AC AND NEGATIVE DC CORONA POWER LOSSES IN AN INDOOR CORONA CAGE

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Abstract: The effects of various parameters on conductor corona losses, under AC and negative DC voltages, have been demonstrated through measurements in an indoor corona cage. Corona losses are dependent on conductor surface gradient, type of applied voltage, conductor size and surface condition. The difference between losses under negative DC and AC voltages appear to be dependent on conductor diameter and surface condition.

1 INTRODUCTION

One of the design factors in high voltage transmission lines is corona activity. Conductors and fittings energised at high AC and DC voltages, are characterised by high corona activity. It is manifested as hissing and crackling audible noise (AN), radiated and conducted TV and radio interference (RI), corona loss (CL) and ozone generation [1]. Corona power losses play a significant role in the operation of both HVDC and HVAC transmission lines. The losses depend on factors such as type of voltage, conductor surface and atmospheric conditions. They become more considerable, even from appropriately designed lines, during wet weather conditions. Ion generation and ground level electric fields are also significant in the case of HVDC transmission lines. Earlier studies have shown that corona activity is related directly to the high levels of conductor surface gradients produced on the small-diameter conductors that were used at the time [2]. The main challenge is to minimise the operational conductor surface gradients during the design stages of the transmission lines. The conductor surface gradient depends very much on the following factors [3]: conductor size, surface condition, height above ground and transmission line disposition.

Dirt and insects on the conductor surface, damage during construction/transportation, moisture on the conductor affect the roughness factor of the conductor and, hence, the corona inception gradient. Reference [2] states that corona processes, such as, movement of charged particles, collisions between charged particles and neutral molecules require energy. In the case of transmission lines the energy required is drawn from the high voltage source connected to the conductor and converted to many other forms of energy. The rate at which the energy is drawn from the source is power and may be identified as corona power loss. According to [2] the electrons created in corona discharges have a very short lifetime and current pulses produced by their rapid movement do not contribute significantly to the corona loss (CL). The theoretical analysis for both AC and DC CL is shown in [2]. However, it is also mentioned that the theoretical calculation or prediction of CL based entirely on a theoretical approach has not yet been successfully accomplished. Under DC and AC conditions, corona power losses are affected by all the factors that affect corona inception and also depend on atmospheric variables such as wind, humidity and aerosols [2]. In the study reported in [4], CL was found to increase with the conductor surface gradient and the conductor size, with all the other parameters remaining the same.

CL measurements for predicting the corona performance of a transmission line under AC conditions can be carried out using test cages and test lines. Measurements in corona cages can be carried out under high field conditions without the risk of flashovers. Results from such measurements can be used to predict corona performance of transmission lines depending on the experimental conditions. However, DC test cage results cannot be used to directly predict the performance of an operating line due to the differences in space charge distributions [2]. For DC measurements, CL in test cages or on test lines are estimated by measuring the current flowing through the conductor and multiplying with the applied voltage [2]. CL under AC voltages are evaluated from dielectric losses measurements using the Schering bridge.

The losses are also dependent on the potential difference between the conductor and the ground. Corona current of a DC line depends on the line geometry particularly the pole spacing [5]. In the case of unipolar lines a change in conductor height has a much larger influence on CL than a corresponding change in conductor size [2]. CL depends on the position of the bundle relative to the ground and the extent to which the position influences the movement of space charge [6]. It also depends on the proximity of the grounded cage effects in cases where test cages are used [7]. According to [8], the line height and the pole spacing in case of bipolar arrangements, influence the amount of corona current that will reach the ground and consequently the corona current that will be measured. Under AC voltages, the flow of current between phases and to the ground depends on the gap impedance, which consists of capacitance and resistance. The evaluation of AC corona losses requires the knowledge of the electric field distribution in the vicinity of conductors whereas for analysis of DC losses, the field distribution in the entire inter-electrode space has to be known [9].

There are no specific design limits stipulated by most of the utilities for corona losses. The selection of the conductors and the conductor bundle must be in such a way that the worst case corona losses under wet conditions do not exceed 5% of the full load conductor losses. In this study corona losses were determined for different conductor sizes in an indoor corona cage for AC and DC voltages. From studies conducted earlier [10], it was reported that the AC corona power losses were higher than under positive DC losses for all conductor sizes and surface conditions. Initial observations of negative DC corona power losses were higher than AC ones, depending on conductor size and electric field range. One of the objectives of this study was to investigate further, the observed differences between AC and negative DC corona power losses.

2 EXPERIMENTAL PROCEDURE

Specific details are provided in the following sections.

2.1 DC measurements

The DC source was a 2-stage Walton-Cockroft generator with a maximum output voltage of +500 kV and –540 kV and rated current of 7.5 mA. The generator was supplied from a 100 kV DC test transformer. A small indoor corona cage with a length of 2 m and diameter of 1.5 m was used. It is cylindrical and consists of three sections. The two outer rings are 1 m long each and are solidly grounded. The centre ring is normally floating to allow voltage and current measurements to be done from the centre as shown on the detailed schematic diagram in Fig. 1. The outer rings are connected to the centre ring only mechanically and electrically insulated from it through vesconite insulators.

Only single conductors were considered due to clearance limitations. Solid and stranded aluminium conductors with diameters 1.6 cm and 2.8 cm were tested. The solid conductor was thoroughly polished before being tested to achieve fairly good surface conditions. The conductor under test was suspended with the polymeric tension 66 kV, 460 BIL insulators obtained from **Pfisterer**, formerly **Hardware Assemblies**. Two corona rings each with a diameter of 50 cm were attached at each conductor end-fitting in order to reduce the electric stress around the end fittings and ensure that corona occurred only on the conductor surface.

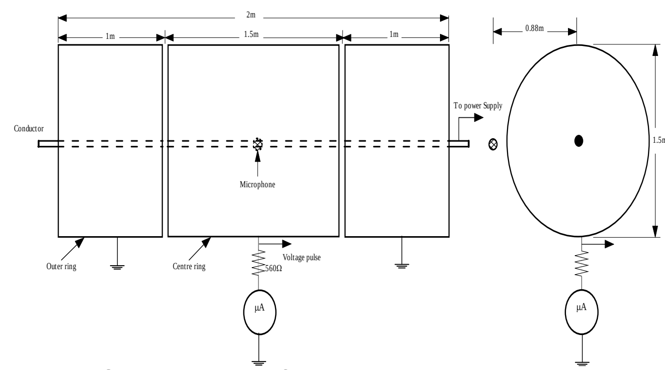

Figure 1: Circuit diagram for indoor corona cage DC measurements

A digital micro-ammeter Fluke Model 187 was used to measure the corona current. It was connected in series with a 560 Ω resistor from the central section of the corona cage. A corona camera was used to accurately determine the corona inception voltage.

DC corona power loss was calculated from the measured current and expressed in terms of the conductor length using Equation 1.

$$P_{dc} = \frac{UI_{dc}}{l} \qquad (1)$$

Where,

P_{dc} = corona power loss (W/m)

U = dc supply voltage (V)

I_{dc} = measured corona current (A)

l = length of the conductor in the cage (m)

Corona losses at a given voltage were calculated using the following expression, for comparison AC measurements.

$$P_{dc} = UI_{dc} = I_{dc}^2 R_{dc} \qquad (2)$$

Where

R_{dc} = (dU/dI) which can be obtained from the I = f(U) characteristic.

The conductor surface gradient in the cage was calculated using Equation 3.

$$E = \frac{U}{r \ln \frac{R}{r}} \qquad (3)$$

Where,

E	= static conductor surface gradient (kV/cm)
U	= supply voltage (kV)
R	= radius of the cage (cm)
r	= radius of the conductor under test (cm)

2.2 AC measurements

The following modifications were made to the corona cage circuit to facilitate AC measurements. In order to minimise the effects of stray capacitance, the outer rings were electrically connected to the inner ring. The corona cage supporting frame was placed on dry wooden blocks to isolate it from ground. The connection of the dielectric losses measuring system to the corona cage is as shown in Figure 2. The standard capacitance used with the Schering bridge was rated at 100 pF and 100 kVrms. This rated voltage determined the maximum voltage applied for both AC and DC measurements. The AC voltages were obtained from a 100 kV, 5 kVA test transformer. The Schering bridge was a ***Haefely Tettex*$^{@}$ *C L Tanδ*** measuring bridge. Parameters that could be recorded were loss tangent, power losses, gap current and the equivalent circuit parameters for the representation of the cage air gap. The applied voltage was increased in steps of about 10 kV, and the various parameters recorded at each voltage level. A corona camera was used to determine the corona inception voltage. Measurements were initially done with and without the outer rings connected to the inner ring, to assess the impact of stray capacitance. Based on the results obtained, it was decided to do the measurements with all the rings connected. Corona losses per unit length at different conductor surface field values were calculated from the recorded power and voltage readings. The conductor surface fields were on the basis of the peak AC voltage, to facilitate comparison with corresponding DC measurements. The dielectric losses were also calculated as follows, for comparison with losses under DC conditions.

$$P_{ac} = \omega C_p U^2 Tan\delta \qquad (4)$$

But Tanδ = $\omega C_p R_p$ for, a parallel representation of the dielectric material.
Therefore:

$$P_{ac} = (\omega C_p U)^2 R_P = I_{ac}^2 R_p \qquad (5)$$

I_{ac} was measured by using the loss tangent recording system.
Equation 3 was also used to evaluate the conductor surface field for the peak value of applied voltage.

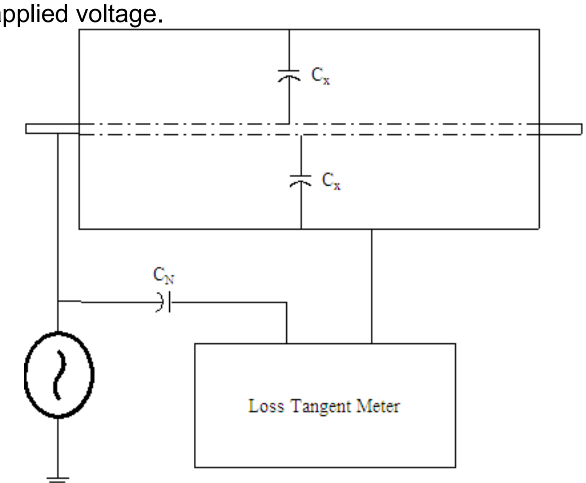

Figure 2: Test set up for AC measurements
Units: Authors must use SI units and internationally recognized terminology and symbols.

3 RESULTS

3.1 Effect of conductor size and surface condition

For both AC and DC conditions, the CL increase with conductor surface gradient as well as conductor diameter (Figures 3 and 4). The effect of conductor size on the power losses is more distinct under AC surface electric fields (Figure 4). Under DC voltages the difference between corona power losses for 2.8 cm and 3.5 cm diameter conductors is small. The effect of the conductor surface conditions on the CL is demonstrated in Figures 5 to 8. Under both AC and DC voltages, the losses are higher for the stranded conductor. The effect of the surface condition is also dependent on conductor diameter, as well as type and level of surface electric field. Comparison of the CL at 30 kV/cm for different conductor sizes and surface conditions for both AC and DC shows that the difference is more pronounced for smaller conductors and under DC surface electric fields.

3.2 Effect of type of voltage

The difference between losses under AC and negative DC voltages was dependent on conductor size and surface condition. It can be seen from Figure 9 that for the 1.6 cm diameter stranded conductor, the losses under AC voltages were higher than those under negative DC voltages for surface field higher exceeding 32 kV/cm. However, for the 1.6 cm diameter solid conductor, the losses under AC voltages were higher than those under negative DC voltage for the entire range of surface fields considered (Figure 10). In the case of the 2.8 cm conductor diameter, for the solid conductor, the CL under AC voltages were higher up to about 32 kV/cm (Figure11). However, for the stranded conductor, the CL under negative DC voltages were higher throughout the entire measuring range of conductor surface electric fields (Figure 12). The crossover conductor surface field, in the case of the 3.5 cm stranded conductor, was about 27 kV/cm (Figure 13).

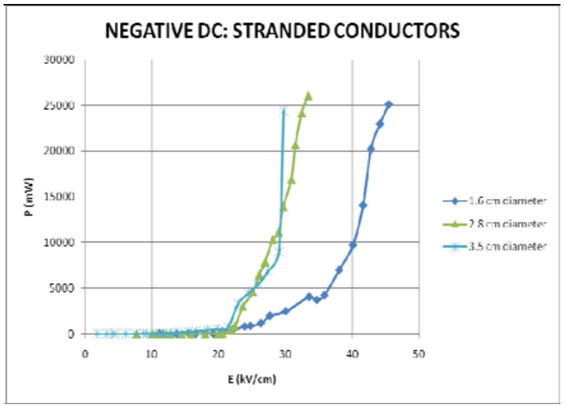

Figure 3: Effect of conductor size on corona losses under dc voltages

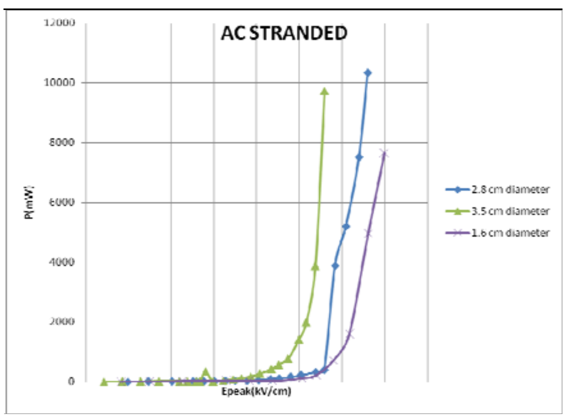

Figure 4: Effect of conductor size on corona losses under AC voltages

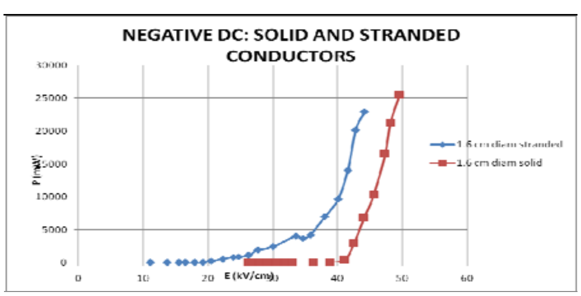

Figure 5: Effect of conductor surface condition on corona losses under dc voltage.

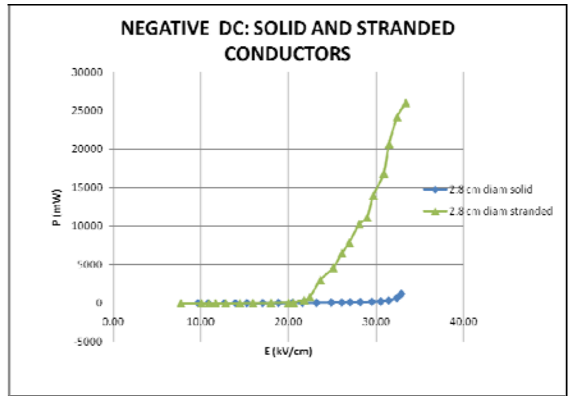

Figure 6: Effect of conductor surface condition under dc voltages

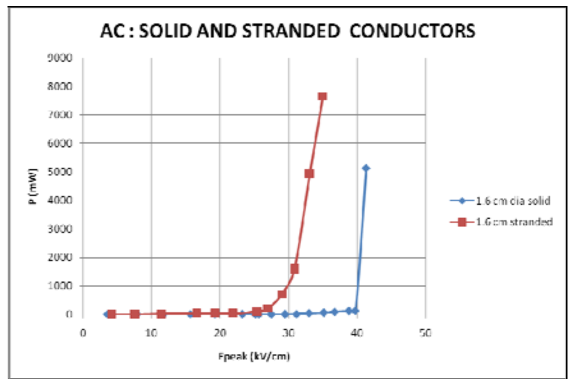

Figure 7: Effect of conductor surface condition under AC voltages

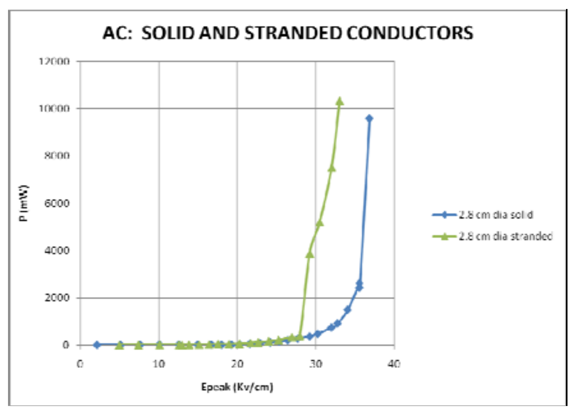

Figure 8: Effect of conductor surface condition under AC voltages

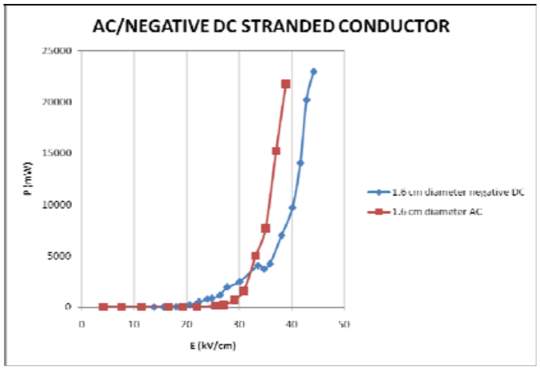

Figure 9: Effect of voltage type on corona losses: stranded conductor

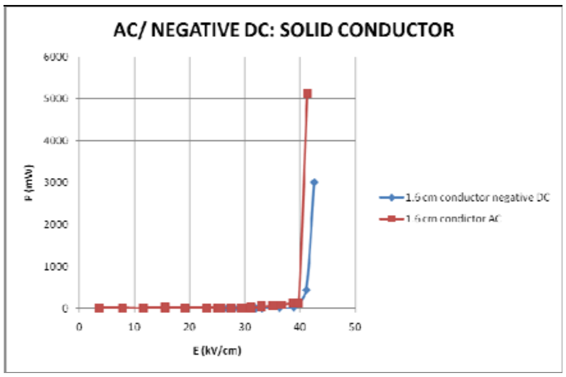

Figure 10: Effect of voltage type on corona losses: solid conductor

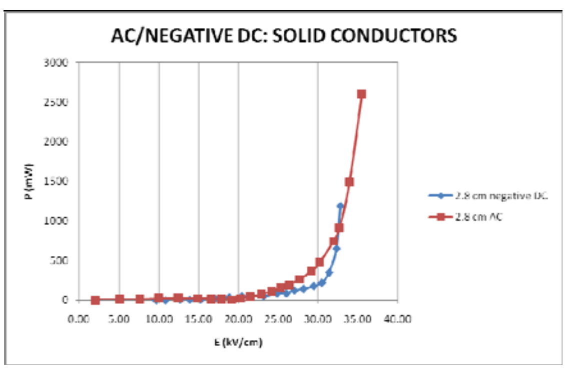

Figure 11: Effect of voltage type on corona losses: solid conductor

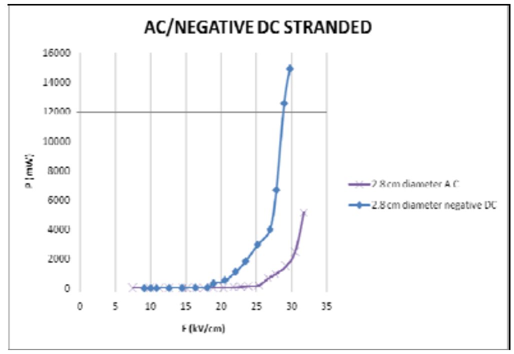

Figure 12: Effect of voltage type on corona losses: stranded conductor

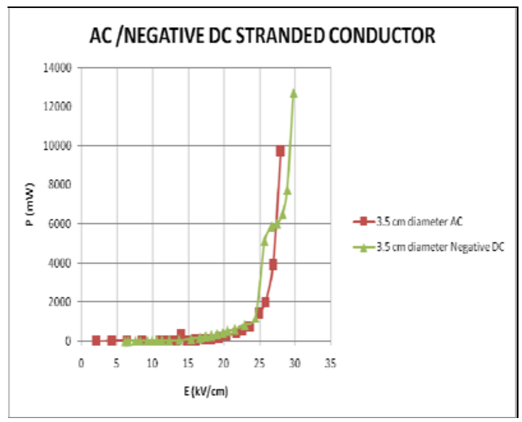

Figure 13: Effect of voltage type on corona losses: solid conductor

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4 DISCUSSION

A comparison of the results shown in Figures 3 and 4 reveals that the AC CL increase with conductor diameter. Negative DC corona losses also show similar trends. This could be due to the fact that large conductors tend to support longer streamers. Similar observations were also reported in [4]. These observations are similar to what was mentioned earlier in [11] and [12]. The higher CL observed under negative polarity could be due to repelled high mobility electrons and negative ions being conducted rapidly to ground. The absence of space charge to suppress corona could be one of the reasons for the higher corona losses under AC conditions [2].

The significance of the cross-over field and its dependence on conductor size and surface condition is not clear. However, it has been observed that for stranded conductors, the negative DC corona losses are generally higher compared to AC losses, in the practical transmission line operating conductor surface fields.

From Equations 2 and 5, it can be seen that the power losses can also be calculated in terms of gap current and resistance. Gap currents measured under AC conditions were comparatively higher and the DC gap resistances were comparatively higher. In the case of AC voltages, the dielectric losses are due to both resistive and capacitive components of the dielectric material (i.e. cage the air gap), whereas under DC voltages the losses are due to the resistance of the air gap only.

5 CONCLUSION

The results obtained show that the difference in CL under AC and negative DC voltages are dependent on conductor surface electric field, conductor surface condition and size. It has also been shown that for both AC and DC voltages, CL increase with conductor surface gradient, as well as with the conductor size for a given conductor surface gradient. The losses under DC voltages are dependent on air gap resistance, whereas the AC losses are dependent on both gap capacitance and resistance. The CL for solid conductors is much less compared to stranded conductors. Therefore, solid conductors should not be used to predict CL produced by stranded conductors. Further work needs to be done to be able to understand the effect of conductor size and surface condition on the observed differences between negative DC and AC corona losses.

6 ACKNOWLEDGEMENT

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