I. Introduction

Isolated down conductors are very important for the safety of the lightning protection system. If it fails it is much more dangerous than any other down conductor as insulation is used to avoid flow of current inside the structure (e.g. in case of an explosive area).

The use of insulated lightning down conductors permit to use less number of conductors and sometimes even one only. A defect of this type of conductor so can have serious consequences.

We carried out preliminary tests on products existing in the market to assess their characteristics and establish if tests described in the technical document IEC 62561-8 are sufficient and necessary to cover the need especially from the user point of view.

II. Cross Section Compliance with IEC 62561-2:

Hereafter the Table 1 of the IEC 62561-2 – Material, configuration and cross sectional area of air termination conductors, air termination rods, earth lead-in rods and down conductors.

In conclusion, the cross-section of the product we tested is 19 mm² (4.92mm diameter), it is not compliant at all with Table 1 of the IEC 62561-2. The minimum cross section must be 50 mm² to be in compliance with the Table 1.

III. Temperature Rise

The cross-section area of the product we tested is 19 mm² (4.92mm diameter), the parameters used for calculation are coming from IEC 62305-1. We used the following formula:

\[
\theta_{D1} = \frac{a}{q} \left[ \frac{\pi}{\pi - \beta_0} \right]^{1/2}
\]

\[
\theta_{D2} = \frac{\pi}{\pi - \beta_0} \left[ \frac{\pi}{\pi - \beta_0} \right]^{1/2}
\]

\[
\theta = \theta_{D1} + \theta_{D2} - \theta_{C}
\]

\[
\theta_{C} = \frac{A}{q} \left[ \frac{\pi}{\pi - \beta_0} \right]^{1/2}
\]

\[
\theta_{D1} \text{ est l'élévation de température des conducteurs (K)};
\]

\[
a = \text{le coefficient de température de la résistance (1/K)};
\]

\[
\Pi/2 \text{ énergie spécifique du courant de choc (J/kg)};
\]

\[
\beta_0 \text{ est la résistance ohmique spécifique du conducteur à la température ambiante (Om)};
\]

\[
q = \text{la section du conducteur (m²)};
\]

Parameters used for calculation:

<table>
<thead>
<tr>
<th>Material</th>
<th>Configuration</th>
<th>Cross sectional area (mm²)</th>
<th>Recommended dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper,</td>
<td>Goldplated</td>
<td>2.58</td>
<td>2.8 mm thicknesses</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.58</td>
<td>8 mm diameter</td>
<td></td>
</tr>
<tr>
<td>Stainless steel 7%</td>
<td>1.60</td>
<td>1.75 mm diameter of each strand</td>
<td></td>
</tr>
<tr>
<td>Total strand</td>
<td>2.17</td>
<td>10 mm diameter</td>
<td></td>
</tr>
</tbody>
</table>

The calculated temperature rises are:

- Temperature rise calculation is as follows:
  For a single return stroke with a single down conductor using formula D7 from IEC 62305-1, the temperature rise is +192.76°C.
  If we take into account subsequent strokes the temperature due to a single subsequent stroke is +2.59°C.

Temperature withstand of the Isolation material use in the conductor: Isolating material for the studied samples is polyethylene (PE), the literature gives the following physical characteristics for PE:

Polyethylene is a thermoplastic polymer consisting of long hydrocarbon chains. Depending on the crystallinity and molecular weight, a melting point and glass transition may or may not be observable. The temperature at which these occur varies strongly with the type of polyethylene. For commercial grades of medium and high-density polyethylene the melting point is typically in the range 120 to 130 °C (248 to 266 °F). The melting point for average, commercial, low-density polyethylene is typically 105 to 115 °C (221 to 239 °F).

We assume 130°C as being the limit not to be exceeded.

Temperature rise conclusions are:

- Technical documentation of this sample shows that it should be handled with care to avoid damaging the coating and especially the semi-conductive coating.
- It is feared that in case of inhomogeneous of the electrical field a breakdown could occur.
- Calculated temperature rise shows that the isolating material can be damaged for Class I level of protection when a single conductor is used and even in low ambient temperature (20°C). The technical documentation is indicating that 70°C is the maximum ambient temperature allowed for such a cable.
- Temperature rise may degrade, damage or even melt the isolating material especially when it is subjected to mechanical stress due to fixing.
- This can degrade the cable on the long term and create a potential hazard with time.

IV. Voltage Drop Along the Conductor:

- The Formula used to calculate the Voltage drop along the conductor is: $U(t) = L \cdot \left[ r \cdot i(t) + \frac{d}{dt} \right]$ where:
  - $U$ Voltage drop from top to bottom [V],
  - $L$ Length of the conductor [m],
  - $r$ Linear resistance of the conductor (2mΩ/m for 50mm²),
  - $i(t)$ current impulse [A],
  - $L$ linear inductance typically 1μH/m.
We want to calculate if the maximum withstand voltage is sufficient:
It is assumed that the maximum withstand is 750 kV for such cable but
internal tests have shown that a gliding surface spark can occur for voltage
as low as 200 kV.
At the top of the conductor there may be metallic grounded parts such as
rebar.
The calculated voltage will then be applied between the internal copper part
and external metallic grounded part will be as follows:
- In case of a first return stroke and for a 10 meter long down conductor:

<table>
<thead>
<tr>
<th>LVL</th>
<th>I</th>
<th>II</th>
<th>III-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak current [kA]</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>di/dt [kA/µs]</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Voltage between top and bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistive drop</td>
<td>400V</td>
<td>300V</td>
<td>200V</td>
</tr>
<tr>
<td>Inductive drop</td>
<td>200kV</td>
<td>150kV</td>
<td>100kV</td>
</tr>
</tbody>
</table>

- In case of a first return stroke and for a 10 meter long down conductor:

<table>
<thead>
<tr>
<th>LVL</th>
<th>I</th>
<th>II</th>
<th>III-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak current [kA]</td>
<td>50</td>
<td>37.5</td>
<td>25</td>
</tr>
<tr>
<td>di/dt [kA/µs]</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Voltage between top and bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistive drop</td>
<td>100V</td>
<td>75V</td>
<td>50V</td>
</tr>
<tr>
<td>Inductive drop</td>
<td>2000kV</td>
<td>1500kV</td>
<td>1000kV</td>
</tr>
</tbody>
</table>

In conclusion:
- For cable length as high as 10 m there is a risk of damaging the cable when
  it passes near grounded metallic parts at the top of the structure.
- For the studied sample studied there is also a permanent mandatory ground
  connection near the top of the cable.
- This can create a hazard to the structure as well as a cable puncturing
  leading to water ingress and long term degradation.

v. CONSTANT AREA CRITERION

In this part of the paper we want to check expressions of the theory of the
constant area criterion that are used to justify the proposed standard tests:
These Conditions are:
- $U_0 = U_{50\%}$
- $U_0[V] = 6 \times 10^5 \times d[m]$
- $A[V.s] = 0.6 \times d[m]$

Experimental setup to verify these conditions:
- Laboratory equipment:
  Power supply DC 0-100kV
  Marx generator:
    1.2/50µs , 50kV – 250kV
    0.2/3500µs, 75kV – 700kV
- Four different geometries studied:
  - Sphere-sphere geometry ø 80mm
  - Rod-rod geometry ø 8mm
  - Rod-rod geometry ø 7mm
  - Rod-rod geometry ø 2.7mm

Validation of the formula: $U_0 = U_{50\%}$.
All curves are Voltage (kV) versus distance (cm):
Sphere-sphere geometry ø 80mm:

Rod-rod geometry ø 7mm:

Rod-rod geometry ø 8mm:

Rod-rod geometry ø 2.7mm:
Evaluation of isolated lightning down conductors

In first conclusion, the assumption $U_0 = U_{50\%}$ does not seem justified when the distance between electrodes increases. Such a law doesn’t work for distances as low as 10 cm. It is necessary to justify such an assumption for distances greater than 60 cm.

Validation of formula: $U_0 [V] = 6 \times 10^5 \times d [m]$.

All curves are: $E$ (kV/cm) versus distance (cm).

Experimental Values for a DC Sparkover electrical field using a 80mm diameter sphere-sphere geometry

The experimental Geometry is 7mm diameter rod-rod and a gap of 10cm $\gg U_0 = 91$ kV
Apply 3 surges 1.2/50µs shape: 140kV, 180kV et 220kV
Measurement of $U_B$ and $t_B$ (mean value 10 shots)
Calculating the area generated by the surge over $U_0$

The area may be considered as constant, but the values obtained during the tests are very different from those obtained by the expression "$A = 0.6 \times d^2$".

Conclusions:
- $U_0$ and $U_{50\%}$ are different as soon as we have a distance of a few cm.
- The formula "$U_0 = 6 \times 10^5 \times d$" seems valid for a rod-rod geometry and $\phi 8$mm distances greater than 15 cm.
- In the case of the standard, $d > 60$cm, this expression can be applied.
- The tests show that the area caused by an overvoltage in relation to a dc sparkover voltage is constant. However, experimentally, the value of this area differs from that obtained by the expression "$A = 0.6 \times d$".
- It would be useful to learn about the limits of validity of this expression and experimental conditions.

All publications used as reference for the draft IEC 62561-8 standard refers to the publication of L. Thione, «The dielectric strenght of large air insulation ». However this article does not give details on the limits of applicability of the different expressions.