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QUALIFICATION, SUPPLY AND INSTALLATION OF THE WORLDS FIRST 420 KV XLPE SUBMARINE CABLE SYSTEM IN NORWAY

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ABSTRACT

The worlds first 420 kV XLPE insulated submarine cable link has been installed from the mainland grid to the island Gossen for power supply to the Ormen Lange gas processing plant. This paper describes the background for selection of a 420 kV XLPE insulated cable system and the extensive qualification testing that has been performed to verify the cable system. The design of the cables and accessories is also described. The cable system was installed in summer 2006 and subjected to an after installation test at 1.7 Uo, 374 kV, before it was energized.

KEYWORDS

420 kV XLPE cable system, type testing, prequalification testing, installation, after installation testing

INTRODUCTION

Outside the west coast of Norway large gas resources has been found. The Ormen Lange gas field exploration is planned to be a main gas supplier to Great Britain. A large gas processing plant is under construction at Nyhamna on the island Gossen. There are other large consumers in the region which has lack of electrical generating capacity. To improve the power supply to the region Statnett has built a new 100 km long 420 kV overhead line and a new transformer station at Fraena on the mainland.

The power supply to the gas processing plant is built as a radial extension from Fraena sub station to the new Nyhamna substation on Gossen.

The 420 kV radial extension includes 6 km overhead line, Hamneset transition compound, 420 kV submarine cables, short land cable sections and the new Nyhamna sub station on island Gossen.

In the procurement process Statnett invited suppliers to tender oil-filled cable solutions as a base case with XLPE cable solutions as an alternative. In the negotiations with Nexans it was agreed to use the XLPE solution as base case and with oil-filled cable as a back-up solution in case the progress in type tests and fatigue tests was deemed to be unsatisfactory and not concluded within a defined milestone.

Statnett SF has been responsible for pre-engineering, procurement and building of the industrial radial in agreement with Hydro representing the owners in the gas field exploration. Hydro and partners in the Ormen Lange license will be owners of the 420 kV radial when all construction work has been finalized.

AMBIENT CONDITIONS AND FUNCTIONAL REQUIREMENTS

The power requirement for the processing plant is planned to be 200 MW as large compressors have to be installed after some years. Offshore field developments in the future may cause need of more power and after evaluation of various potential future developments in the area, the transmission capacity of the cable link was defined to be 1000 MW.

The submarine cables are crossing a straight at maximum water depth 210 m with steep slopes approx. 30 ° towards landfalls on both sides. Heavy wave action may occur at landfalls. Consequently a special protection with pre-installed PE pipes has been chosen near-shore at landfall down to 10 m water depth. These pipes were finally filled with bentonite to secure the required transmission capacity.

At one landfall the routing had to have a significant change of direction at top of the slope. An under water hang-off arrangement was designed and installed at 25 m water depth to prevent sliding of the cables.

As the power supply is a radial cable link it was decided to install a spare cable with completed terminations in both ends. The SF_6 switchgear in Nyhamna substation has been designed with a system that enables fast change between each main cable and the spare cable.

Fatigue testing of the lead sheath of the XLPE design was to be performed to verify the 40 year design life required for cables, accessories and components.

As part of an enhanced QA regime it was concluded to include an AC test of all cable lengths with a maximum stress at the conductor shield of 26 kV/mm in the factory.

TECHNICAL SOLUTION

The design of the cable system was based on Nexans experience from EHV XLPE/oil filled underground cables and the long experience with EHV submarine oil filled cables. Land cable design was used in 400-500 m long land sections on each side. Transition joints were installed in joint locations close to each landfall. Due to very steep slope at Nyhamna landfall the jointing pit was located some 70 m from the landfall close to top of the slope, see Figure 1. The land sections were short enough to allow use of single point bonded underground cables.

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Figure 1. Land fall at Nyhamna.

Submarine cable design

The submarine cable design was based on previous experience from XLPE and oil filled cables.
The cable system had to be designed to carry 1000 MW at a power factor of 1.0 continuously. The limiting parts for the submarine cables were the landings and the short onshore part to the transition joint pits. This requirement was obtained by using 1200 mm^2 round stranded copper conductors and double armour of flat copper wires with a cross section of approximately 1930 mm^2. The spacing between the submarine cables between the shore and the transition joint pits had to be minimum 3.5 meters at a burial depth of 0.8 meter.

A drawing of the submarine cable is shown in Figure 2. The conductor is a traditional design for submarine XLPE cables with round wires stranded in several layers and filled with a semiconductive water blocking compound in the interstices. The insulation system consists of a supersmooth conductor shield, an insulation of superclean XLPE and an insulation shield. The insulation system was applied in a quadruple cross head in a vertical extruder line. Both curing and cooling were done in an atmosphere of dry nitrogen. Water swellable tapes were applied between the insulation system and the lead sheath in order to prevent water penetration in case of a puncture of the lead sheath. The lead sheath is alloy F3 applied in a discontinuous ram press. A plastic sheath of semiconductive polyethylene was applied on top of the lead sheath. The armour consists of two layers of copper wires embedded in bitumen. The lay length of the two layers was chosen to make a torsion balanced cable design. Two layers of polypropylene yarn were applied outside the armour as corrosion protection.

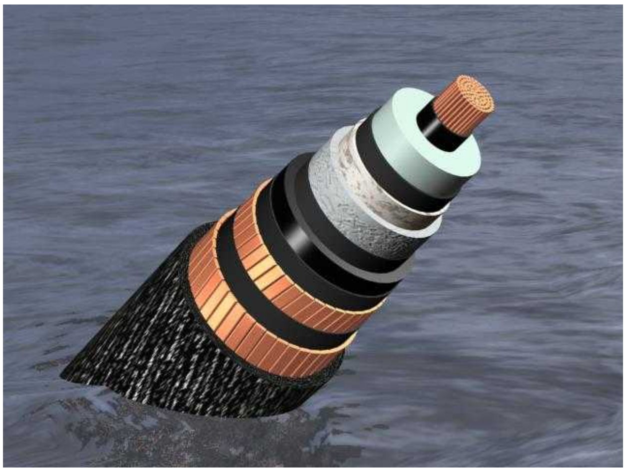

Figure 2. Drawing of the submarine cable.

The main data for the submarine cable is shown in Table 1.

No.	Constituents	Nominal thickness mm	Nominal diameter mm
1	Conductor, stranded copper wires, watertight	91x4.10 ⌀	43.7
2	Conductor shield		
3	Insulation, XLPE	28.0	103.7
4	Insulation shield		
5	Semiconducting water swellable tape		
6	Lead alloy sheath	3.6	116.9
7	Inner sheath, semiconducting polyethylene	3.4	
8	Bedding tape, nylon tape		
9	Armour, flat copper wires	50x7.5x2.5	
10	Bedding tape		
11	Armour, flat copper wires	53x7.5x2.5	
12	Outer serving, polypropylene yarn and bitumen		144

Table 1. Main data for the submarine cables.

Underground cable design

The design of the underground cables is identical to the submarine cables up to and including the lead sheath. On the underground cables the semiconductive polyethylene sheath has been replaced by an insulating sheath with a nominal thickness of 4.7 mm. The insulating sheath has a thin extruded semi-conductive layer outside to enable voltage test of the sheath to verify single point bonding performance. A drawing of the underground cable is shown in Figure 3.

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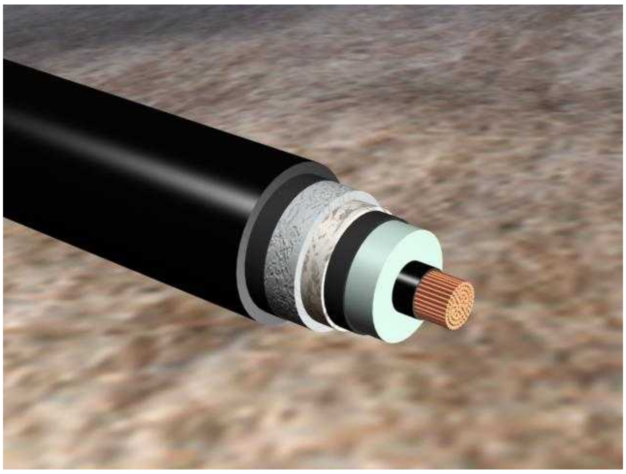

Figure 3 . Drawing of the underground cable.

Accessories design

Underground cable accessories

The design of the accessories for the underground cable system was based on prefabricated components that had been through type tests and long term tests before.

The transition joints were made with prefabricated EPDM joint bodies with a heavy outer protection containing a preinstalled shield break. Figure 4 shows a picture of the transition joints during installation. The shield break insulation was designed for 125 kV impulse voltage because the separation between the transition joints was above 3m.

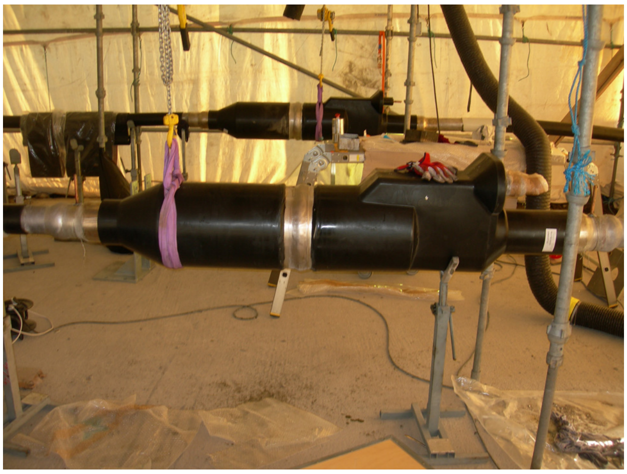

Figure 4. Transition joints under erection.

On Nyhamna the cables are terminated in a SF_6 insulated substation. The GIS terminations are of traditional design with EPDM stress cone inserted into an epoxy insulator filled with silicone oil. The silicone oil is pressurized from pressure tanks and each termination has a pressure sensor and predefined alarm levels in case of significant changes in pressure.

In Hamneset transition compound the cables are connected to an overhead line. The cables are terminated with SF_6 filled composite outdoor terminations placed inside a concrete bunker. The electrical stress is controlled by EPDM stress cones. All terminations are equipped with pressure sensors with predefined alarm levels in case of significant changes in pressure.

Figure 5 shows a picture of the outdoor terminations inside the concrete bunker.

Figure 5. Outdoor terminations at Hamneset.

Submarine cable accessories

The submarine cable length is only approximately 2.4 km so the cable lengths could be produced without factory joints. However, repair joints had to be qualified to enable a repair of the submarine cable system. The conductor joint on the repair joins was made with compression ferrules. Similar prefabricated EPDM joint bodies as used for the transition joints, but without shieldbreak, were used to form the electrical insulation system. The lead sheath was reinstated over the prefabricated joints and reinforced. A brass tube was used for mechanical protection of the joints and as an axial tension member during installation. Brass was chosen in order prevent corrosion problems together with the copper armour on the cable. The armour wires were connected to armour blocks at the flanges of the brass tube and the armour wires were soldered inside the tube to ensure continuity of the wires. Bending stiffeners were used on the ends of the brass tube in order to control the bending radius of the cable close to the joint. Figure 6 shows a picture of a joint ready for mechanical testing.

Figure 6. Repair joint ready for mechanical testing.

QUALIFICATION TESTING

An extensive test program was established at the tender stage in order to qualify the 420 kV XLPE cable system for this project. Mechanical testing was performed according to

the CIGRE recommendations in Electra No. 171 “Recommendations for Mechanical Tests on Sub-marine Cables” [1].
As there are no existing test recommendations for EHV submarine cable systems, the qualification test program was based on the CIGRE recommendations for HV cables published in Electra No. 189 “Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage above 30 (36) to 150 (170) kV” [2] and the IEC standard for EHV underground cables, IEC 62067 [3].
In addition to the mechanical and electrical testing specified in these recommendations/standards, tests were performed in order to verify the fatigue life of the lead sheath for 40 years lifetime.

Type tests

The following components were subjected to type testing:

- Land cable
- Submarine cable
- Transition joint – cross bonding joint
- GIS termination
- Outdoor termination
- Submarine repair joints

A total of four submarine repair joints and 2 transition joints were type tested in order to prove reproducibility.
The mechanical tests of submarine cable and submarine repair joints were performed at a tension of 116 kN corresponding to a installation water depth of 210m according to [1]. The test was performed at a bending diameter of 5 m. As the repair joints were of rigid design they were not spooled onto the wheel during mechanical testing, but they were spooled until the bending stiffener touched the wheel. This test reproduced the stress the joints will experience if installed.
The bending test on the underground cable was performed at a diameter of 4.3 m.

Water penetration tests on the submarine cable were performed on the conductor and under the lead sheath according to CiGRE recommendations [2]. The cable passed both tests.

The electrical type testing was performed according to the standard for underground cables [3] without current in the armour. To verify that the repair joints can withstand the high induced armour current, one joint was subjected to thermal cycling by application of full conductor current in the armour after completion of the standardized test sequence.

Figure 7 shows a picture of a test loop with a repair joint and two outdoor terminations in the HV laboratory. All objects passed the electrical type tests.

Figure 7. Type test loop in the high voltage laboratory containing submarine cable, repair joint and outdoor terminations.

Fatigue testing of lead sheath

The lead sheath on submarine cables at large depths will always be squeezed towards the insulation system by the outer water pressure. As the thermal expansion of the insulation system is rather large, especially for EHV cables, this may lead to fatigue failure of the lead sheath.
The expansion coefficient for the insulation material was measured and the maximum expansion of the lead sheath on installed cable at large depth was calculated to be 0.33% when the load varied from 25 % to 100%. The requirement was that the cable should be able to withstand this cycling for 40 years with a margin of 20%, i.e. 17520 cycles.
In order to verify the fatigue properties of the system lead sheath was extruded onto perforated tubes with the same dimension as the insulation system of the cable. A plastic sheath was extruded on top of the lead sheath. The objects were inserted in a test rig and hydraulic pressure was used to expand the lead sheath to the required strain and to collapse it towards the perforated tube again. Figure 8 shows a picture of the test rig.

Figure 8. Test rig for fatigue testing of metallic sheaths.

The tests were performed with approximately 0.35% strain in the lead sheath. None of the test objects experienced fatigue failure before 17520 cycles.

Long term test

After completion of the successful type test program, erection of a long term test at the outdoor test facility in Calais could start. The following official objects were included in the long term test loop:

- Land cable
- Submarine cable
- Transition joint – cross bonding joint
- GIS termination
- Outdoor termination
- Submarine repair joints

In addition to these official test objects for the Ormen Lange Grid connection a lapped and moulded factory joint was also included in the test loop. This joint was developed just before the test started and it had not been type tested before. It was included to get experience and knowledge about factory joints on this voltage level.
The prequalification program is performed according to IEC 62067.

The prequalification test is not completed before this paper is submitted, but the status is 7735 hours under voltage and 175 thermal cycles. The development factory joint that was included in the long term test experienced a breakdown after approximately 7300 hours under voltage. The dissection revealed that the reason for the breakdown was an irregularity in the conductor screen at the interface between the cable and joint material.

QUALITY ASSURANCE DURING MANUFACTURE

The quality assurance and testing during manufacturing of the cables were basically performed according to the CIGRE recommendation for HV submarine cables [2] with modified test requirements.
Samples for impulse testing and PD measurement were taken from start and stop of each extrusion run. The minimum impulse voltage requirement was 1425 kV and there should be no measurable discharges.
The submarine cable lengths were subjected to a HV AC test before the armour was applied. The test requirement was 480 kV AC for 1 hour which corresponds to a maximum stress at the conductor shield of 26 kV/mm. After armouring the submarine cables were tested again at the IEC [3] level of 440 kV for 1 hour.
The underground cables were also subjected to the test at 480 kV for 1 hour before shipment to site.

The prefabricated joints and stress cones were also subjected to HV tests before they were installed in the cable system.

INSTALLATION AND PROTECTION

Installation of the submarine cables was done with the cable laying vessel C/S Nexans Skagerrak, see Figure 9.

Figure 9. Cable laying with C/S Nexans Skagerrak.

The vessel has a capacity of 7000 tons of cable and is equipped with a dynamic positioning system. An ROV was used for touch down monitoring during the laying operation. The submarine cables were pulled into 200 m long pipes in the wind and wave exposed landfalls at Hamneset. Due to a rather steep slope from 30 to 200 m water depth on the Nyhamna side, the cables were mechanically secured to the sea floor on the top of the slope.
The cables were protected by jetting with the Capjet system to a depth of up to 1.0 m depending on the bottom soil conditions.

The underground cables were installed in trenches in flat formation with spacing between the cables of 0.8 m and a burial depth of 0.8 m. Direct grounding was done at the terminations and via surge arresters at the transition joint pits.

AFTER INSTALLATION TESTS

In order to verify that the installation of cables and accessories had been successful the whole cable system was subjected to an AC voltage test using variable frequency test equipment. KEMA supplied the equipment and performed the test. A picture of the test setup is shown in Figure 10.

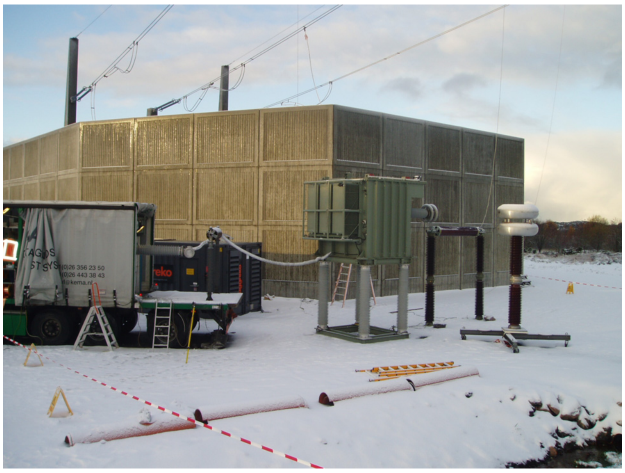

Figure 10. After installation test with transportable resonant test sets.

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All 4 cables were tested for 1 hour at a voltage of 1.7 Uo, i.e. 374 kV and the tests were successful. The sheaths on the underground cables were also subjected to a 10 kV DC test. The link was energized December 1st 2006.

CONCLUSION

The worlds first 420 kV XLPE submarine cable system was successfully qualified, produced, installed and commissioned between the main land and the island of Gossen. The system contains submarine cables, underground cables, cross bonding joints, GIS terminations and outdoor terminations. Repair joints for the submarine cable system has also been designed and qualified. The rating of the link of 1000 MW is designed to cover the need for the Ormen Lange onshore plant and to be part of the future 420 kV main grid.

REFERENCES

[1] CIGRE *"Recommendations for Mechanical Tests on Sub-marine Cables"* Electra No. 171, 59-65.

[2] CIGRE *"Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage above 30 (36) to 150 (170) kV"* Electra No. 189, 29-37.

[3] IEC 62067 *"Power Cables with Extruded Insulation and their Accessories for Rated Voltage above 150 kV (U_m=170 kV) up to 500 kV (U_m=550 kV) - Test Methods and Requirements.*