PERFORMANCE AND DESIGN OF OVER HEAD LV BUNDLE CONDUCTOR SYSTEMS IN AN ENVIRONMENT OF HIGH LIGHTNING ACTIVITY AND HIGH POLLUTION.

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INTRODUCTION

Eskom participates in South Africa’s electrification program which started in 1992 and is still continuing. Eskom made 350 000 connections per year at the peak of the program. Eskom lead the industry in reducing first capital costs in the program by more than 50%. [1]

This cost reduction was achieved by ensuring efficiency and effectiveness of the technology, the design process as well as the logistics and construction and sales processes. This was done without increasing operating costs and maintaining the same levels of reliability.

This paper discusses one of the technology choices that were made and problems that are being experienced currently with LV bundle conductor in especially high lighting activity areas where pollution is prevalent.

The paper discusses the mechanisms that lead to the problem as well as the solutions to the problem.

ESKOM’S BARE NEUTRAL LOW VOLTAGE AIRIAL BUNDLE CONDUCTOR STANDARD

The LV ABC comprise of aluminium conductor covered by XPLE with a bare neutral conductor of 35mm². Standard dimensions used by Eskom are 35 mm² or 70 mm² as phase conductor cross section area. Bundle is used as single phase, dual phase and three phase bundles. Eskom uses a combined neutral and earth system. The insulation thickness for 35 mm² is 1.1 mm ±0.2 mm and for 70 mm² it is 1.3 ±0.2 mm.

One of the major considerations that played a role in choosing a bare neutral system is that it avoids confusion any confusion between live conductors and the neutral conductor by installation lines men. Accidents did occur where such confusion lead to the swapping of live and neutral conductors.

FAILUR E MECHNISM OF BARE ARIAL CABLE

Nature of the failure: Erosion of the XLPE insulation material occurs. It is not clear whether this erosion is caused by slow tracking processes or by flashovers that might have occurred. Erosion of the aluminium conductor occurs; the aluminium is turned into a white power (aluminium oxide?). Thermal damage of the aluminium (could be either I²R, load current or fault current and/or arch damage) is also observed.

Postulation of the total failure mechanism: The failure mechanism comprises of three parts, firstly a puncture of the XLPE covering is required. Several means exist by which punctures in the covering occur. It happens when the covering is damaged during construction or when insulation piercing connectors are removed and the insulation piercing is not sealed. Lightning is also a major cause of pinhole punctures in the insulation covering.

Once the puncture exists the second process is a electro-chemical corrosion process that requires conductive pollutants, combined with the LV operating voltage to cause the aluminium conductor (and the XLPE covering?) to corrode.

The terminal process occurs when the corrosion has eroded the conductor past a critical level where fault current and/or load current cause the final break of the conductor by heating and melting the conductor off at the weakened point.

Lightning induced punctures

Lightning mechanisms: Lightning can strike covered-insulated overhead conductors directly which would be the most obvious cause of lightning induced punctures of the insulation covering. In the event of a direct strike the damage to the covering is substantial; this is a fairly rare event. A more frequent occurrence is when nearby lightning induce over voltages into the overhead line which in turn will also cause punctures especially at fittings near earthed parts of the construction.

A much unknown phenomena that has been observed in with this problem (and elsewhere) is illustrated in figure 2 whereby lighting induces many more pinhole punctures in the insulated-covered overhead conductor than what direct strikes or induced lightning voltage surges does. This phenomenon has been reported by Lagesse and Geldenhuys [2], [3]. In this project lightning induced more than 80 such pin holes in a MV ABC cable with a length of 4.7 km and a height of 5m in

Figure 1. A typical example of the bundle failure mechanism
one lighting season in an area where the average lighting flash density is around 8 flashes per km² per year. (On average only 2.8 direct strikes are expected to such a line per year.)

**Upward discharge.** The phenomenon of upward leaders induced by downward leaders is well known. It is postulated that the downward leader cause upward discharges to form around the covered conductor without initially puncturing the insulation. Initially a bipolar charge separation is induced over the insulation cover as shown in figure 3 with negative charge on the surface of the insulation and positive charge on the conductor. This bipolar charge causes a large electric field over the insulation covering. (Voltage across the cover.)

If the discharge is limited it will not cause any damage, as the discharge grows it finally induce enough charge on the surface of the insulation covering that the voltage (electric field) induced across insulation cause break down of the insulation. The puncture of the insulation covering depend on the extend of the upward discharge. Once the insulation cover has been punctured the field across the insulation will collapse. This however does not affect the lighting upward discharge process, which will continue until the final jump occurs to this point or more likely elsewhere. When the lighting strike terminate elsewhere and the electrostatic field collapses because of the strike, the local discharge will reverse it’s flow and return the charge to a neutral situation. This part of the process happens much faster than the build up of the upward leader process.

**The corona radius required to puncture the insulation covering.** A simplistic calculations was used to estimate the upward leader corona-extend required to cause breakdown of the insulation covering. Geometric electric field calculation with knowledge of positive corona inception was used. A model of the corona induced by the downward lighting leader is shown in figure 3.

Results of a calculation for a single insulated cable with a radius of 14mm are shown in figure 4. It indicates that a corona envelope with a radius of 700 mm will lead to the puncture of the insulation covering. In the case of a MV insulated bundle 11 kV cable that was evaluated in a similar way the corona radius increased to 7m. This is substantially more. However the actual lighting upward leader process can easily result in discharges of this extend.

Figure 2. Downward lighting leaders induce many upward leaders on objects on the ground. The strike finally terminate at only one (or at most two) of these objects on the ground.

Figure 3. A model of the covered conductor where lighting has induced an envelope of corona around the conductor.

The perceived discrepancy still requires explanation. A possible explanation is that where the discharge process is fairly slow (as when the upward discharge forms), breakdown will occur to the bare conductor, however when the field collapses rapidly the voltage difference remains high till travelling waves reaches the stressed points. Breakdown will then still happen regardless of the presence of a bare conductor.

Recent controlled experiments involving this phenomena suggests that the occurrence of punctures on shielded lines are less frequent than on non shielded open lines. This will be explored further.
Pollution, load - and fault current degradation and terminal failure of the conductor

Figure 5. The pollution situation of a 35mm² bundle. The maximum live to earth creepage distance is 15.4mm. The magnitude of the stress at the hole in the insulation depends on where the hole is relative to the neutral conductor. That is the shortest distance between the hole and the bare neutral conductor.

The maximum effective “creepage” distance of a 35 mm bundle is shown in figure 5 as 15.4mm. With a system voltage of 400V the creepage of the bundle is shown in Table 1. The maximum strength of 38 mm/kV may just be acceptable if the insulation material was not prone to tracking (both materials used for this type of insulation PVC and XLPE is prone to tracking).

The problem is that the hole can be as close as 2mm from the neutral conductor in which case the stresses are very high; 5mm/kV; which would not be acceptable even for the best insulation material possible. It is clear that stresses under polluted conditions are extreme and will lead not only to the kind of electro-chemical degradation processes observed, but may also lead to power system flashovers at such points, which in turn may contribute to the downfall of the conductor.

Table 1. Stresses on a 35 mm² bare neutral LV ABC.

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<thead>
<tr>
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<th>35 mm² bundle</th>
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<tbody>
<tr>
<td>Max creepage distance</td>
<td>15.4 mm</td>
</tr>
<tr>
<td>Min creepage distance (max stress)</td>
<td>2 mm</td>
</tr>
<tr>
<td>Max insulation strength</td>
<td>38.5 mm/kV</td>
</tr>
<tr>
<td>Min insulation strength (max stress)</td>
<td>5 mm/kV</td>
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</tbody>
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QUESTIONS RAISED BY THE FAILURE

It is not known to the author to what extent the mechanism would be avoided by the use of copper as a conductor in stead of aluminium. It is postulated that copper is not prone to the same extent to be electrochemically corroded as aluminium and may for that reason not suffer of the second failure mechanism and the terminal failure. Copper however is not considered in SA as a solution due to theft problems with copper conductors.

The relationship between the stress level and the (rate of) electro-chemical corrosion is not known. It would be of value to designers if this relationship was understood. The question exist when would the stress be low enough not to cause this type of failure. Related to this question is the issue that inland LV ABC performance which is believed not to be effected; or is this just a matter of time before these also become a acute problem? The objective would be to have at least a life of 20 years plus for material of this nature.

What is the exact nature of the electro-chemical reaction that takes place? Could this understanding lead to an alternative solution to the problem?

SOLUTIONS ADOPTED

It should be noted that the technology has served Eskom well in all of its areas not exposed to marine pollution. The solutions applied include:

Avoiding the formation of pinholes. When the failure mechanisms are examined, it is clear that damage during the construction and use of the conductor are of prime importance and has to be avoided. Attention has been given to this in contraction and maintenance instructions. This is done through work practices as well as appropriate training.

The solution adopted therefore was to change to an alternative technology only in areas where the problem manifests itself. This is only in regions where marine pollution plays an important role. (This is a rather small area compared to the total.)

Mitigating the pollution mechanism. The pollution mechanism can largely be mitigated if the creepage distance between exposed parts is so large that the electrochemical action is avoided. This can be achieved by using a covered neutral conductor: The likelihood that two insulation punctures (one on the live and one on the neutral) are close to each other are substantially reduced when the neutral is covered as well. Where work induced holes occur as well as in the case of lighting induced pin holes occur the distance between holes invariably are much greater than 50mm and even more. It is unlikely that the electrochemical degradation mechanism will be able to effect this configuration at a frequency anywhere near the current problems that are experienced.

Covered neutral technology has been used by some of the Metro distributors in SA and similar problems have not been experienced on this system which supports this approach as a solution.

REFERENCES