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PROGRESS IN THE PRODUCTION OF HIGH VOLTAGE AND EXTRA HIGH VOLTAGE CABLES

Detlef WALD

Brugg Kabel – Switzerland, wald.detlef@brugg.com

Abstract **– The transmission and distribution of electrical energy requires efficient and reliable networks with low losses.**

Traditionally this role has been fulfilled by overhead networks, which have been considered as a lower cost alternative to underground cable solutions.

This paper will summarise the progress that has been made producing the core, but also the protection of high and to a lower extend extra high voltage cables using different methods producing the core and comparing various approaches protecting the cable against water increase.

It is widely recognised that High Voltage cables are not just larger Medium Voltage cables; they operate at much higher electrical stresses and in more critical parts of the electrical grid. Consequently it is of vital importance to consider the requirements of size and electrical stress when designing HV cables.

These two attributes have a direct impact on reliability: higher stresses make failure more likely and as we have seen earlier larger volumes increase the difficulty of manufacture, as well as the chances of finding a defect.

It highlights in addition the influence of different production steps on the quality of the cables made. This means focusing on improving only one part of the production process could have a negative impact on other properties of the cable, therefore a compromise between different properties has to be made.

The lifetime of extruded cables is determined by internal and external influences.

Keywords: *High Voltage cables, electrical energy, reliable networks, electrical stress.*

1. INTRODUCTION

The demand for energy is growing from year to year and thus the use extruded high voltage and extra high voltage cables is growing too. Recent predictions show that the world will require 60% more energy by the year 2030. In the framework set by the European commission in 2003 [1], the electrical trade between the member countries must be increased. The electrical trade is currently underdeveloped compared with the other sectors of the economy. For this reason a larger number of inter-connectors have to be built across the borders.

The distribution network also faces challenges using the distributed energy generation across the area and moving it to the parts where it is needed; certain distribution networks are close to collapsing. This raises a very real challenge to electric power distributors: "How to maintain the necessary pace of network development and ensure consistently high system performance and reliability". Reliability will become increasingly more important as regulatory frameworks raise expectations in respect of 'supply quality'.

The transmission and distribution of electrical energy requires efficient and reliable networks with low losses. Traditionally this role has been fulfilled by overhead networks, which have been considered as a lower cost alternative to underground cable solutions. However, with progressive advances in technology, calculations show that the costs of overhead lines and cables are much closer when compared on the basis of 'Total Cost'. This comparison goes beyond installation costs only and takes into account a broader range of criteria, including fault rates and dielectric losses.

This paper will summarise the progress that has been made producing the core, but also the protection of high, and to a lower extend extra high, voltage cables using different methods producing the core and comparing various approaches protecting the cable against water increase.

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The lifetime of extruded cables is determined by internal and external influences. Studies in the past have shown that in principle electrical cables do not age over the design life [3,4]. However still the design of high voltage and extra high voltage cables are based on very conservative values for the electrical stress if they are properly produced and the installation is done in a professional manner.

2. DESIGN OF POWER CABLES

The whole design of cables is a compromise on the different properties for example:

1. Electrical design stress
2. Design lifetime of the cable system
3. Mechanical properties
4. Production of the cable
5. Handling of the cable during production and installation.

2.1. Electrical Design Stress

Thin polyethylene films made with cable grade polyethylene have electrical breakdown strength of more than 300 kV/mm. However cables are designed with a maximum stress of 15 kV/mm [5] at the conductor screen and 7 kV/mm at the insulation screen. The lower design stress is due to the lifetime of a cable with 40 years and not just for the time of the electrical testing. In addition a cable insulation can never be produced as perfectly as a thin film under laboratory conditions.

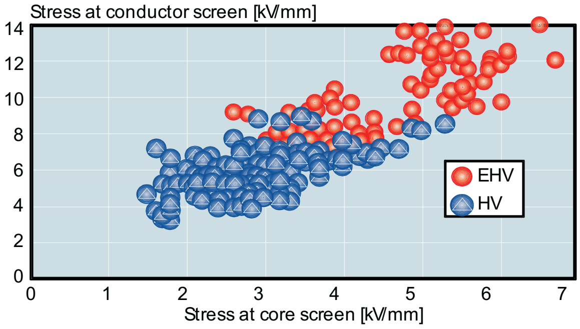

Figure 1. Experience with EHV and HV XLPE cable systems [6].

It is true that a lower electrical stress increases the lifetime of a cable, however this does not mean that thicker cable insulation is intrinsically better. A thicker cable insulation means that you have to process more volume to produce the same cable, this results in several processing challenges:

1. Higher possibility of adding contaminants
2. Higher chances of creating scorch
3. More difficult producing a round cable: pear drop, eccentricity
4. Higher shrinkage if the relation of polymer to metal is too big.

Let’s have a look at these parameters:

2.2. Influence of contaminants

The major cable compound producers classify their materials according to the electrical requirements like medium voltage cables as designed by the IEC standardisation body, which does not mean that in general a cable compound designed for extra high voltage has a better performance than a compound designed for medium voltage at medium voltage level. Here however, we only want to focus on the contamination level which means that the compound producer accepts more contaminations in a compound for medium voltage than for extra high voltage cables. However here the detection is also made on statistics since they are normally not testing 100 % of their compound on cleanliness. However the effect of contamination is evaluated each time that a cable is electrical tested.

So if you get a product which has x contaminant between 70 and 100 mm found in 1 kg tested material which relates to a certain possibility or chance of contamination in 1 t of material (ρ).

$$\rho = f(x) = \frac{e^{\lambda} \cdot \lambda^{x}}{x!};\ \lambda = \frac{N}{x} \qquad (1)$$

where N is the amount used per m of cable.
Thus you get now for 5 contaminants in 1 kg

$$\rho = f(5) = \frac{e^{-\frac{N}{5}} \left(\frac{N}{5}\right)^{5}}{5!} \qquad (2)$$

If you now increase the insulation thickness, the possibility that you may add a contamination already present in the material increases (Figure 3). So adding the famous “one millimeter more” of insulation might be not such a good idea.

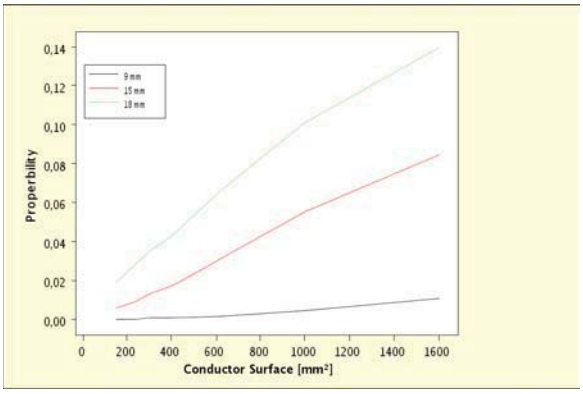

Figure 2. Possibility having 5 contaminations between 70 and 100 µm in 1 m cable.

Detailed studies were reported by Ul Haq and Raju on breakdown values for Aramid films of different thicknesses [7]. The tests have been carried out for a number of electrode sizes, expressed as insulation volume. The data shows that the breakdown strengths (Weibull Scale parameters) reduce as the volume increases. However there is a clear and separate effect of the different thicknesses; even at the same volumes. Here we see that the Shape Parameter, and thus the mechanism of failure, changes with volume. In the case of thin films mechanical damage and thermal effects can have an additional influence above those of the increased concentration of defects.

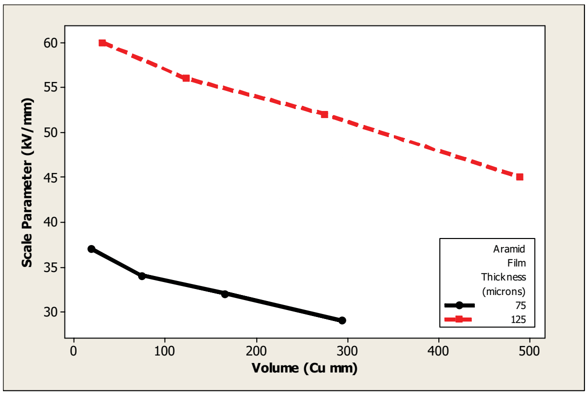

Figure 3. Effect of volume (mm^3) on the breakdown stress of aramid films [8].

2.3. The effect of scorch

The second problem highlighted during the introduction is the risk of scorch. This property is dependent on the material used, the processing and the amount that is processed. Thus the insulation thickness is related to the amount than is used to produce one meter of cable. If you now omit that the melt temperature also increases with higher output, one can produce longer without the risk of scorch for thinner insulation thickness. Highly degraded scorch particles are a potential source for a cable breakdown and might not even been found during partial discharge testing since the dielectric constant of these particles are similar to that of XLPE.

In figure 5 the relative safe processing time for a 110 kV cable with different insulation thickness is outlined.

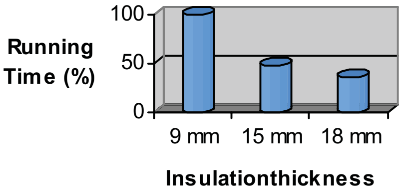

Figure 4. Possibility creating scorch during cable production.

2.4. Eccentricity, Ovality and Shrinkage

Besides the fact that a thicker cable has more problems with eccentricity at least for a CCV or an MDCV line, for a VSC the conductor size gives the handling problem. Since all material has the tendency to follow gravity, which means the bigger the relationship between insulation thickness and conductor, the more difficulties producing a round cable, as they insulation may drop. This is the so-called pear-drop effect.

Naturally the shrinkage is influenced by a numerous of parameters, for example the line speed during production but also the annealing time. Reducing the annealing time by, for example, reducing the degassing time might influence the shrinkage of the cable during operation [9]. One should bear in mind that the sample and type tests are done on quiet short lengths and will not give a realistic value of the shrinkage found during operation of the cable system.

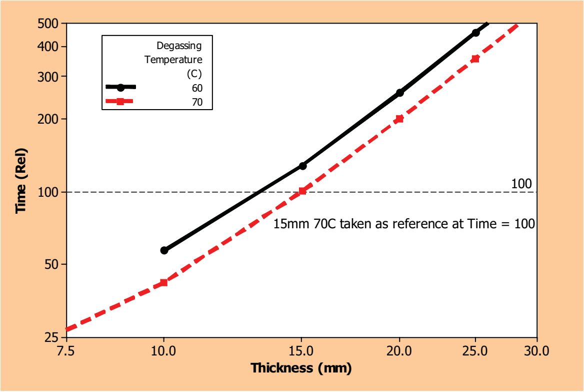

Figure 5. Effect of insulation thickness and temperature on degassing requirements.

A further useful point can be drawn in terms of the dimensions of cables. The green line represents a standard 20kV cable, however approvals can also be carried out on smaller cables. These cables have lower volumes and thus if the same test length is used we would expect them to have a higher strength. The circle in Figure 6 shows the case is the performance of the 20kV systems were impressed upon a 12kV cable. In this case there would be an apparent improvement from 18 to 23kV yet this is simply a volume effect. The contrary is also true: if a smaller cable has the same performance as a larger cable then the true strength of that system will be considerably lower. In the case here if the 12kV cable had the same strength as the 20kV then the system performance would not be 18Uo but 14Uo. Thus qualification data based on unusually small cables should be volume corrected or treated with respect.

The analysis above serves to show that searching long-term tests when coupled with appropriate success levels really can increase the value of cable to reliable service operation.

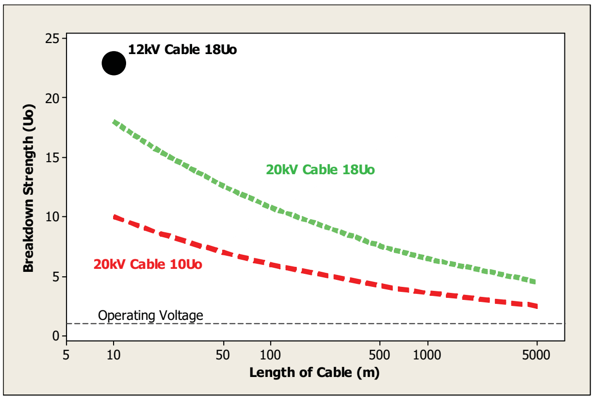

Figure 6. Effect of cable length on breakdown strength.

3. TRANSPORT AND HANDLING

Further advantages of thin cables are that you can transport more meters on a reel, thus reducing the transport costs, but also reducing the number of joints or splices. This will reduce costs and reduce the probabilities of failures in the cables system, as joints and terminations are still the place where most cable failures occur. This is further discussed in Cigre TB 379 where the service experience of high voltage systems in the last 10 years were analysed. At first sight the stress/volume effect discussed in Figure 6 might appear to argue for shorter cable dispatch lengths, but this would in fact require more joints. Joints are acknowledged as having lower performance than the cables. Thus the practical solution for long length transmission is to take advantage of fewer joints and to compensate the increased cable requirement by improving the quality of the cable. Equally this thinking demonstrates the precautions that need to be taken when considering using both long lengths and reduced sizes.

4. PROTECTION DURING SERVICE

The second big subject in designing cables is the protection: meaning the jacketing or sheathing of the cable. The jacketing and armouring is an important factor in the cable design. The sheath has to protect the cable against all outer disturbances. The first generation jacketing material was polyvinylchloride (PVC). It was easy to process and gave reasonable protection against mechanical damage and fire hazard. However especially in electronic areas the danger of developing hydrochloride acid could damage the equipment. Another negative factor was the loss of flexibility due to the evaporation or wash out of plasticers over time. Today in general high-density polyethylene (HDPE) is the standard for power cables. In extreme case flame retardant jacketing materials are used.

Fire tests according to IEC 60331-1 have been performed using 110 kV cables according to the VDE Standard, N2X(FL)S2Y. The cables had no problem passing this test as shown in figure 7.

Figure 7. Fire test of high voltage cables.

A further subject is the armouring or mechanical protection of the cable.

Generally high voltage cables have a good protection against moisture. Depending on the area used or the application various metallic protections exists:

- Laminated aluminium foil, here actually three different designs exists
- Corrugated aluminium or copper
- Lead

It is generally considered that lead gives you the best protection against direct increase of water and therefore if the cable is installed in a very wet environment lead is normally recommended as armouring. However lead also has a couple of disadvantages like weight, handling and fatigue. Compromises can also be made here: taking a modern high voltage insulation, which has sufficient resistance against water trees and an aluminium foil with copper wires as earthing. The wet ageing properties are outlined in figure 8.

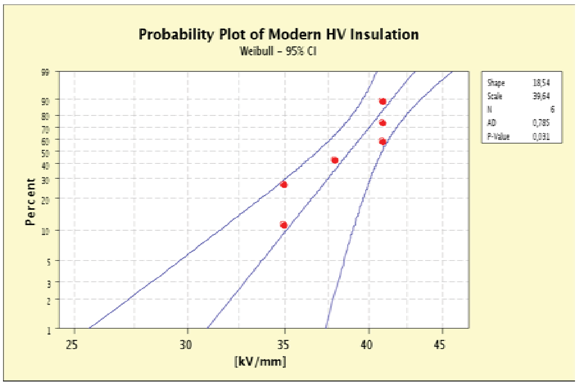

Figure 8. WTR and losses of modern high voltage insulations.

5. CONCLUSION

In this paper we tried to outline that designing a high voltage cable one has to make a compromise on various parameters. Naturally the basic design parameter is the electrical parameters, like stress and impulse strength.

However chemical and mechanical parameters also play a significant role in designing a good cable with a long lifetime of 40 years. So just focusing on one parameter like electrical stress might create other problems. The whole design is a compromise designing the optimal cable with the materials available. Other parameters like compatibility with the accessories should be also taken into account.

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