EVALUATION OF 11kV XLPE CABLE

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ABSTRACT

Underground power cables constitute a bulk part of power systems network. Most of these power system equipments have been in service for decades, thus making their insulation liable to deterioration (ageing) as a result of operational and environmental stresses. For the past decades, the Recovery Voltage Method (RVM) has been widely used to evaluate ageing in oil-paper insulated cables. This work presents the evaluation of ageing in 11kV XLPE cable using the RVM. Statistical Analysis was employed to predict the progress of ageing. Accelerated ageing using AC and impulse voltages was performed on new XLPE cable samples. Within the period of ageing, the state of insulation was investigated and assessed using the RVM. Regression Analysis was used to predict the progress of ageing in cables, with the CTC (central time constant) being the response variable. However due to technical problems encountered in the course of this study, synthetic data were used to model the regression equation. The result of the diagnosis using the RVM showed that the aged XLPE cables had higher values of U_{rmax} (maximum return voltage) than the unaged ones, indicating the samples have undergone thermal ageing. An R^2 of 0.981 was obtained from the regression equation, implying that the predicted values of the CTC were 98.1% close to the observed values. The RVM technique, which was initially proposed for diagnosis of oil-paper insulation systems, was found to be able to detect ageing in XLPE cables, and thus insulation diagnosis using this technique could be extended to extruded-insulated cable systems. The Regression Analysis, a tool for forecasting and prediction, can be used to predict the progress of insulation deterioration and ageing.

ABSTRAK

Kabel-kabel kuasa bawah tanah membentuk sebahagian besar daripada rangkaian sistem-sistem kuasa. Kebanyakan peralatan sistem kuasa ini telah berada di dalam perkhidmatan untuk beberapa dekad, yang menjadikan penebatannya terdedah kepada kemerosotan (penuaan) sebagai kesan dari tegasan kendalian dan persekitaran. Untuk beberapa dekad yang lepas, Kaedah Pemulihan Voltan (RVM) telah digunakan secara meluas untuk menilai proses degradasi di dalam kabel-kabel bertebat minyak-kertas. Tugasan ini mempersembahkan penilaian proses degradasi di dalam kabel XLPE 11kV menggunakan kaedah RVM. Analisis Statistik telah digunakan untuk meramal proses degradasi tersebut. Proses degradasi terpecut menggunakan voltan-voltan AC dan dedenyut telah dilakukan ke atas beberapa sampel kabel XLPE yang baru. Sepanjang tempoh proses degradasi, keadaan penebatan telah dikaji dan dinilai menggunakan kaedah RVM. Analisis Regresi telah digunakan untuk meramal perkembangan proses degradasi di dalam kabel-kabel, dengan CTC (masa malar berpusat) sebagai pembolehubah sambutan. Walaubagaimanapun, disebabkan beberapa masalah teknikal yang dihadapi di dalam kajian ini, data sintetik telah digunakan untuk memodelkan persamaan regresi. Keputusan dari diagnosis menggunakan RVM menunjukkan bahawa kabel-kabel XLPE yang telah mengalami kemerosotan mempunyai nilai-nilai U_{rmax} (voltan kembali maksimum) yang lebih tinggi berbanding yang tidak mengalami kemerosotan. R^2 dengan nilai 0.981 telah diperolehi dari persamaan regresi, menunjukkan bahawa nilai-nilai CTC yang diramal adalah 98.1% hampir dengan nilai yang dicerap. Kaedah RVM, yang pada mulanya dicadangkan untuk diagnosis sistem-sistem penebatan minyak-kertas, telah didapati mampu untuk mengesan proses degradasi di dalam kabel-kabel XLPE, dan oleh itu diagnosis penebatan menggunakan teknik ini boleh dipanjangkan kepada sistem-sistem kabel tertebat-tersemperit. Analisis Regresi, satu alat untuk peramalan dan penganggaran, boleh digunakan untuk meramal perkembangan proses degradasi.

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LIST OF ABBREVIATIONS AND SYMBOLS

AC - Alternating Current
BIL - Basic Impulse Insulation Level
C - Geometric capacitance measured between the two terminals of an insulation under test
C-O - Carbon - Oxygen bond
C-C - Carbon – Carbon bond
CO - Carbon monoxide
CO_2 - Carbon dioxide
C_o - Capacitance of parallel plate separated by a vacuum
Cl - Chlorine
CTC - Central Time Constant
DC - Direct Current
DR - Dielectric Response
DS - Division Spectrum
dU_r/dt - Return voltage initial slope
EHV - Extra High Voltage
emf - Electromagnetic force
EPR - Ethylene-propylene-rubber
ft - feet
HMWPE High Molecular Weight Polyethylene
H_2 - Hydrogen molecule
HV - High Voltage
IEEE - Institution of Electrical and Electronics Engineers
kV - Kilovolts
LV - Low Voltage
m - metre
mm - millimetre

MHz - Mega Hertz
OPIC - Oil-impregnated Paper Insulated Cable
PD - Partial Discharge
PE - Polyethylene
PILC - Paper Insulated Lead Cable
PVC - Polyvinyl Chloride
rms - root-mean-square
RF - Radio Frequency
RV - Return/Recovery Voltage
RVM - Recovery Voltage Method
s - Standard Deviation
SEE - Standard Error of Estimate
S_D - Slope of decay voltage
S_R - Slope of return voltage
$\tan \delta$ - loss tangent/dissipation factor
URD - Urban Residential Distribution
U_o - Applied Voltage
U_{rmax} - Maximum return voltage
$U_r(t)$ - Return Voltage slope
V - Voltage
V_o - Applied AC Voltage
VR - Voltage Response
XLPE - Cross-linked Polyethylene
Z - Impedance
ε_o - Permittivity of vacuum
ε_r - relative permittivity or dielectric constant
ω - Frequency
σ - Conductivity
$\overline{X}$ - Mean
$\sum$ - Summation
μs - microseconds

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CHAPTER 1

INTRODUCTION

1.1 Background

With the discovery of electricity in the early 19th Century, today virtually all countries in the world utilize electricity efficiently as a source of light and energy. This has led to the existence of transmission and distribution system (which are connected together) carrying current, albeit at different voltages and transporting it over long distances to the end users.

Most of the bulk electrical energy generated from the generation centres is being transported to major load centres within a large geographical area by the transmission systems using overhead circuits (lines). On the other hand, the distribution system delivers the electrical energy from these load centres to customers who are within a smaller geographical area. Most of these customers may be either residential or industrial located in urban areas. For safety, reliability and aesthetics, the electric circuits used to transport energy to such customers are usually underground power cables, though this kind of arrangement is expensive but has more advantages than the overhead lines [9].

Over the years, high demand of reliable electricity power supply has led the electricity markets highly competitive, electric utility companies now have to devise means of maintaining, enhancing the safety and reliability of their expensive power system components to operate profitably and meet the demands of their customers.

One of such power system component that constitutes a bulk part of the transmission and distribution systems in urban areas is the underground power cable. For example, in the United Kingdom there are about 93000km of 11kV cable and more than 13000km of 33kV [6]. Here in Malaysia with fast pace of development, which has led to increasing demands of electric energy, underground cable distribution is increasing significantly. It is estimated that there are about 180,000km of underground cables in Malaysia, forming about 80% of the underground power distribution system.

1.2 Development of Power Cables

Power cable technology had its beginnings in the 1880s when the need for power distribution cables became pressing, following the introduction of incandescent lighting. With urban growth, it became moreover increasingly necessary to replace some of the overhead lines for power transmission and distribution with underground cables. The illumination of the larger cities proceeded at such a rapid pace that under some circumstances it was impossible to accommodate the number and size of feeders required for distribution, using the overhead line system approach. In fact this situation deteriorated so notably in New York City that, in addition to the technical and aesthetic considerations, the overhead line system began to pose a safety hazard to the lineworkers themselves, the firemen, and the public. As a result, the city passed an ordinance law in 1884 requiring the removal of the overhead line structures and the replacement of these with underground cables. Similar laws and public pressure were applied in other cities, with the consequence that by the early 1900s, underground electrification via insulated cables was on its way to becoming a well-established practice [19].

A practical lead press was invented in 1879 and subsequently employed to manufacture 2-kV cables for Vienna in 1885. During the same period vulcanized rubber was used to produce cables on a commercial scale, although use of gutta-percha had already been made as early as 1846. Impregnated-paper power cables were first put on the market in 1894 by Callender Cables of England, using impregnant mixtures of rosin oil, rosin and castor oil; only in 1918 were these replaced by mineral oils. In North America impregnated-paper cables were first supplied by the Norwich Wire Company. Varnished cambric cables were introduced by the General Electric Company in 1902; the high-temperature behavior of these cables was subsequently improved the addition of black asphalt.

Some of the more common early solid and liquid insulating employed in various underground cable installations were natural rubber, gutta-percha, oil and wax, rosin and asphalt, jute, hemp, and cotton. In 1890 Ferranti developed the first oil-impregnated-paper power cable; following their manufacture, his cables were installed in London in 1891 for 10-kV operation. The cables were made in 20-ft lengths; as the total circuit was 30 miles in length about splicing joints were required. Nevertheless, these cables performed so well that the last cable length was removed from service only in 1933.

Cable installation continued to proceed at a rapid pace, so that by the turn of the 20th century many major cities throughout the world had many miles of underground power cables. For example, already by the end of 1909, the Commonwealth Edison Company in Chicago had 400 miles of underground cable operated in the voltage range from 9 to 20 kV. Montreal had some 4500-ft circuits of three-conductor cables installed in ducts under the Lachine canal for 25-kV operation; the same voltage was used for cable traversing the St. Lawrence River in 1906. With some experiences behind them, cable manufacturers were increasingly gaining confidence and during the St. Louis Exposition in 1904 power cables developed for voltages as high as 50 kV were put on display [19].

1.2.1 Oil-paper Insulated Cables

OPIC are cables composed of paper strips wound over a solid or stranded copper conductors and impregnated with dielectric fluid (oil).

They were introduced many decades ago, in the early 20th century. Frequently, the mineral oil impregnants are replaced by other dielectric liquids, and for this reason oil-impregnated paper insulated power cables are commonly referred to also as dielectric-liquid-impregnated paper insulated power cables. [19]

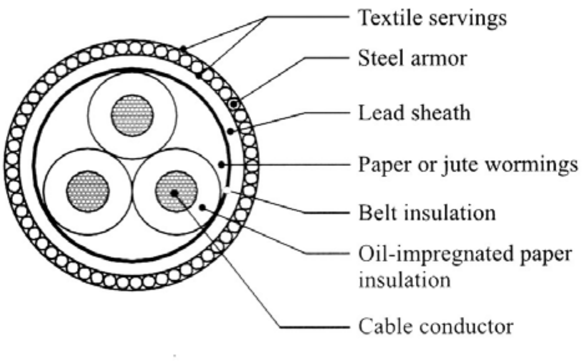

Figure 1.2.1 Cross-section of an Oil-impregnated Paper Insulated Cable

In many utilities a substantial portion of the present-day distribution load is still carried at 35 kV via three-phase oil-impregnated paper belted cables, with the three conductors individually grounded. There is little inducement to replace these cables with solid extruded dielectric cables, whose outer diameter for an equivalent power rating would exceed that of the ducts accommodating the more compact three-phase oil-paper belted cables. Moreover, the oil-paper belted cables have been characterized by remarkably long in-service lifetimes that often exceed 65 years. Belted cables with unshielded conductors are still deployed but only for working voltages equal to or less than 15 kV.

With the individual conductors shielded, it was possible to extend the use of the three-phase belted cables for voltages as high as 69 kV, though on the average their application has been confined to voltages below 35 kV. The main reason for this upper limit has again been associated with the occurrence of partial discharges, which had in numerous instances led to the deterioration and failure of the dielectric at the elevated voltages. The partial discharges were found to take place in voids, which were formed either during the manufacturing process or during the load cycling while in service.

1.2.2 Solid-Dielectric-Extruded Power Cables

With the discovery of the hydrocarbon thermoplastic polyethylene (PE) in England in 1933, polyethylene became rapidly, the insulant of choice for RF coaxial cables. PE was first used as an insulant for power cables in the 1950s.

In the mid 1960s, conventional PE became the material of choice for the rapidly expanding URD systems in the United States. It was known to be superior to butyl rubber for moisture resistance, and could be readily extruded. It was used with tape shields, which achieved their semiconducting properties because of carbon black. By 1968, virtually all of the URD installations consisted of polyethylene-insulated medium voltage cables. The polyethylene was referred to as HMWPE; this simply meant that the insulation used had a very high “average” molecular weight. The higher the molecular weight, the better the electrical properties. The highest molecular weight PE that could be readily extruded was adopted. Jacketed construction was seldom employed at that time. Extruded thermoplastic shields were introduced between 1965 and 1975 leading both to easier processing and better reliability of the cable [32].

XLPE was first patented in 1959 for a filled compound and in 1963 for unfilled by Dr. Frank Precopio. It was not widely used because of the tremendous pressure to keep the cost of URD down near the cost of an overhead system. This higher cost was caused by the need for additives (crosslinking agents) and the cost of manufacturing based on the need for massive, continuous vulcanizing (CV) tubes. EPR was introduced at about the same time. The significantly higher initial cost of these cables slowed their acceptance for utility purposes until the 1980s. The superior operating and allowable emergency temperatures of XLPE and EPR made them the choice for feeder cables in commercial and industrial applications. These materials do not melt and flow like HMWPE.

The emergence of power distribution cables insulated with PE have replaced a significant portion of the oil-impregnated-paper insulated power cables used at operating voltages up to 35 kV. But lower voltage PILC cables are still being manufactured, due to their in-service longevity and reliability.

In spite the long record of service and reliability of PILC cables, they are being gradually replaced by the less hygroscopic polymeric insulated cables, XLPE. XLPE cables have distinct advantages viz. lighter weight, better electrical and thermal properties, less maintenance, and easier terminating and jointing procedure etc. Today XLPE cables are being extensively used in many countries all over the world. In 1959, Japan and USA commercialized XLPE cables up to medium voltage rating. Since then a fast development of XLPE cables has taken place. Presently, XLPE cable of 500KV class has been installed in Japan.

The introduction of XLPE has increased the capability of polymeric insulated cables because of their higher temperature ratings. XLPE insulations perform well at elevated temperatures. Their normal operating temperature is about 90^{o}C and designed to withstand an emergency overload and short circuit ratings of 130 and 250^{o}C, respectively.

1.2.2.1 XLPE Cable Technology

The basic material for XLPE cable is polyethylene (PE). PE has very good electrical properties; however, its mechanical strength decreases significantly above 75°C restricting its continuous operating temperature to 70°C only. The improved thermal characteristics of PE are obtained by establishing a large number of cross-links between its liner molecular chains employing suitable techniques. The introduction of XLPE has increased the capability of polymeric insulated cables because of their higher temperature ratings. XLPE insulations perform well at elevated temperatures. Their normal operating temperature is about 90^{o}C and designed to withstand an emergency overload and short circuit ratings of 130 and 250^{o}C, respectively. The processes for converting PE to XLPE are Electron irradiation, chemical cross linking, organic silane method.

Electron irradiation is a slow process and it is difficult to ensure an even degree of crosslinking throughout the thick insulation required for power cables. Therefore this process is usually restricted to thin insulation of 1 to 2 mm thickness only. Chemical crosslinking process is the process by which cross-linking of PE is established using organic peroxide such as dicumyl peroxide (dcp) at high temperature in the range 250 to 350°C and pressure 15-20 kg/cm^2. This method is employed in the production of XLPE cables of all voltage range, from LV to EHV. Sioplas technique is a relatively new method of crosslinking PE into XLPE. Cross linking is achieved by mixing suitable silane to PE and exposing this to ambient conditions. This method has the distinct advantage of lower capital expenditure as no special arrangements to maintain high pressure and temperature are required. But the process is very slow for thick insulation and hence restricted to low voltage and medium voltage XLPE cables.

The general construction of XLPE cable consists of copper or aluminium conductor, extruded layer of semiconducting material over conductor (for voltage class above 3.3kV), extruded XLPE insulation, extruded layer of semiconducting material (for cables of voltage rating above 3.3kV), copper wire or tape as metallic screen, armour, inner sheath and outer sheath, usually made of PVC etc. Three core XLPE cables are generally used up to maximum 33kV. Cables of 66kV and above voltage rating are of single core construction.

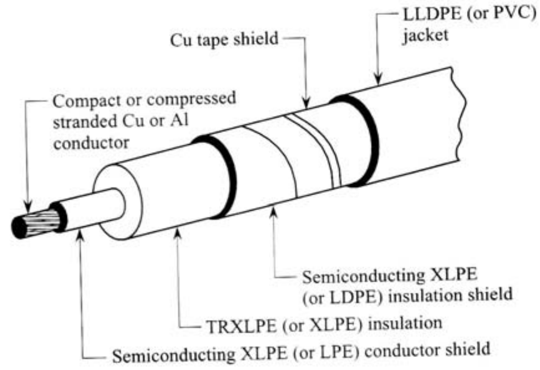

Figure 1.2.2 Solid dielectric extruded power cable [19]

The manufacturing process of XLPE cables consists of mixing of PE with crosslinking agent (dcp) and antioxidants, extrusion of semiconducting layers and insulation over the conductor, crosslinking the PE compound in curing lines at high temperature and pressure and cooling the core to ambient temperature. All these processes are carried out in one step employing catenary lines for curing and cooling, hence the name continuous catenary vulcanization. Semiconducting layers and insulation are extruded using triple extrusion technique. The curing process was initially carried out with steam at high temperature and pressure. This resulted in the formation of microvoids within the insulation and restricted the application of steam curing process up to 33kV. To achieve reliable HV cables, it was therefore necessary to employ curing in the absence of steam. For this reason, dry curing methods were developed, where PE was crosslinked under nitrogen pressure in silicone oil, in molten salt and also in long dies. The numbers of microvoids were drastically reduced. A new curing process has recently appeared namely silane process which is more economical.

XLPE has become the most favoured insulant. Germany, USA, Asian and Scandinavian countries have installed vast quantities of such cables. Japan has developed XLPE cables up to 500kV which is the highest voltage rating of XLPE cables manufactured so far.

Table 1.2.2 Comparative properties of some cable insulating materials

	PVC			Polyethylene			
Property	Flexible	Semiegid	Irradiated	Low Density	High Density	Cross-Linked	Impregnated Paper
Max. Operating Temp.	60 – 105	80	105	80	90	125	-
Dielectric Constant (1Mhz)	6.2 max	4.3	2.7	2.28	2.34	2.3	3.3 – 3.9
Dissipation Factor	-	0.1 max	-	0.0005	0.0007	0.0003	0.0026 – 0.003 (0.14 at 80°C)
Dielectric Strength (kV/mm)	-	-	-	21.6	19.7	21.6	74

1.3 Losses in Cables

Cable losses include losses in conductor, insulation, sheath, screens armors. Conductor losses (I^2R_{ac} losses) depend upon the rms current I effective AC resistance of the cable conductor R, Dielectric losses comprise of losses due to leakage through the cable insulation and caused by dielectric polarization under AC stresses.

The net dielectric losses depend upon cable voltage, its frequency as well as the permittivity and loss tangent of the cable dielectric material, as shown by the equation below

$$\text{Power loss} = \omega C_o V^2 \varepsilon_r \tan \delta \quad [9]$$

Generally, tan δ, which partially controls the dielectric losses, is significantly higher for oil-paper insulation as compared to XLPE insulation. For most of the dielectric materials used in cables, tan δ depends upon temperature, applied stress and supply frequency. For oil-paper insulation tan δ is also strongly influenced by moisture content. Therefore, in voltage cables, a moisture level of less than 0.05% is desirable in order keep dielectric losses within acceptable limits. The presence of voids and microcracks can also influence dielectric losses. These voids are formed in the insulation or at the screens/insulation interfaces during manufacture, installation or operation. In polymeric cables, they are formed during the extrusion process while in paper-insulated cables, during the impregnation cycle. Voids may also form in cables by the differential expansion contraction of cable materials due to cyclic loading or short-circuit conditions. These voids have a higher electric stress as compared to the bulk ' insulation. However, the gas inside a void usually has a lower breakdown strength as compared to the main insulation. When the electric stress in void exceeds the breakdown strength of gas within the void, PD occurs.

Any partial discharge in such voids increases the effective tan δ value for insulation. Consequently, when the applied voltage is raised above the charge inception threshold, the dielectric losses exhibit a distinct increase. Similarly, impurities in the cable insulation and screening materials also increase dielectric losses.

The AC current flowing along each cable conductor induces emf the metallic sheaths of the cable. Without grounding, such sheaths would operate at a potential above the ground potential and can pose a hazard. Furthermore, it will accelerate degradation of the jacket and materials, thereby affecting the cable's life and reliability. When the sheaths are bonded, circulating current flows in them causing power losses. However, for three-core cables such losses are negligible. In addition to circulating currents, eddy currents are also induced in sheaths of both single and multicore cables causing additional losses which usually are of small magnitudes.

1.4 Cable Ampacity

The ampacity or current carrying capacity of a cable is defined as the maximum current which the cable can carry continuously without the temperature at any point in the insulation exceeding the limits specified for the respectively material. The ampacity depends upon the rate of heat generation within the cable as well as the rate of heat dissipation from the cable to the surroundings. The rate of heat generation within a cable depends upon various losses in the cable, whereas the rate of heat dissipation depends upon the thermal resistances of different cable materials and the media surrounding the cable.

When the rate of heat generated cannot be lost to the surrounding, thermal imbalance occurs. This causes rise in temperature of the insulation, which results in increased dielectric losses leading to a thermal runaway situation [10].

1.5 Treeing in Cables

Treeing is an electrical pre-breakdown phenomenon. This name is given to any type of damage which progresses through a stressed dielectric so that, if visible, its path resembles the form of a tree. Tree-like discharge patterns, sometimes leading to total breakdown of the insulation, have been observed many years in oil-impregnated pressboard and in oil-impregnated paper insulated cables, Treeing can occur in most solid dielectrics including glass porcelain but it is a serious problem in polymers, rubbers and epoxy resins, etc. Treeing may or may not be followed by complete electrical breakdown of the insulation; but in organic extruded dielectrics, it is the most likely mechanism of dielectric failure which is the result of a lengthy aging process. Electric stress and stress concentration are always required the initiation and growth of trees. Treeing can progress rapidly under high electric stresses in dry dielectrics by periodic partial discharges or more slowly in the presence of moisture at lower electric stresses without any detectable PD. Treeing can occur under DC, AC and impulse voltages[9].

1.5.1 Electrical Trees

Electrical trees initiate and propagate due to high and divergent electric stress at metallic or semiconducting contaminants and/or voids, etc., by partial discharges occurring in a dry dielectric. Such trees consist of hollow channels resulting from decomposition of dielectric material by the PDs. The tree shows up clearly in PE and other translucent solid dielectrics when examined with an optical microscope and transmitted light. Electrical channels are permanently visible and there is a great variety of the visual appearance of stems and branches of such trees as well as the circumstances in which initiation and growth of such trees occur. Trees which start to grow from within the insulation and progress symmetrically wards from the electrodes are called bow-tie trees because of their appearance. On the other hand, trees which initiate at an electrode (or semiconductive screen) insulation interface and progress towards the opposite electrode are called vented trees.

Access to free air is an important factor in the growth of a vented tree. Such trees are capable of growing continuously and long enough to bridge the electrodes or cause a dielectric failure. Bow-ties or non-vented trees do not have a free supply of air to support continuous PDs. Therefore, the growth of such trees is intermittent and discharge occurs with longer periods of extinction which is believed to be due to an increased void pressure resulting from ionization. During the extinction period, gas pressure in the tree channel is reduced by diffusion and conditions become favorable for the occurrence of another PD causing further growth of the tree.

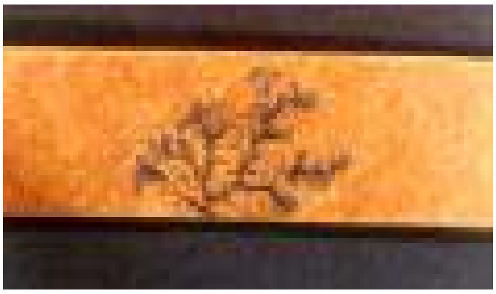

Figure 1.5.1 Electrical trees in a paper insulated cable

There are two distinct periods in electrical treeing. The first is an incubation period during which no measurable PD can be detected, but the end of which a tree-like figure is first observed. The second is a propagation period during which a tree-like figure grows in the insulation significant PD magnitude can be measured. The incubation period depends upon the stress level and distribution at the initiation site, the composition and properties of dielectric and the environmental conditions. Generally, at low stress level cumulative processes are proceeding and eventually foster conditions which initiate treeing [9].

1.5.2 Water Trees

The tree-like figures which appear in water-exposed polymer-insulated stressed cables are named water trees. Water treeing occurs in the presence of moisture. As compared to electrical treeing, water treeing usually starts at lower electric stress values and progresses more slowly without detectable PDs.

Water (or wet) trees are different from electrical (or dry) trees. The propagation time of water trees is measured in years whereas once initiated an electrical tree can quickly propagate through the insulation e.g under the influence of surge overvoltages. The appearance of the two types is usually different from each other as water trees do not exhibit much branching. However, sometimes the two are difficult to distinguish.

Figure 1.5.2 Water trees in extruded insulation

Similar to electrical trees, there are two basic types of water trees, namely, bow-ties and vented trees. Vented trees initiated at the insulation surfaces whereas bow-tie trees are initiated in insulation volume. Both types have different growth behavior and different levels of danger. Both types grow from points having high electric stress values which are also moisture or moisture vapor sources. The moisture source may consist of condensed water or water vapor of approximately 65 – 70% relative humidity. The water vapor may become available from external sources or may be contained in the dielectric during the cable manufacturing.

The concentration of vented trees is often low compared to that bow-tie trees, and at the beginning of their growth, the propagation rate of vented trees is normally lower than that of bow-tie trees. However, at later stage, the opposite may be true since the growth of bow-tie trees is strongly reduced after a certain time and, therefore, their total length restricted. Consequently, a bow-tie water tree is seldom the origin of breakdown. However, vented water trees usually have access to water and are capable of growing long enough to bridge the dielectric. Alternatively such trees may grow long enough to reduce the effective insulation thickness below that required to support the electric stress, after which failure may occur by electrical treeing.

1.6 Objective of study

i. To study and evaluate ageing in medium-voltage power cables.

ii. To predict the progress of ageing and deterioration in medium-voltage power cables.

1.7 Scope of Study

i. This research work will focus on XLPE cables.

ii. Ageing mechanisms in medium-voltage power cables will be studied and identified.

iii. Dielectric Response Measurement will be used to evaluate ageing in XLPE cable.

iv. A technique will be developed to predict progress of ageing in power cables using statistical analysis.