Influence of Hydrophilic Conductor Surface Treatments on OHL Audible Noise

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***Abstract*- Both the ever increasing demand for energy as well as the current change in power generation strategies necessitate a constant augmentation of overall overhead line transmission capacity. However, neither the construction of new overhead lines nor the refurbishment of existing ones is ever met with a lot of acceptance. One of the most annoying side effects associated with power lines is audible noise, which often occurs along overhead lines during foul weather. These noise emissions are caused by corona effects which in return are abetted by water droplets deposited on the conductor ropes. As research has shown, new conductor ropes are much more prone to this effect than well aged ones. This is a fundamental problem frequently encountered during the commissioning of new lines and the refurbishment of existing ones. Adequate ways of mitigation must be found to ensure a minimum of opposition towards planned reinforcements of the overhead transmission line system.**

To be able to assess the different concepts for corona noise reduction comprehensively, this paper discusses the underlying mechanisms. Furthermore, various corrective measures with the focus on hydrophilic conductor surface treatments, which strive to reduce the development of corona-inducing water droplets, are introduced. To investigate their effectiveness extensive laboratory tests with variously treated conductor ropes were carried out in a high voltage laboratory. During all measurements increased efforts to ensure a constant and realistic artificial rain rate were made. For this a specifically developed rainfall simulator was used.

I. Introduction

The emission of audible noise by overhead lines during foul weather (rain, snow, fog, drizzle etc.) is a well-known phenomenon and has been studied extensively in the past [1]. Due to their spectral composition such noises can be a significant source of annoyance for people living close to an OHL. In fact, nowadays audible noise considerations play a major role in the approval processes of OHL projects. It is also a well-known fact that due to various aging phenomena overhead line conductors which have been in operation for several years exhibit considerably lower acoustic emission levels than newly installed conductor ropes. Due to this behavior newly erected overhead transmission lines or existing transmission lines with renewed conductor ropes (uprating or refurbishment) are particularly problematic as far as audible noise is concerned. To minimize the annoyance of people neighboring to overhead lines and to improve general overhead line acceptance suitable mitigation concepts must be found.

This contribution discusses how treatments of the overhead line conductor surfaces can help to reduce the development of audible noise.

For a better understanding of the functional principles of such surface treatments, an overview concerning the underlying mechanisms of audible noise generation will be given. Afterwards results of various audible noise measurements carried out at the high voltage laboratory of Graz University of Technology will be presented. The goal of the experiments was to determine the efficiency of conductor surface treatments under realistic conditions and AC stress.

II. Audible Noise Generation

Audible noise is primarily a corona related phenomenon [2]. The corona events occurring on an overhead line depend on voltage polarity [3]. To get an insight into audible noise generation under AC stress, the two sinus half waves shall be considered individually.

During the positive half-wave the majority of discharges are of the "streamer" type. During the negative half-wave periodic Trichel-discharges are prevalent [4]. Due to their inherent discharge intensity and their fluctuating occurrence sound emissions induced by streamer events are mostly described as "crackling". Trichel-discharges occur far more steadily and therefore produce "hissing" sounds. The visible differences between the two discharge types are illustrated in Fig. 1.

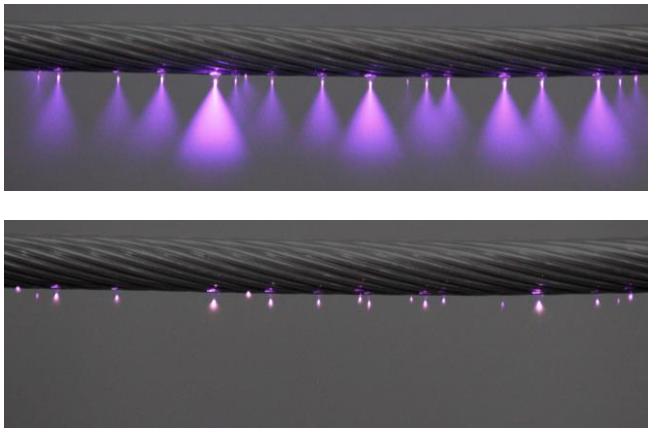


Fig. 1. Streamer discharges (top, positive polarity) and Trichel-discharges (bottom, negative polarity) on a wet OHL conductor at the same voltage level

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Due to human auditory perception the noise perceived under AC stress is a superposition of the aforementioned acoustic phenomena. Under DC stress only one type of sound occurs which is obviously dependent on the applied voltage's polarity. Streamer and Trichel discharges cause high frequency audible noise emissions. However, under AC stress an additional tonal component becomes apparent in the sound spectrum (Fig. 2). This pure tone is caused by periodic ion drift motions of space charges close to the conductors caused by the alternating electric field. The periodically accelerated space charges transfer energy to the surrounding air and by that excite a hum noise with twice the mains frequency [5]. Due to psychoacoustic effects this hum noise, which is mostly referred to as 2*f* hum, 100 Hz hum or 120 Hz hum respectively, becomes fairly bothersome after prolonged exposure. Corona is insofar relevant for this phenomenon as it raises the density of available space charges (ion injection).

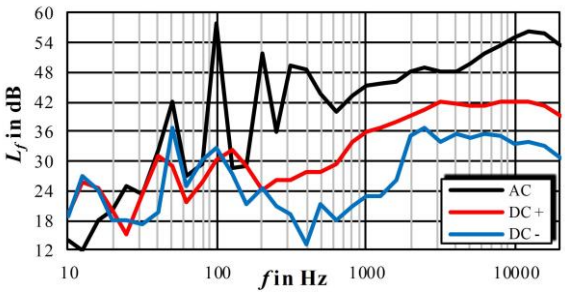


Fig. 2. Third octave spectrum of a single untreated conductor (Ø 22 mm)

Water droplets deposited on the conductors during foul weather events can be considered as tiny imperfections which locally enhance the surrounding electric field (surface gradient) and therefore abet overall corona activity. The degree of field enhancement depends largely on the droplet's volume and shape [6]. Additionally, a field-dependent drop distortion can be observed ("Taylor cones") which gives rise to even higher levels of corona [7].

III. Audible Noise Reduction

Since audible noise emitted by OHL is a corona related phenomenon concepts for the mitigation of corona activity are synonymous with concepts for audible noise reduction. Corona itself is prevalent on inhomogeneous geometries where the surface gradient exceeds a maximum permissible value. Lowering the surface gradient by "smoothing" the surrounding electric field is therefore a viable approach for the reduction of corona and consequently audible noise. In the case of OHL conductors this is typically achieved by using conductor ropes with a larger diameter or by optimizing the bundle's geometry either by increasing the number of sub-conductors per bundle or by reducing the bundle spacing [8]. However, a more direct approach would be to inhibit the undesired deposition of water drops on the conductors. This is usually achieved with hydrophilic treatments of the conductor surfaces. In cases where the geometry is fixed this is the only option anyway.

Water drops deposited on hydrophilic surfaces are spread out and form a continuous layer of water rather than discrete droplets. Due to this decrease in drop-size the aforementioned field distortion is reduced substantially.

Aged conductors (more than 2 - 3 years in operation [9]) usually show considerably better hydrophilic properties than new conductors which are oftentimes even tainted with hydrophobic drawing grease. This effect is considered to be a result of natural surface erosion which roughens the conductor surface. According to Wenzel a surface which has already been slightly hydrophilic before gains in hydrophilicity when it is roughened [10]. Therefore, various methods have been explored to give hydrophilic properties to newly manufactured conductors. The most promising approaches are sand or glass bead blasting and hydrophilic coatings or paints (Fig. 3).

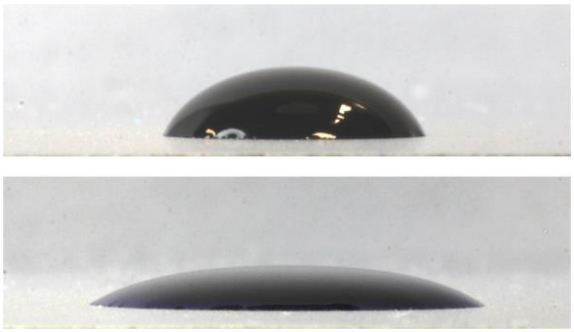


Fig. 3. Drops of dyed water (100 µl) on an untreated aluminum surface (top) and on a glass bead blasted aluminum surface (bottom)

IV. Audible Noise Measurements in High Voltage Laboratory

A. Test Setup

Since the necessity for audible noise reduction has become apparent, manufacturers strive to develop highly hydrophilic "silent" conductor ropes which have to be tested in a controlled environment. At Graz University of Technology such noise emission tests are usually carried out on single conductors or conductor bundles with a length of 10 m which are mounted at a height of $h = 3$ m (Fig. 4). The following four step measurement procedure has been established [11]:

- **Step 0:** Based on the recommendations given in IEC 61284 each measurement series begins with a conditioning phase where a constant voltage is applied for $t = 5$ min to remove any particles which might adhere to the conductors [12].
- **Step 1:** The first test is a voltage step test which is carried out with a dry conductor sample.
- **Step 2:** The test object is wetted thoroughly and then the decay of audible noise is measured while the conductor dries under constant high voltage stress.
- **Step 3:** The third test is again a voltage step test, but this time it takes place under constant precipitation of e.g. 6 mm/h (other rain rates are possible).

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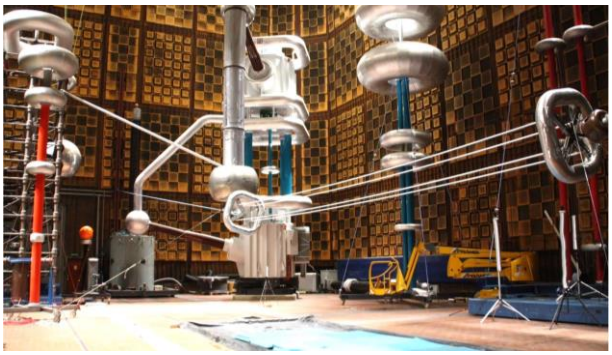


Fig. 4. High voltage laboratory setup for audible noise measurements (4-conductor bundle)



Fig. 5. Wetting of 2-conductor bundle with rainfall simulator

This test procedure is applicable under AC stress and DC stress respectively. Typical surface gradients are in the range of 6 - 28 kV/cm for AC tests and 13 - 30 kV/cm for DC-tests. As will be shown further below, the test voltages need to be chosen whilst taking into account the conductor diameter and bundle geometry. Constant precipitation rates ranging from 1 to 20 mm/h are achieved with a special artificial rainfall simulator which is mounted above the conductors (Fig. 5). The ends of the conductor samples are shielded with corona rings to ensure that the measurement setup is free of discharges.

A full scale noise emission test is comprised of the following measurements:

- Audible noise measurement
- Partial discharge measurement
- Radio interference voltage measurement
- Observation with visual camera
- Observation with corona camera

Due to the noise's stochastic behavior a sufficiently long exposure time is needed. During the step tests each voltage level is applied for at least $t = 30$ s. The background noise in the high voltage laboratory is fairly low and amounts to approx. 22 dB(A). However, the rain noise etc. raises the background level to about 28 dB(A).

V. Results

The measurement results are presented as equivalent A-weighted continuous sound pressure level L_{Aeq}. Fig. 6 shows the results of audible noise measurements which were carried out on a 2-conductor bundle to determine the effectiveness of various surface treatments under AC stress. It is obvious that the untreated conductor shows the least favorable emission behavior. The new, glass bead blasted sample is considerably more quiet. The best reduction was achieved with a special hydrophilic coating, whose emission properties were nearly equal to that of the aged conductor (20 years in operation).

Experiments have shown that the general emission behavior under AC stress ($L_{Aeq} = f(U)$) can be divided into three ranges.

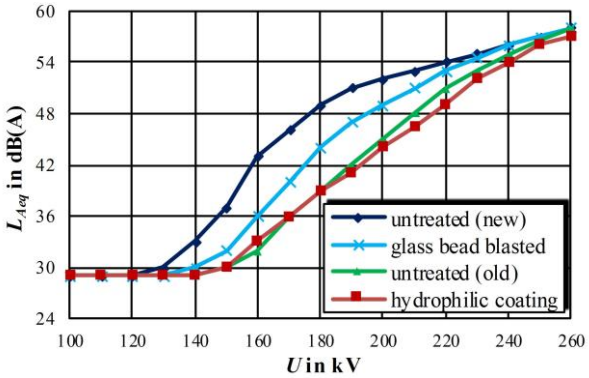


Fig. 6. Audible noise measurement during voltage step tests, precipitation rate: 6 mm/h, 2-conductor bundles (Ø 36 mm), $E' = 0.0631$ kV/(cm·kV)

At low test voltages noise emitted by the conductors is still masked by the background noise (range 1). With increasing voltage, a rise in audible noise can be observed. In this second area of operation the differences between various surface treatments become obvious (range 2). However, once the emission curves enter range 3 they flatten out and converge. At this point surface treatments are no longer able to mitigate noise emissions significantly. This effect sometimes even causes untreated conductors to exhibit lower emission levels than treated ones. This behavior has been observed with rather thin single conductors.

The described behavior is of utmost importance for the testing as well as operation of overhead line conductors. An assessment of the efficiency of various surface treatments is only possible in range 2. The test voltage levels therefore need to be chosen in such a manner, that the resulting field intensities in the high voltage laboratory are comparable to those occurring at a real overhead line. Therefore, FEM electric field simulations should be carried out before all measurement series.

The achievable noise reduction strongly depends on the number of sub-conductors: While the achievable noise reduction is limited to a few decibels for a single conductor differences of up to 10 dB(A) can be observed for 4-conductor bundles as shown in Fig. 7. In the presented case the aged conductors have only been in operation for one year and their hydrophilic properties are therefore not fully developed.

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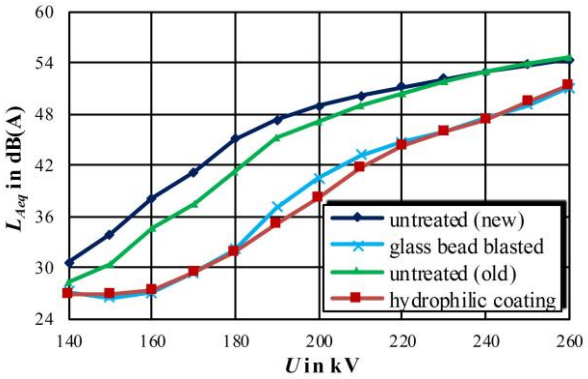


Fig. 7. Audible noise measurement during voltage step tests, precipitation rate: 6 mm/h, 4-conductor bundles (Ø 25 mm), E' = 0.0665 kV/(cm·kV)

To the best of the authors' knowledge a mathematical relationship between the partial discharge behaviour and the emitted audible noise levels has not yet been found. However, it ought to be pointed out that a strong correlation between the results of the noise measurements and the PD and RIV measurements can be observed, which can be used for verification purposes (Fig. 8).

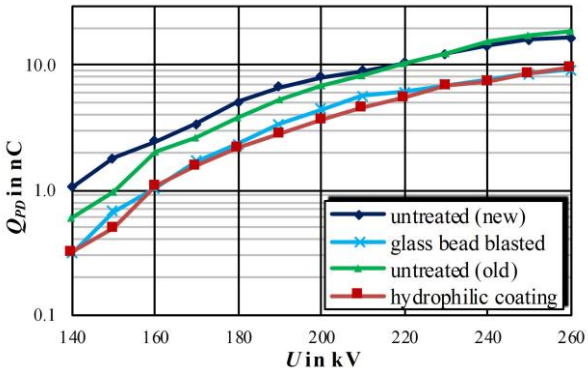


Fig. 8. Partial discharge measurement during voltage step tests, precipitation rate: 6 mm/h, 4-conductor bundles (Ø 25 mm), E' = 0.0665 kV/(cm·kV)

The time-dependent noise characteristics of untreated as well as treated conductors during a decay test can be observed in Fig. 9. This test helps to predict how long noise emission persist after a rain event has stopped. Minimizing the time needed for dry off is crucial since the rainfall masking the corona noises is missing.

VI. Conclusion and Outlook

All audible noise measurements carried out so far clearly show that overhead line conductors which have undergone surface treatments exhibit lower audible noise emission levels than new, untreated conductors. However, one also needs to keep in mind that surface treated conductors can only take effect when they are operated within the permissible limits regarding the surface gradient. Furthermore, significant noise reductions can only be expected for bundle conductors, not for single conductors.

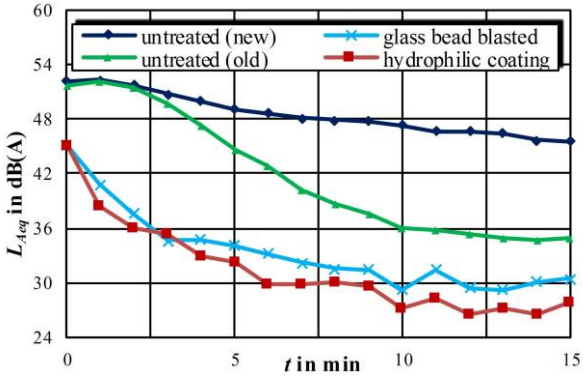


Fig. 9. Audible Noise measurement during decay tests with U = 220 kV, 4-conductor bundles (Ø 25 mm), E = 14,6 kV/(cm)

Future work will focus on the development of detailed prediction formulas with suitable correction factors dependent on the conductors' surface condition which has been neglected by existing formulas so far. Furthermore, while its background is now well understood, measures for the mitigation of the 100 Hz tonal component are still to be explored individually.

Last but not least standardization of surface treatments and the corresponding terminology and testing procedures will have to be considered as well to assure consistent quality for end-users.

References

[1] Taylor, Chartier, Rice, "Audible Noise and Visual Corona from HV and EHV Transmission Lines and Substation Conductors – Laboratory Tests", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88(5), pp. 666 - 679, 1969

[2] Pokorny, Schlomann, Miller, Barnes, "Investigation of Corona Effects from Wet Bundle Conductors for Applications to UHV Configurations", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-91(1), pp. 211 - 222, 1972

[3] Ianna, Wilson, Bosack, "Spectral Characteristics of Acoustic Noise from Metallic Protrusions and Water Droplets in High Electric Fields", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-93(6), pp. 1187 - 1196, 1974

[4] Trichel, "The Mechanism of the Negative Point to Plane Corona Near Onset", Physical Review, Vol. 54(4), pp. 1078 - 1086, 1938

[5] Straumann, "Berechnung und Reduktion der tonalen Geräuschemission von Hochspannungsfreileitungen", PhD thesis, ETH Zurich, Switzerland, 2007

[6] Pfeiffer, Schultz, Hedtke, Franck, "Explaining the Impact of Conductor Surface Type on Wet Weather HVDC Corona Characteristics", Journal of Electrostatics, Vol. 79, pp. 45 - 55, 2016

[7] Taylor, "Disintegration of Water Drops in an Electric Field", Royal Society of London, Mathematical and Physical Sciences, Vol 280(1382), pp. 383 - 397, 1964

[8] Pischler, Schichler, "Bundle Conductor Geometry Optimization for Reducing Audible Noise of Overhead Power Lines", 20th International Symposium on High Voltage Engineering, Report 536, Buenos Aires, Argentina, 2017

[9] Booker, "Natural Aging of Non-Energized Aluminium Conductors", IEEE Transactions on Power Delivery, Vol. 1, pp. 269 - 274, 1986

[10] Wenzel, "Resistance of Solid Surfaces to Wetting by Water", Industrial Engineering Chemistry, Vol. 28(8), pp. 988 - 994, 1936

[11] Schichler et al., "Innovation-Section: Test-Run for Uprating a 220 kV OHL to 380 kV Using Insulated Crossarms and Coated Conductors", CIGRE Session Paris, Report B2-301, 2016

[12] IEC 61284, "Overhead Lines – Requirements and Tests for Fittings", 1997

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