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A Deep Insight on Improvement in HV and EHV XLPE AC Cable Technology

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Abstract: This paper highlights on continuous improvement in Extra High Voltage (EHV) & High Voltage (HV) AC Underground Transmission Cables (UTC) Technology like real time monitoring, improved XLPE insulation. Due to improvement in manufacturing technology & long-term technical experiences of cable manufacturers with EHV XLPE cable systems, there is increase in reliability of cable. For UTCs accessories, a high level of quality & reliability has been achieved with the technology of pre-fabricated & pre-tested insulation bodies of silicone rubber. Frequency of internal failure in XLPE insulated UTC is very low of value 0.088 as compared to failure in 230 kV Overhead Transmission line (OTL) =0.7997. This paper is based on the recent Service Experience & statistical data obtained from TSO, Working Groups, & EHV XLPE UTC manufactures.

Keywords: Underground power transmission lines, Cables, Power cables, Power transmission economics, Power transmission maintenance.

I. INTRODUCTION

In Switzerland, the first 400 kV XLPE UTC & accessories with silicone rubber insulation bodies were installed in the network at the beginning of the year 1990. These systems is doing well up to the date. All tests & many years of practical experiences have shown that solid XLPE insulation for high voltage & extra high voltage UTCs & silicone rubber insulation for their accessories are characterized by long electrical lifecycle. To keep the potential of a long-term reliability, it is very important for the EHV XLPE UTCs & accessories to be free from any Partial Discharges. The partial discharge measurements as routine tests for EHV XLPE UTCs & accessories are therefore an important step for the quality of the EHV XLPE UTCs & accessories. Recent developments supported by the cleanness of the polyethylene material & experiences in EHV UTCs resulted in a mature technology with proven benefits i.e., lower TCO & high design flexibility that allowed the use up to 380/400 kV networks as well. Based on all these positive experiences with EHV XLPE UTCs & accessories in service & in prequalification tests for 420 kV, the article also reports on the continuing development of UTC design due to optimization of wall thickness & field strengths. When we speak life of UTC, we are expecting approximately “40-year”, but it doesn’t mean that after 40-years of lifecycle UTC needs to be replaced. A more clear meaning is that UTC is substantially trouble free for 40 years, after which the failure rate starts to increase. No short term laboratory or field diagnostic test can establish the operating life of a UTC, especially one made of a new insulation for which unanticipated failure mechanisms may occur, as was the case for first generation polyethylene dielectric distribution UTC which was afflicted by the unanticipated phenomenon of water treeing. Generally lifecycle of UTC can only be depicted when some large volumes of EHV UTCs installed in a wide range of conditions. In this paper there is continuous decrease in the (OM) cost due to improve in UTC manufacturing & monitoring process in the recent years taken place. With the improvement in the UTC manufacturing technology there is small (about 10%) increase in capital cost of UTC system mainly due better partial discharge monitoring system & better manufacturing system. Also with service experiences of EHV lines for last two decade reduces the (OM) cost & improve the reliability of whole UTCs system. Third generation UTCs have less thicker & less capacitance value compared with previous generation XLPE UTC. Recent statistical trends shows that failure in XLPE UTC occurs only after few years of commissioning of UTC system, after that failure rate is very low. Mostly cause of failure is defect in workmanships & manufacturing defect.

II. LIFE CYCLE SERVICE EXPERIENCE & IMPROVEMENT IN MANUFACTURING TECHNOLOGY OF EHV UTC SYSTEM

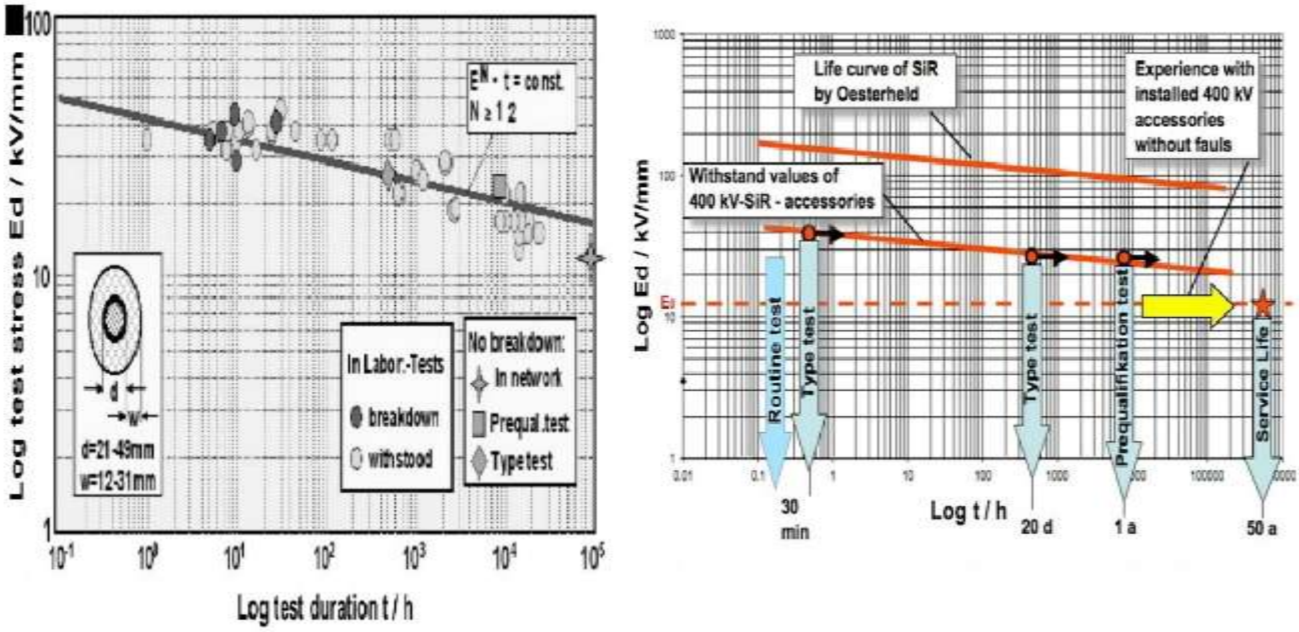
A. Improvement in EHV XLPE Insulation and Silicone Rubber Technology

Many utilities around the world own & operate a lot of equipment that can be described as old (equipment which was worn out due to the stress of time in service or completion of lifecycle). Therefore, breakdowns & failures rate is very high. Even if a utility does not have a high portion of aged equipment in its system today, it will at some time in the future. So there is little doubt that aging infrastructure will become increasing concern for utilities in terms of both reliability & operating cost. So, increase in the reliability of equipment can reduce the operation & maintenance cost. Increase of the lifecycle of EHV cables with XLPE insulation & their accessories of Silicone Rubber is determined by internal & external factors. With applied voltage, basically two electrical ageing processes take place, partial discharge ageing & field ageing [1], [2], [3]. Partial Discharge ageing arises due to discharge processes in cavities very quickly leads to an electrical breakdown of both, the XLPE & Silicone Rubber insulation. It is vital that both, the cable & accessories of EHV cable systems are free of Partial Discharge. Therefore, Partial Discharge measurements are a standard in routine testing as a post-production quality control for the XLPE UTCs and the silicone parts of the accessories [4]. Field ageing is described by the lifecycle law as given in equation (1):

$$E^n * t = constant \quad (1)$$

Whereas,
E: electric field;
n: lifecycle exponent;
t: time;

Rise in field ageing phenomenon is caused by spurs & occlusions in the XLPE cable insulation. Therefore, this cause increase Electrical field at that place of concern & the electrical ageing process rate becomes very high. Therefore, XLPE materials of high purity & highest level of clean manufacturing process are prerequisites for the production of EHV cable system. In detailed investigations on breakdown of XLPE UTCs, it was found that XLPE has a lifecycle exponent of around 12 (Fig. 1) [1], [2], [3]. Service Experiences shows that high voltage UTCs can withstand at least as long as the lifecycle law proofs. This is even more valuable as the real XLPE UTCs additionally suffers from higher electrical & mechanical stresses, which further increase the electrical ageing process. In detailed investigations on breakdown of silicone rubber (SiR), it was found that SiR has a lifetime exponent of greater than 40 (Fig. 1) [1], [2].



Breakdown values and electrical ageing for XLPE UTCs and values of practical experiences. Breakdown values and electrical ageing for Silicone Rubber samples. (Right)

Fig. 1 Breakdown values & Electrical ageing for XLPE UTCs (left) & silicon rubber sample (right).

B. Developing experiences of HV and EHV XLPE UTCs and SiR Accessories

EHV XLPE insulation UTCs along with SiR accessories are produced for long duration of time up to 275 kV gives the required experiences for the manufacture of 400 kV XLPE insulated UTCs & accessories made up of SiR (Fig. 2), [2]. The first 400 kV XLPE insulated UTC was produced with a corrugated copper sheath at Nordostschweizerische Kraftwerke, Switzerland, & the first high voltage UTC system with EHV XLPE insulation in the 380 kV network were set up on the site of the Bonaduz/Grisons substation in spring 1993. The UTC system initially comprised two outdoor terminations & length is about 200 m of UTC. After five years of operation, the UTC system have no damage, this UTC was divided into two parts, after that, a single piece prefabricated & pre-tested joint with Silicone Rubber(SiR) insulation body was introduced & the operation of the system was resumed. After further three years of operating in the network without faults, the joint was diagnostically tested with a new broadband partial discharge measurement system in 2001.

This new testing process, based on the directional coupler sensor method, allows reliable recording of possible Partial Discharge ageing processes in the joint, even in unscreened conditions [7], [10]. The tests showed that the joint is free of Partial Discharge after many years of operation at network voltage. With that, no damaging processes that could shorten the lifecycle took place in the joint. After the measurement, network operation was continued until today without any fault. Frequency of internal failure in XLPE insulated UTC is very low of value 0.088 as compared to failure in 230 kV Overhead Transmission line (OTL) =0.7997 [5], [6].

C. Improvements in UTC manufacturing

Over recent years numerous modifications in the basic polymer structure of insulation (XLPE) material can be made to maximize productivity & quality during the manufacturing process. This results in higher line speeds in cases where limitations in either the curing or cooling processes within the continuous vulcanization (CV) tubes used to cross-link the insulation. PEX insulations can be modified to limit the amount of byproduct gases generated during the cross-linking process. This is particularly useful for EHV applications, where degassing requirements can significantly lengthen UTC manufacturing time. The size & number of metallic & non-metallic impurities in the compound have been considerably reduced. They have now attained the levels shown in Table 1 [8].

TABLE I Highest permissible concentration (number/kg) of contaminants for selected size classes [8].

SIZE($m*10^{-6}$)	50-70	70-100	100-200
HV	-	15	0
EHV	15	5	0

The size & quantity of impurities present in the insulation material determine the electrical breakdown strength of XLPE insulation material. There is increase in field strength around the surrounding area near the fault & locally accelerated field ageing starts. The influence of the size of these impurities on the A.C. voltage breakdown strength was investigated using model UTCs [9] & real high-voltage UTCs (Fig. 2) [2]. Due to the volume effect with regard to breakdown probability & due to the desired failure probability for a UTC in the energy distribution network of 1 fault per 50 year in 100 system kilometers, the values determined on model UTCs with insulation thickness of 1.5 mm only cannot be used as a field strength for the purposes to determine the design of real high voltage UTCs. The critical sizes for impurities in the XLPE insulation for EHV UTCs are shown in relation to the maximum field strength on the conductor in Fig. 3[2].

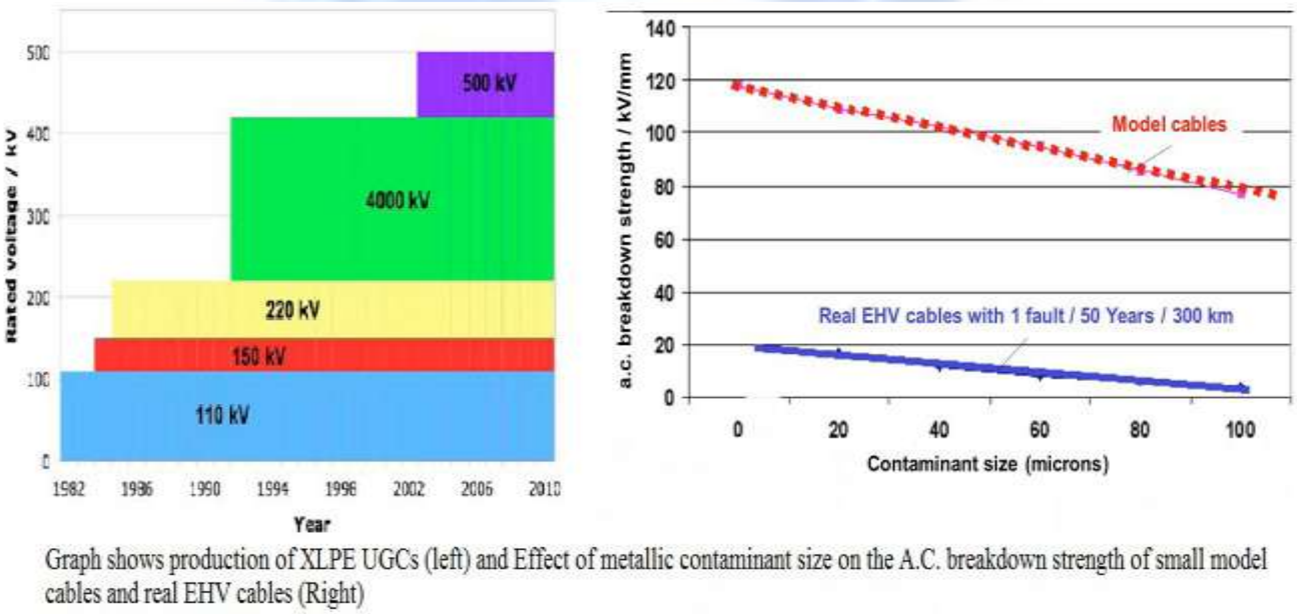
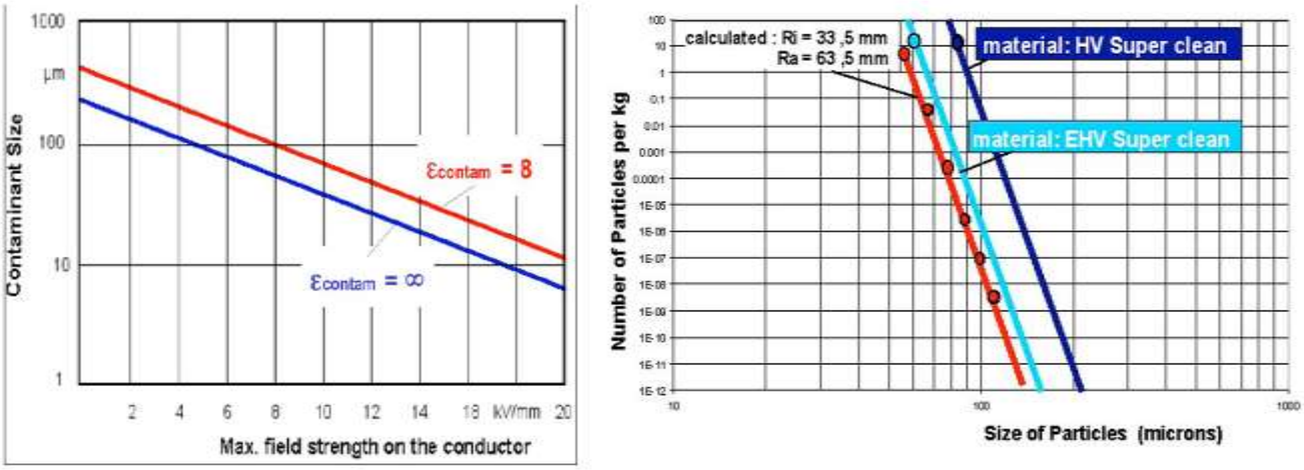


Fig. 2 Graph shows the manufacturing of XLPE UTCs (left) & consequences of metallic contaminant on the A.C. breakdown strength(right).

Fig. 3 shows that the size of particle, & number of impurities per kg with the same risk of electric breakdown exerts a strong influence [3]. For given reasons & with the specified design field strength of >10 kV/mm, insulation material of class EHV Super Clean with purity levels as shown in Table I is used to manufacture EHV XLPE UTCs. The proven high purity of the compound made it possible to use higher design field strengths & to reduce the insulating wall thicknesses [2] (Fig. 4). With that, the maximum field strength always remains the same for a given voltage & the insulation wall thicknesses can be dimensioned in relation to the conductor cross section (Fig. 4). The manufacture of EHV XLPE UTCs uses horizontal technology is very reliable. Clean material handling & precise temperature & pressure monitoring during extrusion, dry curing & cooling guarantee a high standard of quality during the manufacturing process.

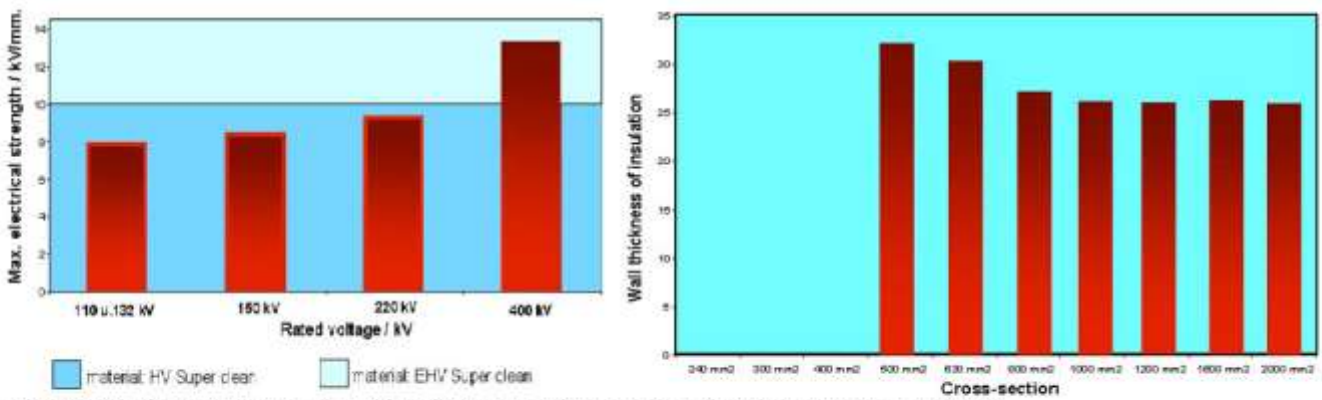


Critical size of contaminant in the XLPE-insulation (left) and No. of particles and size with same risk of electrical Breakdown (Right).

Fig. 3 Critical size of contaminant in XLPE- insulation(left) & no. of particles & size with same risk of electrical breakdown(right).

D. Improvement In termination point and joints manufacturing

With the improvement in manufacturing technology during past few years high reliability can be achieved with prefabricated, pre-tested single piece slip on elements of Silicone Rubber. The slip-on elements consist of semi-conductive deflectors, a semi-conductive middle electrode (only for joint bodies) & the insulation compound. They ensure field grading between the semiconducting layers of the UTC & the conductor clamp at a joint & the field grading at the end of the UTC for a termination. The deflectors & middle electrode are made of solid semiconducting material. Although costly, this ensures that they function properly especially at fast BIL voltages (BIL = basic impulse insulation levels) & guarantees a long & reliable lifecycle. Among many factors like high breakdown strength, high temperature stability & high lifecycle exponent, main advantage of the Silicone Rubber is the high flexibility which ensures an optimum level of surface pressure on the UTC & avoids any air gaps at the interface UTC insulation body, thus allowing a long reliable functioning. Due to the high stability of the Silicone Rubber, the optimum surface pressure remains constant throughout the lifecycle of the joint. At a glance, the main advantages of the Silicone Rubber are Temperature stability of minus 50°C to plus 180°C, High life exponent of n greater than 40, high breakdown strength of greater than 23kV/mm at 50/60 Hz.



Maximum Electrical strength in XLPE UTCs (left) and Wall thickness of insulation of 400 kV XLPE UTCs (right)

Fig. 4 Max. Electrical strength in XLPE UTCs (left) & wall thickness of insulation of 400 kV UTC (Right)

Void free contact pressure on the UTC at normal & elevated load due to high elasticity of Silicone Rubber, Easy to install due to excellent mechanical properties & elasticity. To keep all advantages of the Silicone Rubber up to commissioning of whole UTCs system, the insulation bodies are produced in one-piece in a clean surrounding & proper care should be taken while installation of cable taken place.

CONCLUSION

This article shows continuous improvement on EHV XLPE UTCs 380/400kV technology & this cause decrease in operation & maintenance cost & failure cost. With the improvement in the XLPE cable system technology, number of failure in the XLPE UTCs system reduces & therefore, reliability & lifecycle of the whole system increases. With the increase of cable life there is reduction in operation & maintenance cost, also burden of capital cost of development of new transmission line extends for 10 year (expected additional lifecycle increase of EHV XLPE UTCs). Failure rate shows that mostly UTCs fault are of external type, i.e. third party failure which can be controlled by proper maintenance especially patrolling. Extensive tests & many years of practical experiences have shown that solid XLPE insulation for EHV XLPE UTCs & Silicone Rubber insulation bodies for their accessories are characterized by long electrical lifecycles. In addition to all above XLPE UTCs once properly commissioned provide hassle free operation for complete lifecycle. From recent survey it is also concluded that fault generally arises in the starting years of commissioning due to workmanship or manufacturing defect. Once the XLPE UTC system is energized & is subjected to electrical loads at network voltage, an electrical lifecycle of well over 50 years can be expected.

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