Electrical and Environmental Aging of Modern Cable Insulation

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***Abstract*— Reliable distribution and utilization of electrical power is a challenging demand in today's power market. Distribution and utilization of electrical energy all over the world has a mixed combination of underground and overhead systems. Overhead system has low cost but suffers from different kinds of failures. In order to ensure extreme reliability, utilities in developed countries prefer underground distribution systems. The major cost difference between overhead and underground system is that of electrical insulation and mechanical shielding. In addition to cost, insulation itself poses many problems of dielectric failure and corresponding faults. Due to these factors many researchers are working on electrical, mechanical and environmental factors which can cause early failure of underground cable insulation. In this paper, the research is going on electrical and environmental testing and aging of underground cable insulation material is presented. Research on different cable insulation materials like XLPE, EPR, LDPE and other blends when used in different configurations along with oil and paper is presented. Dielectric spectroscopy, dielectric characterization, conduction modelling and step stress tests used by different researchers to estimate aging of cable insulation are also presented. Literature presented in this paper is particularly useful for cable manufacturers and researchers working in the field of cable insulation.**

Keywords*— Insulation aging; dielectric spectroscopy for insulation; conduction modelling of insulation; XLPE; extruded cable;

I. INTRODUCTION

All over the world energy utilization is increasing every day. Unlike transmission and distribution, the utilization of electrical energy in domestic/industry sector cannot be done with overhead/bare cables. With the growing industry and population, the demand of underground cables is increasing. The most common problems which underground cable suffer are mechanical stress and thermal/environmental degradation. The mechanical stresses can be classified as internal and external. Internal stresses can be due to manufacturing faults (like annealing fault) and air voids etc. The external stresses include bending and torsional loading effects. The electrical stresses include capacitive currents which in case of dc are further intense. The environmental stress includes chemicals and other attacking substances in soils. To date most commonly used insulation materials for underground cables are extruded cross-linked polyethylene, ethylene propylene rubber and low density polyethylene (LDPE).

XLPE is used since long time in high voltage cables because of its excellent dielectric, thermal and mechanical properties. Nowadays EPR and LDPE are also very common for underground cables. However, all these materials suffer from some kind of degradation after long term exposure to stresses which are present in service environment. The electrical and environmental aging phenomena in underground cable insulation materials are still under investigation all over the world. The most common reason of failure is reported to be formation of sub-micro cavity. To prevent this cavity formation, the intermolecular bond can be broken down by the energy and the required energy should be higher than the energy of solidity of the insulation material. After long duration aging in high electric fields, sub micro cavities may coalesce to eventually form micro cavities.

In recent year's extruded cable have also been used in some transmission systems. A number of projects have used XLPE and HDPE in HV and EHV applications. In most of the research it is reported that their deterioration is more dependent on imperfections with in the insulation materials instead of electrical stresses and environmental factors. This paper presents the research on aging performance of underground cable insulation materials, techniques to estimate the state of health for these materials along with a focus on recent developments.

II. AGING PHENOMENA IN UNDERGROUND CABLES

Nowadays mostly used the polymeric materials for insulation are LDPE, XLPE and EPR. XPLE has the breakdown strength of about 300KV/cm. It has the enhanced melting point 75-90 °C [1]. Dielectric Breakdown strength for LDPE is 109-116 kv/mm [2]. First, E. David et.al, [3] investigated the use of XLPE insulated cable under different mechanical and environmental stresses. When thermal mechanical and environmental stresses were applied for long time in combination with electrical stress, performance degraded. Mechanical stresses were internal (fabrication cooling) and external stress (bending) while thermo-mechanical stress was the thermal expansion of insulation material Sample in a plan and pin geometry measured to analyze the effect of machine-driven strains on the characteristics of the dielectric PE.

The first type of geometry used the ribbon unwrapped from chuck wires and the ductile machine-driven strain was utilized in vertical to electric flux. In second type of geometry, measurements were also taken from cross-linked polyethylene insulation. and low density polyethylene models with different magnitude of remaining machine-driven strains across the integrated electrode. At different voltages the growth rate of electrical trees and the time to inception were reported in this research. The highest residual stress has the shortest inception time and under different voltages taking highest value later one hour maturing. The measured treeing resistance improved significantly when the mechanical stress was removed. It observed that electrical and mechanical stresses reduce dielectric properties and dielectric strength of materials. The magnitude of stress can be classified as time to break, tree length and break down field.

M. Muhr, et. al, [4] reported that Thermal, electrical, environmental and mechanical stress affects the insulation system of XLPE. The probability of increasing breakdown of

XLPE shielded high voltage wires as given facility due to technical issues, the conductivity of the materials and little feeble points. The process of electric charge reduces the strength of dielectric charge of dense fenced XLPE insulation. After lab tests performed on the cable model, one can predict the strength of double charging of XLPE high voltage and extra-high voltage wires [5, 6]. Weibull distribution is used to determine the parameters of insulated wires polymers and power cables to attain the highest consistency in the package and selecting the best materials for the development of polymer insulation. It is also good for efficient tests and optimal dimensioning.

J. C. Fothergill et.al, [7] investigated the Underground Residential Distribution wire situation analysis. The research describes the outcomes after a master package designed on an underground primary distribution system. This system serves a lot of closely occupied areas in a residential area of City New York. The expertise utilized in this master package is the measurement of power frequency which has the capability to evaluate the situation of the underground distribution wire structure and can be utilized to make choices on the wire structure health. This master package facilitated the wire manufacturer to look into the possible problems and worth of the wire consistency. The cables were tested and again laid down for service. It can be reverified in the impending. Some of the wire pieces will be detached from provision at any time which was investigated at Consolidated Edison's Wire and Connection Center to find out the types and nature of the faults in the field. Con. Edison operations directors and engineers are processing to progress this program. The purpose of this research is to design strategies to reduce the cost of maintenance and finally refining the wiring structure consistency.

Tong Liu, et al. [8] reported that HVDC cables have greatly improved in recent years. For testing HVDC cables there are many recommendations but still no standards available. A new method to evaluate different parameters of a cable to be used on HVDC is presented in this research. In this method step stress test is used to avoid complex approximation in the data solution, reduce error and easily provide aging parameters. Step stress test is difficult to apply than constant stress test, but it has many advantages which include reduction in time of the test and quick failure occurrence. To solve the problem of parameter evaluation several methods have been introduced and applied. To estimate the data from step stress accelerated test Wayne Nelson [9] improved maximum likelihood estimation method. Maximum likelihood method is not easy to solve, to include the state where the stress change times were random, Chengjie Xiong [10] developed this method. To estimate the parameter from step stress data W. Khachen and J.R Laghari [11] gave an easy and simple method.

G. Mazzanti, [12], proposed the process of the long haul approximation of high voltage alternative current wire by using three models, named as Zurkov, Crine, and Arrhenius-IPM design. This life estimation procedure is for real operating conditions. They account for load cycle, thermal transient and electro thermal synergism. This provide that the life estimation procedure is very feasible in the presence of load cycle. The sensitivity analysis and electro thermal model although have various systematic terminologies and constraint's points, but they give a shared sign of wire strength. The results proved accurate HVAC cable life interference which requires precise explanation of warm air transmission as well as proper models of electro thermal life.

Jean-Luc Parpal et al. [13], proposed a model for electrical aging by using concepts of Eyring theory, Crine and Vijh's model .In this model they focused on molecular chain deformation. Therefore higher frequencies more effected the cable and as a result reduces the life of cables. This model describes that we have two parameters which describes the aging process, one is stimulation vivacity of inter-chain to break the bond and second is the measurement of sub-micro-cavities. Features of model show that the primary way in electrical maturing is the electrically tempted machine-driven distortion in the molecular bonds. The two basic parameters are ΔGo, activation energy of inter-chain breakdown and the length of sub-micro-cavities. These parameters change with applied electric field, temperature, applied pressure and morphology of polymers.

K. Steinfeld and W. Kalkner [14] investigated the degradation phenomenon of the inner semicon layer of extruded cables and for this purpose accelerated aging tests were performed on XPLE cable's core and a model sample, having aluminum wires, semicon and XLPE insulation layer. These tests show that channel like structure are produced in semicon. The vented trees are also initiated when these channel like structure reach to interface of insulation. The experiment result shows that generally the inner semicon is vulnerable to SIED when aged by the effect of aluminum wire, electrolyte and mechanical stress. SIED does not produce cracks. A porous zone is produced which consist of NaOH at molecular scale. SIED structure grows inside the inner semicon layer which leads to vented trees in the adjacent insulations. In the development of SIED, the mechanical stress and electro thermal generation of NaOH play very important role.

M. Marzinotto, G. Mazzanti [15] investigated the influence of Weibull figure constraint and also conduction temperature when negative voltage reduces with wire measurement. They also investigated the behavior of cumbersome function H_{DC}.It is analyzed by Monte Carlo method. An expression is proposed for H_{DC}.This type of analysis shows that use of amplification rule shall perform with overhaul. In enlargement law's the H_{DC} function gives result which have no physical meanings. If two component of this formula lies inside a precise array of points, then specific attention is given to avoid misleading results.

High quality and high level of cleanliness is required for insulation materials used in extruded dielectric medium for transmission of high and extra-high voltages. Methods required for high level of cleanliness of insulation of insulation and smoothness of the semi conductive materials are discussed in this paper by L. H. Gross et al. [16]. The excellent cable parameter requirements for extruded dielectric cable transmission are presented. Besides their extensive use in distribution side, the extruded cables are also increasing their usage in transmission side because of their excellent properties. XLPE and PE cables have low dielectric loss and make the cables long life cables and resistant to thermal mechanical aging. A number of projects in the world are using these materials in HV and EHV applications. Failure mechanism in these cables is associated electrical aging and formation of sub micro cavities and molecular fatigue studied by C. Dang, J. L. Parpal et al. [17, 18].

Mass impregnated paper insulations are completely replaced by the polymeric rubber insulation materials because of their excellent electrical and aging properties. Insulation thickness reduction may result in a considerable reduction in price which is very important. D. meurer [19], investigated different desgns of 4mm thickness XLPE and EPR insulation for voltages of 12/20/24 KV. Result of this study shows that an increase of 30 % in the applied voltage above rated voltage of the cable does not result in any significant degradation in performance of cable.

In past, there were different standards and traditions for the insulation thickness. These standards were developed for mass impregnated paper insulations on the bases of safety regulations and rated voltage. These standards are applied on extruded insulation materials as well. Rather than to adopt geometrical dimensions or standard evaluation methods were adopted by H. Schädlich [20,21] for testing the life span and performance of XLPE or PE cables under wet conditions. Experiments show that it is possible to reduce the dimensions rather than older standard dimensions while maintaining the same life time and performance. This necessitates because the utility companies demand low price cables and suitable possible method is reducing the insulation thickness. Increasing demand of the distribution cables by the utility companies require cost effective cables. This requires less cost of materials particularly the insulation thickness. This can be done by a close co-operation between cable manufacturers and utilities.

The relation between PDs and ETs arising due to imperfections is presented by Nezar Ahmed and Nagu Srinivas [22]. These imperfections may be due to manufacturing faults or during shipping or installation. Extruded cables are not deteriorated due to electrical stresses they encounter during their operation. Rather, their deterioration is associated with imperfections of the insulation material. Imperfections are also due to contaminations, solid particles, cavities and may arise due to shipping and installation studied by EPRI EL-7090 [23]. It is found that the electrical network is the last phase of structure of energy loss. Electrical networks are started from protrusion, metal contaminations, power distribution sites studied by T. Tanaka [24] and alteration of water network into the electrical network. In most conditions, power distribution is not the reason for the electrical network spread.

11 KV XLPE cable is subjected to accelerated or artificial aging and results are investigated using reverse voltage measurement method by Nouruddeen Bashir and Hussein Ahmad [25]. For artificial aging AC voltage is used on the XLPE samples and it is observed that the samples have undergone thermal aging. The RVM method was initially adopt for oil paper insulated cables and this method is also found good for detecting aging in extruded cables. With the growing industry and population, the demand of underground cables is increasing discussed by M.A.

Abdul Rahman and P.S. Ghosh [26]. XLPE and EPR are most widely used throughout the world. Extruded dielectric cables almost replaced the paper insulated cables. Oil-paper cables are easily deteriorated. Polymeric cables are light weight and their cause of deterioration is only ETs, WTs, and PDs. Dielectric losses mechanism is associated with the applied electric field by the application of polarization and conduction studied by B. Oyegoke et al. [27]. Non-destructive artificial aging using AC voltage has been done on XLPE cable. The results show that the cable has undergone thermal aging. This technique was initially adopted for oil-paper insulation cables. Further investigation could be done in future to determine the cause.

N. Srinivas et al. [28] studied the various aging mechanism. There are many methods in determining the aging process of extruded cables. Results obtained from these methods are used in the predictive maintenance of the cables. On-line condition assessment is method which provides non-invasive and non-destructive technique in determining the defects that cause aging. Silicone fluid injection method can increase the life of aged extruded cables may be in good manner. Water treeing is the starting phenomena of degradation in extruded power cables. WTs may be caused by manufacturing defects or ionic contaminations caused by material imperfections. Dielectric strength of the insulation is reduced due to WTs presence. Failure of insulation starts when a WT is converted into electrical tree (ET). WTs consist of locally oxidized regions while ETs consist of continuous charred regions. During operation, a cable continuously emits signals. These signals change their nature on different types of defects. These are detected by some equipment which in turn identifies the type of defect.

D. L. Dorris et al. [29] carried out the research on condition assessment is the most helpful of all the diagnostic tools available. As it identify the weak sections of the cable. Non-destructive diagnostic techniques are the best tools for the reliability of the distribution power cables. The condition of the aged cable is determined by on-line non-destructive cable wise method and then two techniques are used to increase the reliability one is the silicone injection and second is to replace the sections which cannot be repaired.

III. DIFFERENT ANALYSIS TECHNIQUES USED FOR STATE ESTIMATION OF CABLE INSULATION

Werelius, et al. [30] investigated the use of dielectric spectroscopy measurements for detection of non-linear dielectric response in different insulation materials. In an accelerated aging test more than 200 field measurements and lab demonstration were used to clarify the relationship between water network development and two-way charging retort. It was observed that two-way charging retort of water network reduced the crosslinked polyethylene can be recognized and characterized into many categories of retorts based on the maturing condition and break down value. The field investigation shows that failure degree decreases gradually when the approach is constructed on problem-solving standards. It is suitable for field measurements as well as lab measurements. The characteristic response of water treed XLPE can be categorized into different types based on their frequency of water network reduction and left failure degree. These responses have been observed in small samples which were artificially aged in lab, and field. The response of water network declined the padding are affected by time, level and frequency of applied voltage. In addition to that humidity also affects the response of water tree deteriorated insulation. So stable and well established method for the diagnostic measurements should be used. So the author proposes 3 different procedures for assessment of MV XLPE cables are proposed, which are based on water tree analysis, break down test in laboratory and dielectric response. It has been shown that water tree deteriorate having less failure degree can endure in use for several year.

E. David et.al. [31] Identified the aspects which affect the degree of ageing. For this purpose different categories of medium voltage crosslinked polyethylene, wire was examined and characterized their dielectric responses. The measurement results of dielectric were associated with water network which were achieved on the equivalent cable. Randomly selected XLPE cables was aged in service for 15-25 year in wet environment, which shows the low density of water trees. In frequency domain by using simple approximation, the discharge

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current and return voltage measurements have same dielectric response. The testing voltage is higher in order to estimate the degree of ageing of XLPE cable accurately. Electrical failuare checking is now applied on all type of cable. The author is doing work on advance type in time domain HV spectrometer that will check the electric current by taking the direct conduction current in this regards.

M. Acedo, et al. [32] presented a complete investigational and hypothetical learning of the flow of current characteristics of low-density polyethylene influenced by various stages of filth by water network. The layers of water network of several lengths were developed in enhanced medium. Water tree layers were categorized by water network motion, polarization current, capacitance and time-dependent permittivity. It was observed that polarization current follows the law of Curie-von Schweidler which is applied to describe the consequence of maturing period. This examination gives a superior comprehension about the conduct of the administration power links matured by water trees. The most extreme normal incentive for the general permittivity of water trees in low-density polyethylene was observed to be 4.1 by consolidating water tree energy and capacitance estimations. Polarization current estimations were fitted in the potential Curie-von Schweidler law to ponder the development of its parameters with maturing time and polarization voltage. Dipole connections which is another conduction model in low-density polyethylene which is the altered rendition of two-wells Debye model which gives us the Experimental outcomes. The proposed model gives explanatory articulations for the exploratory Curie-von Schweidler parameters on both minuscule and naturally visible factors of the low-density polyethylene plane-plane examples under test. This technique improved the conductive procedures in water-tree corrupted polyethylene which can permit better portrayal of intensity link protection under administration conditions.

Tong Liu et al. [33] investigated the dielectric properties of power cables. Taking into account to find the failure structure of common and correlation molecular cross-linked polyethylene power cables, their dielectric responses were investigated in both time and frequency domain with two electrical charging electromagnetic radiation. In this learning, warm air aging influence were investigated for various kinds of framework power wires with two electrical charging electromagnetic radiation architecture ranging from 10^{-4} to 10^{2} Hz. The extruded power cables geometry has been reduced from the previous full sized cable, but it obeys the same techniques and material as observed in full-sized cable. The purpose of these techniques is to encounter less dielectric failures dielectric of typical wires. The results were compare with new model power cable. It was observed that thermal aging increases the permittivity, dielectric loss, conductivity (low frequency) and the discharge current.

Nirmal Singh, [34] presented the state and health valuation of the flow of charge in the transmission wire, control transformers and expelled link terminations containing a dielectric liquid through Dissolved Gas Analysis. DGA hardware demonstrates the degree of protection harm from the minor to the serious. The US is confronting the issue of maturing electrical hardware especially in transmission links and power transformers. To dispose of such circumstance, better and financially savvy demonstrative tests and examination ought to be created. This strategy is ideal, solid and is performed wherever for pipe type link and power transformer. Additional comprehension and participation among the clients and experts of DGA is required. Different tests, for example, fractional release, vibration investigation, acoustic outflow and IR ought to likewise be given consideration. The utilization of an indicative system for one item can be connected to another. The mindfulness about maturing framework in power frameworks is deferred. The creators propose that all the more financing ought to be spent so as to comprehend about maturing of foundation in future.

J. C. Fothergill, et al. [35] Used a dielectric spectrometer for the frequency range 10^{-4} to 10^{-2} Hz. Using a Fourier transform technique a bespoke noise-free power supply was constructed to measure the dc conductivity, TFT was also used to measure the very low dielectric tand losses at frequencies of 1 to 100 Hz. Tand measurements $<10^{-5}$ were found in this frequency range, β-mode dielectric relaxation lying above 100 Hz because of motion of chain segments in the amorphous region and an α-mode relaxation lying below 1 Hz window because of twists of chains in the crystal lamellae. The dc conductivity measurements were same with those of the dielectric spectrometer and shows that lower dc conductivities in vacuum aged cables than have been previously reported for XLPE (less than 10^{-17} $S.m^{-1}$). Higher conductivities were found for non-degassed cables. The activation energy of approximately 1.1 eV was needed for the conduction process. A transformer ratio bridge was used for measurements in the range of 1 to 10 kHz, there was loss in this range due to the series resistance of the semicon layers. Thermal ageing of the cables caused significant increases in the conductivity and tand at 135 °C after 60 days. The dielectric response of the XLPE power cables can be designed as a resistance due to the total resistance of the semicons, in series with a parallel combination of dc conductance of the XLPE insulation and the its capacitive response. The dc conductivity is very hard to measure and the development of a bespoke noise-free supply was necessary to get this thing. The two measurement techniques of low-frequency dielectric spectrometry and a bespoke very low-noise power supply showed excellent accordance with each other.

Tong Liu et. al, [36] reviewed the dielectric spectroscopy technique and also presented some results for homo-polymer XPLE model cables by using techniques of frequency response analyzer, discharge current measurement and transformer ratio bridge. The measurement results show three mechanism of dielectric loss. First one is DC conduction behavior for low frequencies, second is a relaxation peak for middle frequencies and third one is the additional dielectric loss of outer semiconductor for higher frequencies. The results give three identified mechanisms for dielectric loss, which are:

1. Below 1Hz, mean, in short frequency range DC conduction behavior is overriding.
2. In the frequency range 100-300Hz, we have a peak (relaxation) at 200Hz.
3. Larger frequencies and external surface of the semiconductor is the reason of dielectric failure in the given range of frequency (500Hz-20 KHz.

E. David, N. Amyot, J. F. [37] Measured the time domain dielectric response of unaged and field aged cables up to 25KV by using HV time domain spectrometer. Frequency domain dielectric spectroscopy was also performed for comparison purpose. For this purpose water tree examination and AC breakdown tests were conducted on cables. The results of tests show that all cables retrieved from the Hydro-Quebec's network have low density of water tree and also some vented trees. The tests results show that all these cables had low dissipation factor i.e less than 10^{-3}. Cable 12 and 13 show strength under 4 u_0. The results show higher dielectric losses than all unaged cables. The cable 12 shows a non linear behavior for voltage higher than $0.1U_0$.

Zoltán Ádám Tamus, István Berta [38], determined the maturing condition of combined oil paper and chuck wire by doing some new correction in voltage response method. By this newly developed correction method a possible value of dielectric constraints of the paper insulated lead covered segment of assorted cable lines are calculated. By using voltage response method for oil paper insulation we have two processes which causes problem, one is thermal aging and second is moistening. These two are investigated separately. The result shows that in mixed cable lines slope of decay and return voltage are not changed by thermal aging. By this method we can evaluate the degradation of oil paper insulated cables.

The technology and principle of preventive maintenance of long shielded power cables based on partial discharge location. Tests are conducted on over 6000 km of medium voltage cable. Matthew S. Mashikian, [39] discussed the economic, technical and limitations of the diagnostic test methods. Large scale industrial plants use extensively medium voltage distribution cables and the plant reliability depends on the performance of these cables. Any kind of power interruption caused by the failure of these cables may lead to an unbearable economic loss of the whole system. Preventive maintenance tools and methods are employed for the cable reliability so that faulty sections may be corrected or replaced. PD defined by R. Bartnikas and E. J. McMahon [40], defects lead to failure mechanism. Locations of the PD sites are helpful in the preventive maintenance of the cable. PDs sites are identified by elevated stress on the defective regions for very short intervals. This paper describes how to implement this method. PD location testing is a powerful preventive testing method for the cables used in distribution power system and it is particularly useful in paper and pulp industry.

Different types of flaws that are electrical networks linked with water network, padding contaminations, and physical fault instigated by roughly covering are revealed using off-line limited emancipation diagnostic examination technique [41]. XLPE are the most widely used cables in the world for medium voltage. Their deterioration and aging are the main consideration for their reliability and life span. They deteriorate due to cavities, imperfections, contaminations of solid particles, protrusion and physical damages during installation. These all effects put a great impact on their reliability. A. Bulinski et al. investigated different techniques for predictive maintenance [42]. In this paper one of the techniques called off-line limited emancipation place has been presented using 50/60 Hz voltage. Identification of typical defects in XLPE cables and their location and characteristics are discussed. G. Bahder, C et al. searches that water treeing is the starting phenomena in cable degradation [43] after which electrical treeing starts which is the final failure mechanism. PD does not appear in WT studied by S. Bamji et al. [44], S. Hvidsten et al. [45] and J. Kirkland et al. [46]. However S. Bamji et al. [47, 48] found that application of PD can convert WT into ET. We found that electrical networks linked with water networks have not lead to final loss although the next years of service. To perform off-line test cable is disconnected from the system. Higher electrical stresses cause ETs in areas adjacent to the WTs. Off-line PD testing is useful for sorting out the defective portions of the cable from healthy ones. Cavity type defects are very rare. PD sites do not lead to formation of ETs. Solid impurities cause PDs and ETs. ETs may arise due to large WTs after years of service.

Our system requires uninterruptable and continuous line of supply and it depends greatly on the reliability of the cables. As cables undergo aging and other degradation phenomena, so there repair or replacement is necessary with economical aspects. Therefore, predictive diagnostic tools are employed for their best operation [49]. The best process for the commissioning and procedure for applying the predictive diagnostic tools for extruded cables of 5 KV and higher is discussed by Gary Hartshorn et al. [49]. Failure mechanism is also presented. The effects of destructive and non-destructive withstand tests are also discussed. Then aging process comparison for metal taped shield and other shields is also discussed. In petrochemical plants and other industries XLPE, electron paramagnetic resonance and wires with coated paddings for example, fluid infused paper shielded pin covered wires are extensively used. M. Mashikian, A. Szatkowski studied that these cables are associated with the defects of aging, electrical and water treeing [50]. All these defects lead to cable failure. Several methods are used to identify these defects studied by G. Bahder [51]. One of the methods is off-line PD location technology of 50/60 Hz. It is concluded that off-line PD location method is most powerful method for predictive maintenance of extruded power cables [49].

Cavities present in the insulation medium lead to degradation of the extruded power cables. Dielectric bounded cavities and electrode bounded cavities have different aging phenomena studied by Z. P. Lei et al. [52] DBCs are associated with the PDs that result in decrease surface conductivity. In this paper dielectric characteritics of XLPE neoprene are discussed by Zhipeng Leil et al. [52] in the frequency domain (0.01-1Mhz) it is found that dielectric failuare of clear models increases with rise in temperature in short frequency regions only. Dielectric loss due to DBC is more in low frequency regions. To determine defects caused by cavities it is necessary to study the dielectric characteristics of the materials. ERP padding cables have better life than XLPE cables and have better mechanical and thermal properties against temperature. A. Metwally found that EPR is also better than XLPE against water treeing resistance [53]. EPR is most widely used in extruded power cables. Although they are expensive and have higher dielectric loss than XLPE Cavity also increases the dielectric loss of the material. Electrical degradation process is also associated with the cavities. When EPR samples containing DBC and EBC are subjected to AC voltage, PD distributions are observed within the samples. Dielectric failure of clear electron paramagnetic resonance inclined with increase in temperature in short frequency region. It is very much subtle to temperature but does not change at higher frequency above 50 Hz. The EPR containing cavities have more dielectric loss than pure EPR [52].

IV. CONCLUSIONS

All over the world aging of electrical equipment particularly cables and power transformers is a big problem of future. This requires development of new techniques for condition assessment of electrical equipment.

Different analysis techniques for determining ageing phenomena in flexible insulation materials and their results are as follows.

Power distribution can be measured on offline power frequency (60Hz) that is an efficient method to evaluate the state of cross-linked polyethylene wire structure and utilized to make choices on the wire structures strength.

By using voltage response method for oil paper insulation we have two processes which causes problem, one is thermal aging and second is moistening. These two are investigated separately. The result shows that in mixed cable lines slope of decay and return voltage are not changed by thermal aging. By this method we can evaluate the degradation of oil paper insulated cables.

Non-destructive diagnostic techniques are the best tools for the reliability of the distribution power cables. The condition of the aged cable is determined by on-line non-destructive cable wise method and then two techniques are used to increase the reliability one is the silicone injection and second is to replace the sections which cannot be repaired.

Off-line PD testing is useful for sorting out the defective portions of the cable from healthy ones. Cavity type defects are very rare. PD sites do not lead to formation of ETs. Solid impurities cause PDs and ETs. ETs may arise due to large WTs after years of service.

PD location testing is a powerful preventive testing method for the cables used in distribution power system and it is particularly useful in paper and pulp industry. PD location method is most powerful method for predictive maintenance of extruded power cables.

When EPR samples containing DBC and EBC are subjected to AC voltage, PD distributions are observed within the samples. Dielectric failure of clear electron paramagnetic resonance inclined with increase in temperature in low frequency region. It is very much subtle to temperature but does not change at higher frequency above 50 Hz. The EPR containing cavities have more dielectric loss than pure EPR.

Non-destructive artificial aging using AC voltage has been done on XLPE cable. The results show that the cable has undergone thermal aging. This technique was initially adopted for oil-paper insulation cables. Further investigation could be done in future to determine the cause.

It is found that electrical treeing is the last phase of loss architecture. Electrical networks are started from the overhang, metal contaminations, power distribution sites and transformation of water network into electrical network.

Normally power distribution is not the cause of ET delay. Hence, electrical maturity is a cellular procedure and the role of electron act crucial part of the last failure. This model is not only suitable to discuss the physical procedure but can consider the range of values of the investigational status for enhanced maturity. To conclude this method is applied to other insulating polymers signifying that the structure is also applicable to all sorts of polymers and is not only for wire padding.

Thermal aging increases the permittivity, low frequency and DC conductivity, discharge current, dielectric losses and the thermal activation energy of insulation materials.

It is suitable for field measurements as well as lab measurements. The characteristics response of water treed XLPE can be categorized into many forms based on their power of water network decline and left failure degree. It has been shown that water tree deteriorate having less failure degree can remain in use for many years.

For testing HVDC cables there are many recommendations but still no standards available.

The results give three identified mechanisms for dielectric loss, which are:

1. Below 1Hz, mean, in short frequency range DC conduction behavior is overriding.
2. In the frequency range 100-300Hz, we have a peak (relaxation) at 200Hz.
3. Larger frequencies and external surface of the semiconductor is the reason of dielectric failure in the given range of frequency (500Hz-20 KHz).

The tests results show that all wires had less power loss influence i.e. less than10^{-3}. Cable 12 and 13 show degree under $4u_0$. The results show higher dielectric failures at high rate than all immature wires. The wire 12 shows a nonlinear performance for voltage that is greater than $0.1U_0$.

The sensitivity analysis and electro thermal model although have various systematic terminologies and constraint's points, but they give a mutual sign about wire life estimation. The results proved accurate HVAC cable life interference which requires precise explanation of thermal as well as proper models of electro thermal life.

Features of model show that the initial phase step in electrical maturity is the electrically persuaded machine-driven distortion of cellular bonds. The two basic parameters are ΔGo, initiation energy of interchain breakdown and the length of submicrocavities. These parameters change with applied electric field, temperature, applied pressure and morphology of polymers.

The experiment result shows that generally the inner semicon is vulnerable to SIED when aged by the effect of aluminum wire, electrolyte and mechanical stress. SIED does not produce cracks. A porous zone is produced which consist of NaOH at molecular scale. SIED structure grows inside the inner semicon layer which leads to vented trees in the adjacent insulations. In the development of SIED, the mechanical stress and electro thermal generation of NaOH play very important role.

In enlargement law's the H_{DC} function gives result which have no physical meanings. If one of the two component of this function lies within a specific range of values, then specific attention is given to avoid misleading results.

It is very important to understand the quality factors within utilities in order to increase the operational life of the power cables. XLPE compounds can be utilized to increase the durability and long life for the power cables used for transmission and distribution application.

By the results and statistics it can be claimed that offline partial discharge diagnostics is the predictive diagnostic tool for analysis of performance of systems utilizing medium voltage specification. Type 1 tests are not recommended as they reduce reliability. General condition assessment test are proven to be uneconomical. Offline diagnostic testing is used for commissioning and reliability is improved by use of periodic predictive diagnostic maintenance. Copper tape shield cable specification should be changed to concentric or round wire for better results.

The developed system shows good result in detection of water trees effects in XLPE cables. Based on degree of the effect and breakdown strength, the characteristic response can be categorized into many forms. The influence of used accessories and systems can be separated from cable response by attained characteristic response. It is also concluded from field experience that cables with relatively lower breakdown strength and having water tree effects can further sustain in service for many years.

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HVDC paper insulated cables contains time and field dependent conductions. In case of stable capacitive or resistive stage, we can compute field distribution analytically. Temperature also effects the intermediate field change and insulation losses distort field distribution. Super imposed DC voltage pulses with polarity reversal causes high intensity field near conductor.

While performing line diagnostics, cable accessories should also be considered. High permittivity based accessories had very severe non linearity. Field aged cable joints had PD below diagnostic applied voltage. The dielectric response should be analyzed on different frequencies for longer duration so that cable accessories response can be distinguished from cable response itself.

Crine model is the convenient model applying the thermodynamic concepts and rate theory to the life equation as compared to Lewis model hence resulting in very few parameters in life and activation volume computation.

There is a need for statistical analysis as breakdown is dependent on many uncontrolled factors like defects, Cavities and impurities. The reliability of the values of observed life exposed to constant fields can be enhanced if analysis can be done for longer time duration. It is recommended to compute AV and AG values with lesser error if impulse breakdown field is added with acbd values.

After aging process, the magnitude of partial discharge increase more in XLPE than EPR cables. Both cables face degradation with application of switching pulses. On the other hand, significant linear drop in AC breakdown voltage after application of 5000 pulses is observed in EPR cables as compared with XLPE cables.

Increasing demand of the distribution cables by the utility companies require cost effective cables. This requires less cost of materials particularly the insulation thickness. This can be done by a close co-operation between cable manufacturers and utilities.

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