REQUIREMENTS FOR DIFFERENT COMPONENTS IN CABLES FOR OFFSHORE APPLICATION

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ABSTRACT
The installation of offshore wind-farms and the increase in electricity trading between countries has resulted in an increased number of offshore submarine cable installations as an efficient way to solve many electricity supply issues. Although offshore cables with XLPE insulation are similar to land based cables, the offshore environment adds to the challenges of very long lengths, much more onerous installation conditions and an aggressive environment.

This paper discusses how these issues are confronted in distribution cable designs. In addition, the necessities for long-lasting medium voltage cables up to the lower high voltage level in wet conditions plus the increase in performance needs are discussed. It also covers the different requirements of 3 Core installation and water tree retardency tests in sea water applications. This paper will focus on medium and high voltage cables as they are used extensively for offshore applications connecting wind farms, for lake crossings and for inter-island connections.

INTRODUCTION
The need to ensure better power system interconnections and to connect offshore wind parks in regions that are separated by water involves more and more extensive use of offshore links. Generally speaking, the total cost of such links is greater than that of conventional land cables, since their component costs are higher. For this reason, a life of more than 40 years is generally required for these cables systems. Damage causing the loss of transmission in these cable installations will cost considerably more than good design selection and initial safeguards of the link. Specification and protection of offshore cables is of fundamental importance [1], so it is advisable to face it at the feasibility stage, when the best solution from the technical and financial point-of-view can be implemented. [2]

The main steps to be undertaken are the following:
• Choose an appropriate cable route
• Provide the cable with suitable metallic armouring
• Choose the right insulation system for the application

The cable route selected as well as installation conditions will have a big influence on the cable parameters, since it will dictate the type of protection required for the cable and will determine the physical requirements that the cable has to withstand.

In addition to the above requirements, tensile and torsional stresses during installation will influence the choice of armouring that must be compatible with the characteristics of the installation method and so match the characteristics of the seabed to prevent damage to the cable.

PROTECTION OF CABLES
Mechanical protection of submarine cables should be provided according to the hazards that they are to face during their in-service life. Damage to cables can result from both natural phenomena and human activities. This situation must be anticipated both at landfall, as well as at greater depths. In beach areas for example, it is necessary to distinguish between areas on dry land and in water. Above the high water mark the cable may be damaged by heavy vehicles that operate on the beach or by an accumulation of pack-ice in colder areas, or by beach sand movement in high current or large tidal locations.

Below the low water mark, which is the focus of this article, the current and wave-induced motion can increase the chafing and corrosion suffered by a cable. Routing and burial assessment reports will formally take into account input from the following specific commissioned studies:
• Environmental report (Flora/Fauna and impact assessment on any animals/fish due to either installation [seabed movement] or operation [magnetic fields etc.])
• Shipping/Navigation (Density and size of shipping)
• Fishing (Density and type of gear used)
• Full Geotechnical/Geophysical survey encompassing seabed mobility study and thermal resistance measurements

The studies performed can be used to mitigate damage through:
• Ship movement/anchoring/fishing/trawling
• Seabed movement/vortex induced oscillations due to cable free spans
• Overheating in a thermally challenging
environment
Based on the above a suitable Burial Protection Index (BPI) [3] can be chosen to keep the external failure risk at an acceptable level.

PROTECTION DURING LAYING AND INSTALLATION
The first hazard that the cable faces is the laying by either a cable laying vessel or a barge. The vessel floating action on the surface causes two types of cyclic motion at the top end. The first (first order motion) is at a frequency similar to that of the waves at the surface, while the second order motion (slow drift) is at a much lower frequency and can be analyzed quasi-statically.

1st Order Fatigue Analysis
The equations of motion are complicated by the fact that the boundary conditions beyond the touch down point are difficult to state as these are constantly changing. An asymptotic solution has been sought using the method described by Chen et al [4], and very high levels of dynamic tension are suggested. However, a problem with this method is that vertical motion is suppressed at the touch down point and all tangential displacement is absorbed elastically by the cable using numerical frequency domain analysis. Quasi-static analysis is inappropriate here as the excitation frequency is similar to the centenary natural frequency.

2nd Order Fatigue Analysis
The cable will move from its neutral position according to vessel response to the prevailing sea state. At each sea state the cable top end motion can be characterized by an oscillation about a new mean position.

Figure 1 Stress distribution along an offshore cable [1]

For higher sea states the oscillation has greater amplitude and the new mean position is further from the original neutral position. Such oscillations mean that the cable profile changes, being altered by movement of the touch down point as well as by the vessel. As a result cyclic changes in bending stresses and tensile stresses occur that will contribute to fatigue of the cable components. The amount of fatigue damage in the metallic layers can be found using appropriate diagrams. The fatigue analysis shows that the amount of damage accrued by the second order motions is small, giving a cable life well in excess of the transmission system life. However, the tension within the cable should be very closely monitored and the flexural modulus of the whole cable should be measured.

One of the possibilities here is increasing the flexibility of the insulation. Polymer-WTR insulations have a far lower flexural modulus than classical or additive WTR insulations as outlined in Figure 2.

Hazard during operation
Most offshore windfarms have high structures such as Wind Turbine Generator towers and substation platforms where the cables, either inter-array or export, have to be terminated. Depending upon the arrangement, internal or external J-tubes, I-tubes or telescopic tubes, the cables have to be pulled from the seabed to the cable deck through a vertical pulling arrangement which may involve a few angles. Tensions up to 100kN have been encountered with the need to keep the bending radii to a minimum. Once operational or installed, the subsea cables will be subject to all sea states and if exposed to wave motion, the cable response for 50 year predicted metocean conditions should be investigated.

Figure 2. Flexural Modulus of different insulations

Figure 3 shows an example how a cable can move and sway sideways due to wave and current motion.
Originally this 33 kV 400mm² cable was laid straight down (no sideways deflection) with Polyurethane bend restrictors.

Additionally, today most medium voltage cables are laid as 3C-cables, thus increasing the complexity.

Purchasing protection system based on just common sense and judgement may not have the required results as the behaviour of all the subsystems is highly non-linear and therefore the consequences of sea states coupled with currents and wind direction could have disastrous consequences leading to cable failure.

A significant pre-sanction engineering is required to specify the route, satisfactory the mechanical cable design as well as the installation technique. It is also recommend to establish suitable cable designs, by type testing to an appropriate standard, for example, CIGRE Electra 171/189. Additionally a satisfactory polymer insulation package should be chosen and verified by the appropriate HD620/HD605 test.

**Design of the cable—Cables without metal sheaths**

During the design phase of the project it should be decided if with the cable is to be a wet design or a dry design. For medium voltage cables up to 36 kV there is no problem using a wet design if a reliable water tree retardant insulation has been selected. A very good selection criterion for the insulation and the semicon is the Cenelec HD620 protocol which is used throughout Europe. Here six cables are aged under wet conditions for two years under higher stress of 4 U₀ and at 40°C cable temperature. The breakdown values are then recorded. In Figure 4 the performance of a polymer water-tree retardant compound is shown after this test. The breakdown value is more than 4 times higher than of a standard classical homo-polymer.

A high value in this test insures a cable life of more than 40 years [5].

There is a common approach to add water swelling powder or tapes into the conductor to increase the water tightness. However this might increase the risk of deterioration of the electrical breakdown strength over time as outlined in Figure 5.

One of the reasons for this faster deterioration of the cable might be the creation of so called stress-introduced-electrical degradation (SIED) which is still under investigation at several laboratories [6].

![Figure 5. Weibull distribution of relative breakdown values of cables using water swelling powder in the conductor according to Cenelec HD620 protocol](image)

The second difference between land and offshore cables is that the surrounding or ambient temperature is in general much lower for the off-shore cables [7]. Here we should take a closer look at the influence of the ageing medium on the growth of water treeing especially vented trees as shown in Figure 6.

![Figure 6. Effect of ageing medium on the electrical endurance of XLPE insulated wires](image)

**Ion migration**

In sea water, the migration of soluble ions into the cable is a factor to consider. To this end, T. Boa et all reported the different parameters that influence the migration of ions into the cable. One of the important parameters besides the nature of the ions is the degree of crosslinking of the different parts of the insulation. Only with 40 % of the semiconductive shield crosslinked the ion-migration can be reduced [9]. So if thermoplastic insulations components are used, the water tree retardancy has to be significantly increased.
High voltage up to 170 kV – Cables with metal sheaths

In terms of higher voltage cables, a dry design should be preferred, since all the WTR materials have a higher loss factor than standard polyethylene which plays a significant role at higher stresses.

However, for high voltage cables the degassing burden should also be taken into account. Long submarine cables are not easily degassed and will take considerable time to process. The methane level as well as the other by-products has to be reduced significantly. Storing high voltage cables outside will not help. Work has been done to establish the impact of different by-products on the performance of the cables. The amount of methane should be below 50 ppm [10]. There are different methods how to measure methane and CIGRE Working Group D1.26 is trying to determine a common one. Each additional day required for degassing will increase the delivery time and hence reduce the opportunity to deliver the cable on time.

CONCLUSION

Today’s electrical supply industry depends more and more on the interconnection of offshore cables, connecting wind-farms and power utility networks together. Submarine cables need mechanical protection as well as special protection against water treeing and other contaminations that can be detrimental to these cables, since lying and repair costs are high. Modern cable compounds are giving the cable manufacturer the option to choose the right compound for specific applications. For medium voltage or low stress cables a polymer-WTR-compound is recommended and for high voltage cables a modern high performance insulation compound should be considered.