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Estimation Method of Polyethylene Power Cable Insulation Subjected To Electric Field In The Presence of Water

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*Abstract:**An approach to estimate the polyethylene power cable insulation of Medium Voltage cable system is presented. It is shownthat many factors affect the speed of degradation of a Medium Voltage cable system and that the degradation mechanisms varybetween different types of cables and accessories. It is also pointed out that various analytical methods exist todetermine the extent of ageing.During service, underground power cables are subjected to degradations due to the growth of water trees. Therefore, their lifetime is reduced. In this paper,estimation method for low density polyethylene insulated undergroundcables subjected to electrical fields in the presence of water are presented. The methodis based on laboratory accelerated ageing tests using high fields.***

I. INTRODUCTION

In order to connect the cable to a circuit breaker, a fuse holder or a transformer, terminations are required. Besides, in many cases the required cable length is too long to be manufactured and transported in one piece, so that joints are necessary to connect the individual cable parts together. The reliability of the electricity transport by the cable connection is determined by all links of the chain.

Replacing paper oil power cables insulations with polyethylene ones represented a true revolution in electric power transmission. This was a consequence of the numerous advantages of polyethylene (easy to manufacture, etc.). During service, the polymeric insulations of power cables are submitted to electrical, thermal, mechanical, environmental stresses etc. that contribute to the initiation and development of certain degradation processes. In 1969 Myashita [1] reported water trees presence inside the polyethylene insulations of submersible cables. After that, the inception and development of water trees under the action of variable electric fields in the presence of water with different salt content was studied in different papers. Water trees are diffuse areas made from micro-cavities filled with water, connected by very thin channels. They appear in regions with intense electric fields, like the insulation/conductor interface (vented trees, Fig. 1) or in the vicinity of cavities and impurities (bow tie trees, Fig. 2) and start to develop from the areas where the electric field is more intense towards the areas where the electric field is less intense [2], [3].

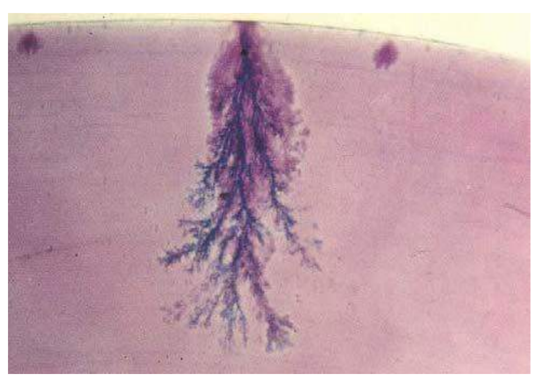


Fig.1. Vented tree

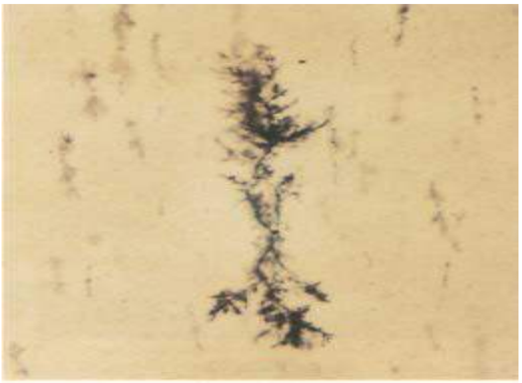
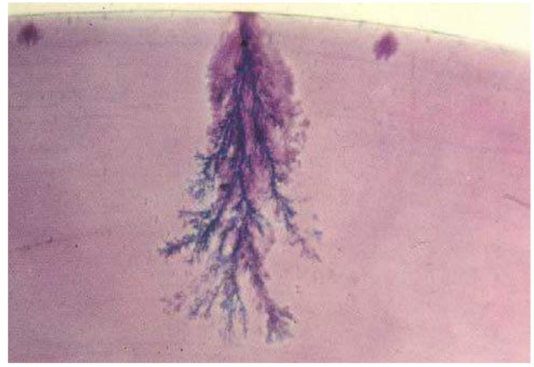


Fig.2. Bow tie tree

Power cable insulations are submitted during service to permanent and accidental stresses (electrical, thermal, mechanical, water, radiations etc.). Under the effect of these stresses, the insulations suffer different degradation processes, which lead both to the decrease of physical properties and to the reduction of lifetime [4]. As heat, oxygen and moisture are considered as main ageing agents, heat-resistant (cross-linked) polyethylene, oxygen-resistant polyethylene (with anti-oxidants) and water-tree resistant polyethylene (containing water-tree retardants) have been manufactured [5-6]. Moreover, the cable manufacturers provide the cables with barriers against moisture and water trees. However, most of the operating medium voltage cables are not equipped with barrier against water penetration, and their insulations do not contain water tree retardants. Tests allowing to detect the water trees' presence in cable insulation and to estimate the insulation ageing state and the remaining life are therefore needed.

Several methods, from which ones are already used whilst the others are still being experimented, have been proposed for this purpose [7-9].This paper deals with thermal and water tree ageing of polyethylene insulation used for medium voltage cables. Laboratory-made flat polyethylene samples have been aged thermally and under the effect of water and ac electric field, at high frequency fields.



Shielding of an electric power cable is accomplished by surrounding the insulation of asingle conductor or assembly of insulated conductors with a grounded, conductingmedium. This confines the electric field to the inside of this shield. Two distinct types ofshields are used: metallic and a combination of nonmetallic and metallic.The purposes of the insulation shield are to:

- Obtain symmetrical radial stress distribution within the insulation.
- Exclude from the electric field those materials such as braids, tapes,and fillers that are not intended as insulation.
- Eliminate tangential and longitudinal stresses on the surface of the insulation.
- Protect the cables from induced or direct over voltages. Shields dothis by making the surge impedance uniform along the length of the cableand by helping to attenuate surge potentials.

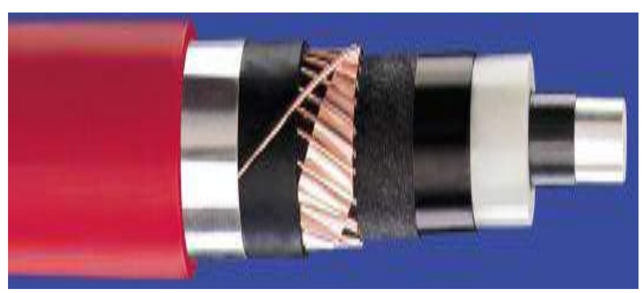


Fig.3. Single core XLPE cable, with aluminum and copper conductor

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II. LITERATURE SURVEY

Electrical insulation materials are utilized to provide electrical isolation over the metallic conductors of underground cables. The insulating materials physically protect the conductor and provide a margin of safety. These materials are comprised of either synthetic or natural polymers. The polymeric insulation material selected for use may vary with the voltage class of the cable. Compatible polymeric shields are employed between the insulation and the conductor, and over the insulation to grade the voltage stress; these are comprised of flexible polymers blended with conducting carbon black that imparts the semiconducting characteristics.

In addition to use as primary insulation, polymers are employed as components ofconductor and insulation shields. These materials are ethylene copolymers that possessquantities of carbon black (and sometimes other ingredients) to provide thesemiconducting properties required for shields. The co-polymer itself can be viewed as a"carrier", but this carrier must possess the property of controlled adhesion to theinsulation. It is the use of a conducting material dispersed throughout the polymer matrixthat makes the mixture semi-conducting in nature; hence the term "semiconducting" isapplied to shield materials.

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MV cable: The insulation shield for a medium voltage cable is made up of two components: (1) asemi conducting or stress relief layer and (2) a metallic layer of tape or tapes, drain wires,concentric neutral wires, or a metal tube. They must function as a unit for a cable toachieve a long service life.

The two main types of MV cable are PILC (Paper InsulatedLead Covered) and XLPE (Cross Linked Polyethylene)cables. These names refer to the material being used toisolate the "live" parts of the cable from the surroundingearth, which is oil impregnated paper and polyethylenerespectively. The first type, PILC cable, has been used forseveral decades, so that large parts of the present electricitynetworks consist of this type of cable. However, during the last 20 to 30 years it has gradually given way to XLPEcable and hardly any PILC cables are installed anymoretoday.

The insulation systems of high-voltage power cables and their accessories are subject todifferent kinds of stresses during their service life and thus suffer degradation and deterioration.These can lead to a reduction of life which in turn can lower the reliability of electrical powersystems. Therefore, a lot of research effort, activities and publications are directed towards abetter understanding of degradation phenomena, the finding of tools for insulation diagnosis andthe establishment of remaining life estimation techniques. In order to check the quality anddependability of a cable system, it is important to perform diagnostic tests before putting thecable system into operation and after a defined period of operation. On-site insulation diagnosisto determine the degradation state of high voltage equipment is of great interest within the powerand grid companies and utilities.

It is impossible to carry out diagnostics measurements on all cable systems in use. It is evenharder to carry out full laboratory scale testing of every cable system in use. Cable insulationmust be stripped and cut during the repair of a cable fault. This is a natural point to collect cableinsulation samples for further analysis. Analysis results should give more information about theactual condition of the cable insulation system.

III. INSULATION AGEING

Generally in services, an insulation systemsubjected to one or more stress that causesirreversible changes of insulating material propertieswith time. This progressively reduces the attitude ofinsulation in enduring the stress itself. This processis called ageing deterioration and ends when theinsulation is no longer to withstand the appliedstress. The relevant time is the time-to-failure ortime-to-breakdown, alternatively called insulationlife time [11]. The main causes of ageing ofpolymeric cables [10] are:

a) Thermal degradation.
b) Partial discharges due to manufacturingimperfections or to mechanical damage.
c) Water trees, i.e. tree-like micro-cracks thatgrow from internal defects when the insulation issubjected to electrical stress and moisture.
d) Aggression by the environment.
e) Losses.

IV. AGEING MODELS

Although many models and theories have beenproposed for ageing of insulating material but feware reliable, mainly due to they are unable todescribe all the interactions among the variousparameters. Insulation life time modeling consists oflooking for adequate relationships among insulationlife time and the magnitude of the stress applied toit. In the case of electrical insulation for polymerichigh voltage cables, the stresses most commonlyapplied in service are an electric field due tovoltage, temperature and loss, however otherstresses, such as mechanical stresses (bending,vibration) and environmental stresses (such aspollution, humidity) can be presented.A physical life model is one of ageing modelsthat its model parameters can be estimated only afterlife tests, often lasting for a very long time. Thesearch for physical models, based on the descriptionof specific degradation mechanisms assumed aspredominant within proper ranges of appliedstresses. Such models are characterized by physicalparameters that can be determined by directmeasuring physical quantities. Some examples of physical models are as follows.

- Field Emission Model
- Treeing growth model
- Thermodynamic Model

V. ESTIMATION METHOD

Electrical lifetime estimation methods allow the lifetime estimation of polyethylene insulations of underground power cables subjected to electric field stresses in the presence of water. For this, samples taken from model cables are used. They are insulated with layers of thickness g = 0.5...1 mm of the samePolyethylene as the one used for cables and obtained by the same technological process (temperature, pressure etc.). This method involves performing accelerated ageing in an electric field equalto the maximum field value of the cable insulation during operation (Emax),respectively the electric field strength value in the points from the vicinity of theinner semiconductor:

$$E_{\max} = \frac{V}{R_i \cdot \ln \frac{R_e}{R_i}} ,$$

where V represents the nominal voltage of cable, Ri– the inner radius and Re – theouter radius of the insulation.

The ageing voltage values of the $Vt$are determined with the relation:

$$Vt = E\max . ri . \ln(re/ri),$$

where $ri = d/2$ represents the conductor curvature of the tested sample and $re = ri + g$ – its outer radius.

VI. CONCLUSION

It was concluded that many factors affect the speed of degradation of a Medium Voltage cable system and that the degradation mechanisms vary between different types of cables and accessories. It was also pointed out that various analytical methods exist to determine the extent of ageing. The use of intense fields and/or high ageing frequencies field allows the growth of water trees with relatively large dimensions in short ageing times.The increase of ageing time determines a considerable increase in water trees dimensions and a reduction of the breakdown voltage of power cables polyethylene insulations. The method proposed allows a quick estimation of the electrical lifetime of underground power cable insulations.The use of polyethylene power cable in water will degrade the cable life.

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