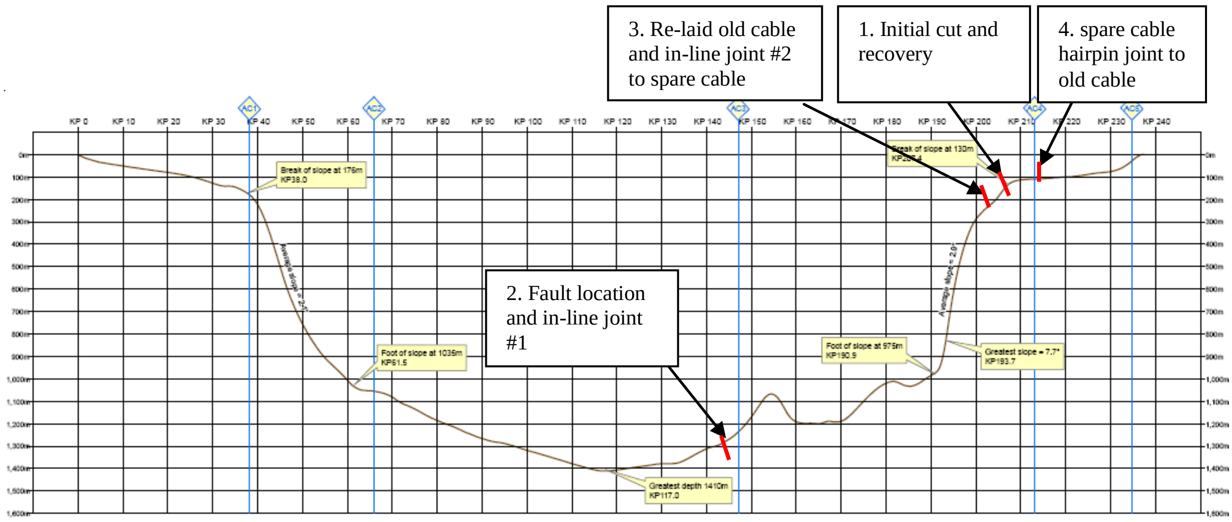

Figure 6. Principle for repair of a fault in very deep waters.

5 Conclusion

The Spain-Morocco and the Aqaba project were ground braking projects for fluid filled cables at large water depths. Requirements from new projects have also lead to qualification of the mass-impregnated cable system for very deep waters. We have just qualified the cable system for the Cometa project for a maximum water depth of approx. 1500m.
Installation of deep water cable systems is very demanding for the equipment and for the operators. If a fault occurs in very deep waters one may have to cut the cable in shallow waters, retrieve the cable until the fault area, remove the damaged cable section, make an inline joint, relay the cable, joint in a spare cable of necessary length and then install a hairpin joint in shallow waters.

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