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DEVELOPMENT OF EXTRUDED SINGLE CORE CABLES FOR DEEP WATERS

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ABSTRACT

*The installed amount of polymeric insulated HVDC cable has become impressive. Presently 1566 km cable has been installed since the start in 1999[1] with more than 5000 km*years.*
The first installations were land cables, but the latest projects, the Cross Sound, the Troll A[2] and the Estlink are submarine with 340 m as the record laying depth for extruded DC cables.
This paper will describe the development, including mechanical and electrical testing, of extruded cable systems for deep sea laying to support the commercial evolution of extruded high voltage cable technology. Special emphasis is put on the limit with conventional designs.

KEYWORDS

HVDC, polymer, cable, system, deep water installation

INTRODUCTION

The electricity networks of today increasingly need control and stability at high levels of loading. Due to restrictions in right-of-way or limits to acceptable short circuit currents, simply increasing the stability through adding more lines is not always an option. For these cases, HVDC transmission solutions using undergrounding through extruded cables systems offer unique advantages.

Other reasons for introducing HVDC Light® cable systems in the network are the bulk transport of power both at land and sea, the interconnection of different parts of network for stability or control reasons and the connection of remote loads as for example off shore oil-platforms.

Both underground and submarine projects have been realized using the HVDC Light® converter and the HVDC Light® polymer cable technique. The installed systems, so far, work on voltages of 80 and 150 kV. The installed powers have increased from the first project (Gotland) at 50 MW to the latest installed (Estlink) at 350 MW. At the moment of writing a total of 1566 km of HVDC Light® cable has been installed.

A gradual increase in both power and voltage is foreseen. For the larger powers, i. e. more than 3-400 MW, it is more suitable to use a higher transmission voltage. The next DC voltage that complies with AC system levels is 320 kV. This new voltage level opens a window of power transmission between roughly 400 and 1000 MW. In parallell to this we also see a need for larger installation depths.

DEVELOPMENT OF DEEP WATER CABLE SYSTEM

The development of the deep water cable system follows the same cautious philosophy as the development for higher voltages, starting at lower voltages and establishing limits of existing technology to build experience and ensuring a solid basis for further development. In this first stage reported here, we use an 80 kV cable system. As the same design concept is used for the higher voltage levels, we are able to extrapolate results from this testing to these.

Cable system

An extruded HVDC Light® sea cable links requires, apart from the cable itself, terminations, flexible factory joints as well as prefabricated land and repair joints.

Prefabricated Joint.
The electrical design of the prefabricated joint used for the land part is shown in Figure 1 below.

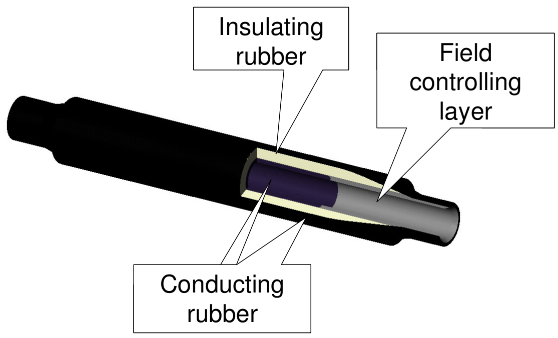

Figure 1. Electrical design of prefabricated joint.

The prefabricated joint consists of an EPDM insulated body, where a non-linear dielectric layer controls the electric field under stable DC as well as transient conditions. Over this layer, the insulating EPDM takes over the electric field from the cables. The final layer is a conducting layer of EPDM rubber that confines the field to the inside of the joint. A deflector of conducting rubber at high potential shields the field from the sharp edges of the conductor connection, not visible in the figure. The electrical design of the stiff submarine prefabricated joint is the same as for the land design, but due to the harsher environment, the mechanical design requires a combination of mechanical strength and water integrity. The water tightness was achieved by swaging down a lead sheath over the joint, and this is then soldered against the lead sheath of the cable. To maintain and ensure the continuity of the PE-sheath, a heat shrinkable tube was employed over the lead tube. To obtain sufficient mechanical protection against e. g. a rocky seabed the joint is then enclosed in a galvanized steel pipe and with stiffeners as described in Figure 2.

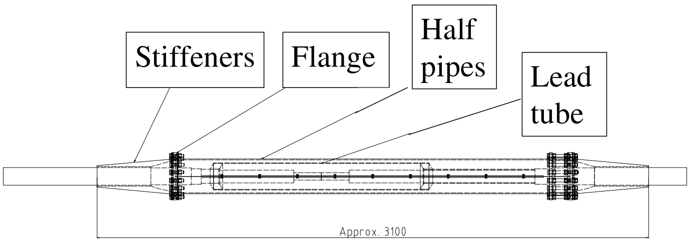

Figure 2. Mechanical design of stiff repair joint.

Flexible joint

The flexible joint is a crucial part of any sea cable link enabling long laying lengths on the laying vessel, minimizing the number of jointing operations at sea. It consists of the same cross linked insulation material and semiconducting layers as the cable and is thus considered an integral part of the cable after completion. It is manufactured by lapping thin tapes of insulating and semiconducting tapes on the conductor followed by a crosslinking process. Since a flexible joint entails both a mechanical discontinuity in the conductor, due to the conductor weld, and a risk of insufficient bonding between the original extruded insulation and the new, tape moulded part along the insulation cone, this was recognized as a possible weak spot for deep water applications.

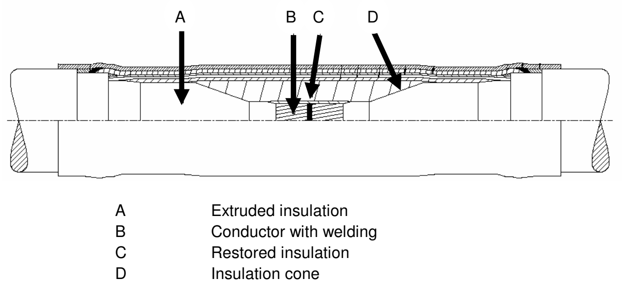

Figure 3. Principal drawing of a flexible joint.

Restoration of armouring

After manufacturing the flexible joint one must restore the cable armouring layer(s). This is performed by wire to wire welding over an extended length of the cable in order to distribute the mechanical tensions during laying. In Figure 4 we see the restored lead sheath and the armouring strands prior to welding and in Figure 5 we see the successfully restored armouring.

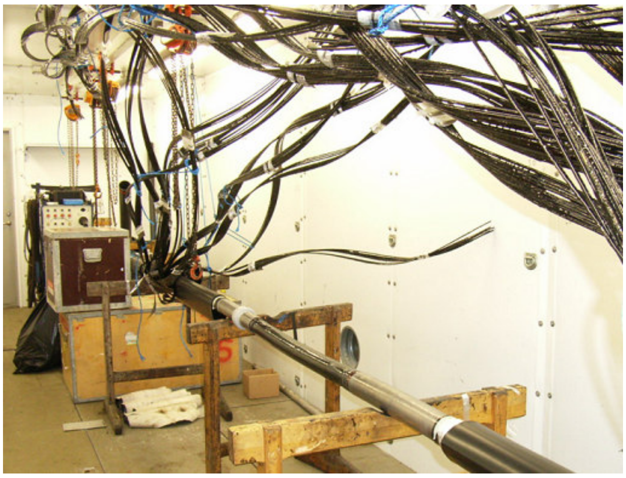

Figure 4. Showing several armour strands prior to welding.

Figure 5. Showing wire to wire welded armouring after restoration

Establishing limits with today's technology

The laying depths of the above mentioned projects are moderate with a maximum depth of 340 m. It is of interest to establish the maximum laying depth for conventionally designed cables before taking any special measures to further increase this, e. g. by utilizing special high strength steel armouring or lightweight polymeric armouring.

The maximum laying depth of a certain cable is dictated by its own weight, governed by the design as well as by the dynamic tension experienced by the cable during laying. The dynamic tension depends on the vertical movement of the laying sheave, the mass of the cable and the circular frequency of the laying sheave or, in other words, it is defined by the weather and wave conditions during laying. To qualify a cable system for a certain laying depth a mechanical tensile bending test is performed. The test force is calculated using equations as defined in CIGRÉ “Recommendations for mechanical tests on sub-marine cables” published in Electra No.171, April 1997. The test force calculated includes not only the cables own weight but also the dynamic tension mentioned above.

After the test has been performed the cable sample is required to undergo a visual inspection and the test shall not give rise to “permanent deformation of the conductor or armouring” according to the above named recommendation. This is an important and limiting demand. During the tensile bending test, the conductor and armouring may be permanently deformed in terms of local increase in length and local decrease of the diameter. This happens typically at the weakest point of the sample, which is the joint. This deformation depends on design parameters as for example maximum allowable tension in conductor and armouring.

As no exact definition is given in the recommendation concerning “permanent deformation” one is to some degree free to choose the maximum allowable conductor and armour tension. As manufacturer we tend to stay on the safe side and choose values between 70 and 100 N/mm^2 for jointed copper conductors and 40 to 55 N/mm^2 for jointed aluminium conductors.

Of course, when one allows a larger tension in the cable and joint, larger laying depths can be reached. To get a rough feeling, some depths are calculated for two different cable designs with 170 N/mm^2 armour tension and 100 N/mm^2 conductor tension.(See Figure 6 and Figure 7).

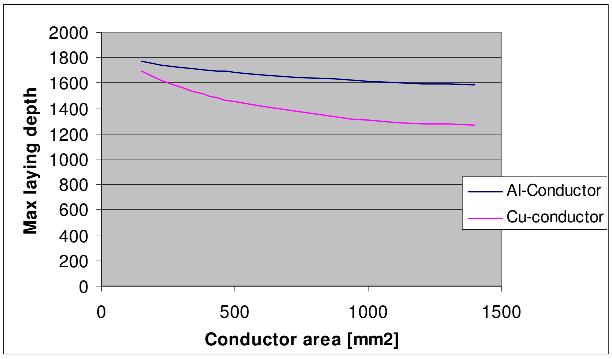

Figure 6. Maximum calculated laying depth for an 80 kV HVDC Light® design.

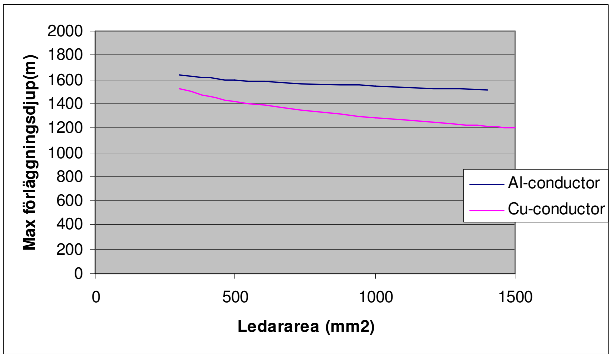

Figure 7. Maximum calculated laying depth for a 150 kV HVDC Light® design.

From this it is concluded that depths up to about 1500 meters can be reached with today’s design rules. Still larger depths can be reached with existing technology, if one allows for a more progressive interpretation of Electra No. 171, i.e., to allow a permanent, but small and local deformation of the conductor joint. The expected deformation is a local decrease in diameter of a few percent, too small to affect the electrical performance of the cable systems.

Testing

To prove this statement an 80 kV HVDC Light® cable including a submarine flexible joint was subjected to a tensile bending test and a subsequent electrical test.

Test object

The cable system tested consisted of a 300 mm^2 Cu, 8 mm insulation, double steel armoured cable, terminations and a flexible joint. It was designed for operation at a DC voltage of 80 kV and had previously been type tested for this level[3]. The 300 mm^2 conductor is round, circular stranded, compacted and filled with longitudinally water blocking compound. The tensile armour consists of two layers of galvanized round steel wires, 4 mm in diameter close to each other twisted round the cable. The two layers are applied in opposite direction around the cable. By this crosswise laying a very strong torsional free armour is obtained, i.e. it does not introduce any significant torsion in the cable when exposed to axial tension. This cable system is the same as the one used for the Troll project, where 2 * 2 * 68 kilometres of HVDC submarine cable are connecting the Troll A gas production platform at the continental shelf in the North Sea west of Norway to the Norwegian mainland[(2)].

Tensile bending test

The tensile bending test was performed according to Electra No.171[4]. A force of 380 kN was used, resulting in a measured conductor tension of 130 N/mm^2. The test corresponded to a laying depth of more than 2000 meters. In order to asses whether this had any degrading effect on the cable system, an electrical type test was performed after the tensile bending test.

Electrical test

The test scheme was performed according to IEC60840[5] based on an AC voltage U_0 = 52 kV. The reason for choosing an AC test was that this would be a more sensitive test of any mechanical damages to the insulation system, such as delamination and cracking. The test consisted of the following steps:

- PD test at 39 kV, Tan δ test at 26 kV
- 20 days of heat cycling at 52 kV (4 hours heating, 8 hours cooling, maximum conductor temperature >95°C). On line PD measurement
- Hot impulse test at 250 kV (10 positive and 10 negative impulses)
- Power frequency voltage test at 65 kV followed by a PD test at increased voltage (65 kV)
- Additional 6 days of 20 days of heat cycling at 72.5 kV (4 hours heating, 8 hours cooling, maximum conductor temperature >95°C)

The test was performed with shorter temperature cycle duration in order to include more cycles within 20 days. However, it was ensured that the test object reached the required steady state temperatures for conductor and sheath within each heating and cooling cycle. More cycles induce more mechanical strain and were judged to be a tougher test in order to check the integrity of the cable and joint after the tensile bending test. The objects passed all the tests without any remarks.

A visual inspection was performed after the test and was concentrated on any dimensional change of the conductor joint. A local and permanent maximal decrease in diameter of less than 3% was measured. Demonstrably this had no effect on the functionality of the cable and joint.

CONCLUSIONS

The successful test of a conventionally designed HVDC Light® cable after mechanically pulling with a force corresponding to a laying depth of more than 2000 meters indicates that it is a feasible way to further extend the HVDC Light® market also to include larger laying depths for deep sea interconnections and off shore applications. The next step is to perform a formal DC type test on such a cable system.

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[2] ABB Review Special Report 2003

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[5] "IEC 60840 Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) Test methods and requirements"