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DIELECTRIC SYSTEM FOR SUBMARINE ELECTRO HYDRAULIC UMBILICAL UP TO 35KV

Mario Daniel TEIXEIRA JUNIOR, MDR Consultoria, (Brazil), mariodaniel@globo.com
Luciana ABIB, Marine Production System do Brasil, (Brazil), Labib@oceaneering.com

ABSTRACT

The main purpose of this technical paper is to analyse the various kinds of polymeric insulations currently available for use in power cables, with insulation voltage up to 35kV, for application as a component of Submarine Electro Hydraulic Umbilical.
The umbilical application could be interconnect offshore oil platforms or supply electrical energy for down hole, deep water, oil pumps.
Analysis must take in account the dielectric system, comprised of the conductor shield – insulation – insulation shield. The single and simple analysis of the insulation, in the event of cables for medium voltage, becomes partial and must be complemented by the specification and definition of requirements for the semiconductor materials components for the conductor and the insulation shield.
Real data for the different dielectric systems under investigation are presented, discussed and also confronted with current standard.
An economic analysis for different dielectric systems is present for a complete evaluation.
This paper also describes the methodology, established by the authors, for evaluating and validating of the electrical system design for application in a depth up to 3000m.

KEYWORDS

Electro Hydraulic Umbilical, Polymeric Insulation, Dielectric System.

UMBILICAL CABLE APPLICATION

Powering submerged pumps to overcome ultra-deep water pressures, low reservoir pressure, long offsets connections from a central platform, high produced fluid viscosities, extend the life of mature fields or accelerate production on new fields calls for a Electrical Subsea Pump (ESP).

Figure 1 – Submarine Multi-Phase Cable 6/10kV

Each design is property balance mechanical, thermal and electrical evaluation, for static and dynamic operation in subsea application up to 3000 meters water depth and a service life of 25 years.
A typical subsea multiphase pump may need a megawatt or more of electricity and some fields need more than one pump. Normally, each pump is fed by its own Variable Frequency Driver (VFD), requiring one 3-phase cable per pump.
Detailed analysis and rigorous tests are performed to ensure the umbilical systems reliability during installation phase and during throughout service life. Crush, bending, tensile and cycle tests verify umbilical behavior under a broad range of installation and operation scenarios.
A subsea umbilical cable can also be composed by steel tubes, hydraulic hoses, optical and signal cables.

Figure 2 – Electro Hydraulic Umbilical

DIELECTRIC SYSTEM

The dielectric system can be unique, comprised only by the insulation in the case of low-voltage cables or composed by the conductor screen – insulation – insulation screen in the case of medium and high voltage cables.
The pure and simple analysis of the insulation, in cables for medium or high voltage, becomes partial and must be complemented by the specification and definition of requirements for the semiconductor materials components of the conductor and insulation screen.

POLYMERIC INSULATIONS

According to its thermo-mechanical behavior, the insulation polymers can be divided into: Thermoplastics and Thermoset compounds.
Due to the thermal limitations of the thermoplastic polymers, in stead state and mainly during short circuit transients, only

the thermoset materials will be analyzed for application in medium voltage cables components of electro-hydraulic umbilical.
The thermoset insulations used in power cables are the Cross-Linked Polyethylene (XPLE) and the Ethylene Propylene Rubber (EPR).
Both EPR and XLPE can have polymeric bases and distinct processes of curing which will result in differentiated physical properties and performance according to the application.

CHARACTERISTICS OF EPR INSULATION

The Ethylene Propylene Rubber (EPR) is a polymer obtained from the copolymerization of ethylene and propylene (EPM) or terpolymer ethylene propylene diene monomer (EPDM) giving origin to an elastomer with excellent electrical and physical characteristics.
The EPM copolymer or the EPDM terpolymer, are amorphous or semi-crystalline elastomers. The crystallinity of the polymer is a function of the reason of the quantity of ethylene and propylene in the polymeric base.
EPR formulations for medium and high voltage cables must have a base of semi-crystalline polymer, which can formulated with no mineral oil and a low content of mineral load (HEPR–High Module EPR). As a result, compounds with good mechanicals characteristics and low loss factor are obtained, allowing its application in cables with insulation voltage of up to 138kV.
There are HEPR formulations commercially available for medium and high voltage cables that are intrinsically resistant to the water treeing phenomenon.

CHARACTERISTICS OF XLPE INSULATION

The Cross-Linked Polyethylene (XLPE) is obtained from the change of the structure of the Polyethylene Thermoplastic (LDPE) into another Cross-Linked where the molecular links provide a better thermal stability to the polymer.
The Cross-Linked Polyethylene (XLPE) has essentially all the electrical properties of the LDPE; however, it presents better physical properties and better retention of these properties with the increase of temperature. Because of being a thermofixed material, it has a greater resistance to deformation in the operation temperatures.
The XLPE has the LDPE as a polymeric base that is partially crystalline and has a melting point in the order of 105ºC – 110ºC, for this reason, the recommendation remains of limiting the temperature of the emergency regimen for the XLPE in 105ºC in the case of 138kV cables and above.
In the 80's the first Tree Retardant (TR) XLPE [1] was introduced by the addition of a polar ingredient in the polymeric base of the XLPE. The purpose was to minimize the defects caused by the growth of the water trees and the result was the improvement of the working life of the power cables in wet environmental [2].
The XLPE is available in different degrees of purity for use in medium or high voltage cables. On the other hand, the TR-XLPE is normally used only in medium voltage cables that may have permanent contact with water.
The result and the typical appearance of the XLPE and the TR-XLPE when submitted to the testing of ASTM D 6097-00 [3] are presented in figure 3.


XLPE

TR-XLPE

Figure 3 –XLPE sample with electrical trees of great intensity from the end of the electrode and TR-XLPE sample with electrical trees confined to the end of the electrode.

INSULATION SELECTION

When a liquid comes into contact with a polymeric compound, it permeates through the molecular diffusion of the steam high-pressure regions for the low-pressure areas until a balance is achieved. Further, the liquid that penetrate the cable core will penetrate on the insulation, causing water treeing, even under low-intensity of electrical fields.
The water diffusion rate depends on many parameters, i.e., temperature, pH, conductor temperature and type of load cycle and the construction of the cable and the permeability of its component elements.
Since the medium voltage electrical cables component of electro-hydraulic umbilical remain in permanent contact with water, the specifications of insulation intrinsically resistant to the water treeing become imperative and that its physical and electrical properties are preserved when in permanent operation in this condition.
Both TR-XLPE and HEPR could be specified over this point of view.
The characteristic that differentiates the HEPR from TR-XLPE is the density. The density of 1.22 of the HEPR makes its mass 30% above that of the TR-XLPE (density 0.92). In an umbilical installed in a depth of 3000m this mass increase must be taking into account.
Flexibility is an important parameter. Being a high crystalline polymer, the TR-XLPE has less flexibility than the HEPR.
A simple and illustrative test was made with a cable, 240mm^2, 12/20kV. The strength to bending 1,5m across a corner is recorded as being 60% superior for the TR-XLPE. This characteristic must be taken into account in both the manufacturing and the laying processes, mainly during the umbilical operation.

SEMICONDUCTORS

Conductor Screen

The conductor screen comprised of non-metallic conducting polymeric material, normally called semiconductors, and has the main purpose of giving a perfectly cylindrical shape to the conductor and eliminating voids between the conductor and the insulation.
The conductor screen must be in close contact with the internal surface on the insulation and adherent to it, seeking the elimination of voids and discontinuities in the interface,

avoiding the occurrence of partial discharges, thereby optimizing its function.
The polymeric base of the shielding compounds acquires their conducting capacity by means of the incorporation and the dispersal of special kings of carbon black in the base polymer matrix.
To be effective, the conductor screen must have a maximum resistivity of 1000 Ω.m at 90ºC [4].
A perfect compatibility between the conductor shielding and insulation must to be achieve during the cable service life.

Insulation screen

The main function of the insulation screen is to provide radial and symmetrical distribution for the electrical field, so that the dielectric is stressed in a uniform manner.
Similar to the conductor screen, for the insulation screen to be effective, it must maintain a perfect contact with the external surface of the insulation, thereby eliminating the possibility of bubbles and imperfections that would give rise to partial discharges.
There are basically two kinds of non-metallic shielding for the insulation, i.e.: the ones fully bonded to the insulation and the ones partially adherent to the insulation of the easy strippable kind.
The fully bonded have as an advantage the greater electrical and mechanical stability of the dielectric system in installation and operating conditions. Its disadvantage lies in the greater difficulty of assembly the accessories; splices and terminals.
The easy strippable insulation shield allows a simpler and safer assembly of accessories.
To be effective, the insulation semiconductor must have a maximum resistivity of 500Ω.m at 90ºC [4].

MANUFACTURING PROCESS

In the case of medium voltage cables up to 20/35kV, both on TR-XLPE and HEPR, for use in systems that demand a high reliability as in the case of electro-hydraulic umbilical component cables, the process of vulcanization by peroxide must be specified jointly with the most adequate polymer.
To obtain a homogeneous dielectric system, the simultaneous extrusion of the conductor shielding, the insulation and the insulation shielding in a single extrusion head is required and the cure in Nitrogen (Dry Curing) is required.

DIELECTRIC SYSTEM WITH HEPR and TR-XLPE

Following practical results are presented for physical properties in 95mm^2 - 12/20kV cables using HEPR and TR-XLPE dielectric system, compared with the requirements of IEC standard [4].

Characteristics	IEC 60502	TR-XLPE	HEPR
Tensile strength	12,5	24	
(N/mm²)	8,5		13,5
Elongation	200	530	
(%)	200		290
After aging /air oven			
Tensile strength	+/-30	6,6	
Variation (%)	+/-25		18,5
Elongation	+/-30	7,4	
Variation (%)	+/-25		1,8
After aging /air bomb			
Tensile strength	+/-30		7,4
Variation (%)	-	-	-
Elongation	+/-30		10,3
Variation (%)	-	-	-
Modulus at 150%	4,5		8
(N/mm2)	-	-	
Hot set Under load	175		15
(%)	175	75	
Hot set Without load	15		0
(%)	15	2	

Table 1 – TR-XLPE and HEPR characteristics

The analysis of the presented values shows that the dielectric systems that use HEPR or TR-XLPE as a proper peroxide cure process have physical and electrical properties that exceed the specifications.
The presented values must not be used as requirements in purchase specifications, however they serve as a marking for recognizing an adequate and well-processed insulation system.
In figure 4 results are obtain on comparative testing are presented for model cables 25 mm^2 , 6/10kV with insulation system of TR-XLPE and HEPR and proper semi conducting materials peroxide cured in true triple head, gas curing and water cooling.
The cables are tested at lest 15 days after the manufacture and they are not degassing.

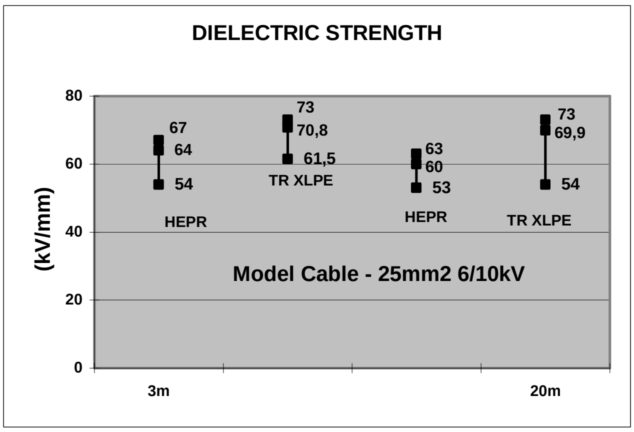

Figure 4 – Dielectric Strength HEPR and TR-XLPE Dielectric System

The results are maximum, minimum and average values obtained from break down test in 20 samples of 3m and 20 samples of 20m of model cable.
The differences in the dielectric strength between HEPR and TR-XLPE are not significant for operating voltages up to 20/35 kV.
In figure 5 data presents the behavior of the loss factor for the HEPR and the TR-XLPE from its original state up to 60 days of accelerated ageing.
The testing was performed in 120mm² 20/35kV cable by applying an AC voltage equivalent to 8kV/mm in the conductor and a thermal cycle 8 hours every 24 hours with sufficient current so that the conductor temperature reached 130ºC for 30 days and 140ºC for another 30 days.
The power factor measurements were performed with the conductor at 105ºC.

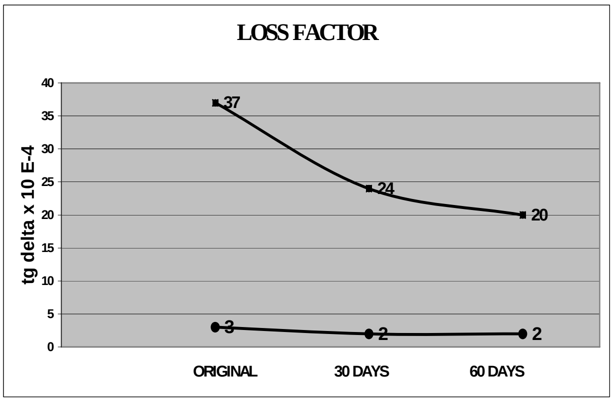

Figure 5 – Loss Factor for HEPR and TR-XLPE Dielectric System

In the event of TR-XLPE, the loss factor was stable and very low when compared with the original maximum value specified of 80x10E-4 at 90ºC [4].
Now the HEPR, on account of being a compounding material, showed a decaying stabilization curve over the thermal cycles and presented values well below the original specified of 400x10E-4 at 90ºC [4].
Typical values for original resistivity of the conductor screen and the insulation screen and after performing thermal cycles of ageing during 30 days at 130ºC and 30 days at 140ºC are presented at figure 6 and 7 for a dielectric system based on TR-XLPE and easy strippable semiconductor screen.

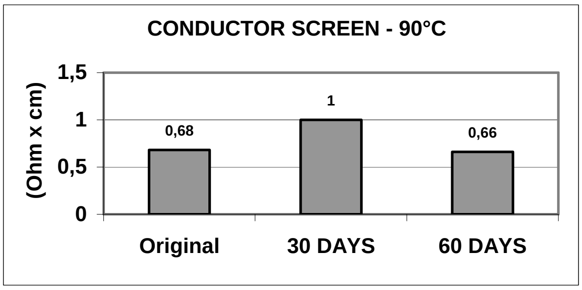

Figure 6 – Resistivity of conductor screen

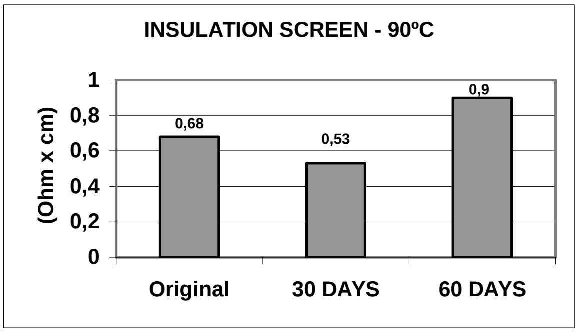

Figure 7 – Resistivity of insulation screen

In the event of dielectric systems based on HEPR easy strippable semiconductor screen, the results for the conductor screen are similar to those of TR XLPE and for the insulation screen it is a bit higher (4Ω.m original at 90ºC and 6Ω.m at 90ºC, after thermal cycles, however, much lower than the maximum specified [4].
For the insulation screen that uses easy strippable semiconductor, a relevant characteristic is the stability of adherence between this and the insulation in the course of the operational cycle.
In figure 8 shows the force required to remove the easy strippable semiconductor of the TR-XLPE insulation, obtained by a triple extrusion system and cure in nitrogen and water cooling, when submitted to 30 thermal cycles at 130ºC and 140ºC.

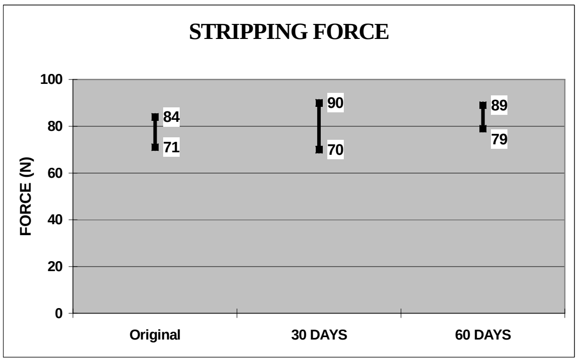

Figure 8 – Stripping force for easy stripping insulation shield for TR-XLPE

The presented values are the maximum and minimum obtained in three test specimens.
The minimum specified value is 13N and the maximum 105N for original stripping force as Brazilian standard [5] and 4N to 45N as IEC standard [4].
HEPR insulation system with easy strippable insulation screen presents values stable and similar as TR-XLPE but with stripping forces of 40N original and 30N after 60 days.

METHODOLOGY OF VALIDATION

A testing program for validation must be prepared, applied on a prototype of actual cable, where particular characteristics will be tested and, mainly, tests are created that simulate the cable use condition under requirements of extreme operating stress.

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The testing content IEC standard [4] comprises a check of both physical and electrical properties for the materials; combinations and dimensions of power cable of up to 36 kV and must be used in cable design validation process.
For a specific application of power cables as components of electro hydraulic umbilical, some test must be done after pressure or the preference under pressure, to stress the cable as operational condition.

Long duration electric voltage testing

The object of this testing is to check the influence of pressure in the dielectric strength of the electric system of an umbilical component cable up to 3000m deep.
As a testing methodology, a complete cable sample must be positioned in the pressure chamber with both ends outside the chamber.
After the pressure stabilization in 300kg/cm^2 for 30 minutes, an AC voltage of 4Uo must be applied during 4 hours.

Testing of the loss factor in relation to pressure

Seeking to verify the influence of pressures up to 300kg/cm² in the loss factor, the follow test procedure is suggested.
The reading of the loss factor, the atmospheric pressure and the ambient temperature must be carried out, with the application of 2kV AC voltage.
The pressure must be gradually increased up to 100kg/cm² and maintained for 30 minutes, and a new reading of the loss factor must be carried out.
This procedure must be repeated for a new degree of pressure of 200kg/cm² and then for 300kg/cm².
The values of the loss factor must be analyzed to check for the eventual influence of the pressure in the geometrical and electrical parameters of the cable's dielectric system.
Special attention must be given to the external medium pressure chamber transition region to avoid the concentration of mechanical tensions to the cable.

Water penetration in the conductor

Selected water tight conductor is recommended to prevent longitudinal water migration.
Normally, the kinds of blocking come in the form of polymeric compound or tapes impregnated with powder that expands in contact with water.
In the event of the underwater cables, which may come in to contact with salt water, and that use tapes impregnated with powder for the blocking of conductors, adaptations must be made in the methodology of IEC [4]. Since the expansion capacity decreases, when the concentration of sodium chloride increases, only a few tapes with particular characteristics are effective in the effectiveness of blocking.
For this verification, the water penetration test must be carried out in accordance with the IEC [4], but adding 30g of sodium chloride per liter of water used in the testing.

ECONOMIC ANALYSIS

As seen before, there is a difference of 30% in density between TR-XLPE and HEPR and the addition to the cost variation between both materials makes TR XLPE only 57% the HEPR cost for the same material volume.

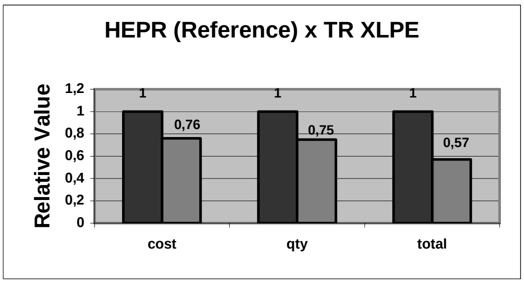

Figure 9 – Relative cost HEPR and TR XLPE

The other cable component materials would significantly absorb the incidence in the insulation in the cable total cost. If we take as a reference a typical cable, 240 mm^2 tinned copper conductor, 12/20kV, shielded with two tinned copper tapes and LDPE jacket, as specified for supply energy for oil pumps in deep water.
The use of the TR-XLPE as insulation leads to a cable cost 3.9% less than HEPR one. This difference is will be more significant if the copper LME decrease and for cables with small conductor cross section. For this cost analyse the copper LME used was 6,350 U$/t.

Conclusions

There is an equivalence of electrical properties between the TR-XLPE and HEPR when the application is in cables with insulation voltage up to 20/35kV in contact with water.
The mass of the HEPR is 30% above the TR-XLPE and could make some difference in cables with small cross section in deep water.
The TR-XLPE is 60% less flexible than the HEPR normally the umbilical design, manufacture and installation are not sensitive to this characteristic.
The HEPR is more expensive than TR-XLPE and for shore makes difference in cables with small cross section were the incidence of insulation material in the cable total cost is higher.
The analysis of dielectric system stability under pressure, of 300kg/cm², must be proven through the complementary tests suggested.

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