Audible Noise Performance of OHL Conductor Bundles

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SUMMARY

The transmission of electrical power in the world today is achieved mainly by the use of overhead lines with voltage levels of up to 1100 kV. A correct design is necessary for the OHL conductors to avoid corona effects under dry and foul weather conditions. The occurrence of corona at the surface of OHL conductors causes environmental effects like audible noise and radio-interference voltages, which are both limited by international standards. In foul weather (high relative humidity, light rain, fog etc.) the corona phenomenon intensifies due to the presence of water drops on the conductors and the level of audible noise increases. The surface voltage gradients and conductor surface are important factors in regard to the corona phenomenon.

Hydrophilic conductors are able to reduce the acoustic noise caused by corona under foul weather conditions due to the presence of a water film instead of water drops. The hydrophilic properties of conductors can be realized by different treatments of the conductor surface (e.g. blasting with glass beads, coating).

A defined test procedure was used for audible noise measurements in the laboratory and supported by FEM calculation of surface voltage gradients for different bundle arrangements. First the A-weighted audible noise is measured under foul weather conditions (artificial rainfall) in dependence on the test voltage resp. conductor surface voltage gradient (step 1). After rain stops audible noise is measured for a set time period at constant test voltage while the conductor starts drying (step 2). Different rainfall rates can support the characterization of the conductor performance. The single phase laboratory tests on twin-conductor bundles and three-conductor bundles with different conductor surfaces show an audible noise reduction of up to 10 dB(A) at typical operating voltages for coated conductors with hydrophilic surface in comparison to new standard conductors. The coated conductors show a similar and often better audible noise performance as service-aged standard conductors.

KEYWORDS

Overhead Line, Corona, Audible Noise, Conductor Bundles, Hydrophilic Surface

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INTRODUCTION

The transmission of electrical power in the world today is achieved mainly by the use of overhead lines (OHL) with voltage levels of up to 1100 kV. A correct design is necessary for the OHL conductors to avoid corona effects under dry and foul weather conditions. The occurrence of corona at the surface of OHL conductors causes environmental effects such as audible noise (AN) and radio-interference voltages (RIV), which are both limited by international standards. In foul weather (high relative humidity, light rain, fog etc.) the corona phenomenon intensifies due to the presence of water drops on the conductors and the level of audible noise increases. The surface voltage gradients and conductor surface are important factors in regard to the corona phenomenon.
Much of the information available today about the corona performance of overhead lines was developed during research work in North America started in the 1960s [1-3] and summarized in EPRI's reference book on transmission lines [4]. The audible noise phenomenon under foul weather conditions is still not fully understood, however, and continues to be the subject of scientific investigations [5-7].
Hydrophilic conductors are able to reduce the acoustic noise caused by corona under foul weather conditions [5, 6, 8, 9]. The hydrophilic properties of conductors can be realized by different treatments of the conductor surface (e.g. blasting with glass beads, coating).
The surface voltage gradients of OHL conductors can be optimized by the conductor diameter, surface smoothness and the application of conductor bundles. 400 kV OHL make use of conductor bundles which consist of two, three or four conductors per phase. For new OHL projects and OHL upgrading projects detailed investigations are necessary to find the optimal conductor bundle arrangement [9]. Electric field calculations by FEM software tools can support these investigations.

PREDICTION OF AUDIBLE NOISE LEVEL

The mechanisms of audible noise from transmission lines under foul weather conditions are still under discussion. However, some empirical equations from corona cage testing results are widely applied to predict the audible noise level [4]. The influencing factors for the calculation of AN level at a given rain rate are: number of sub-conductors in the bundle, sub-conductor diameter, maximum conductor surface voltage gradient, bundle diameter, and the distance from the phase to the measuring point.
It should be noted that the available equations show deficiencies due to the negligence of the conductor surface and its influence to corona in the presence of water drops.

CALCULATION OF SURFACE VOLTAGE GRADIENTS

Analytical methods or numerical methods can be applied for calculating field strength. Maxwell's potential coefficient method and approximations were used in the past for electric field calculations on transmission lines and single phase laboratory tests [3]. Some important factors need to be considered for the calculation of OHL conductor surface voltage gradients: e. g. conductor sag, proximity of towers, profile of ground surface, and conductor stranding. The real 3D transmission line is typically represented by a 2D model with cylindrical conductors. The application of FEM software tools for the calculation of surface voltage gradients shows high flexibility and allows multi-physical field coupling. The calculation results of modern FEM software tools are satisfactory due to their high accuracy. The electric field distribution of a three-conductor bundle is shown in Fig. 1, which was calculated for a single phase laboratory test arrangement (u = 100 kV, height above ground = 3 m, cylindrical conductors, conductor diameter = 36 mm, bundle spacing = 400 mm). A maximum surface voltage gradient of E_{max} = 6.04 kV/cm was calculated with regard to the mentioned test parameters (Fig. 2). It should be noted that the surface voltage gradients alter along the conductor's circumference. An increase of height above ground to 7 m results in a maximum surface voltage gradient of E_{max} = 5.07 kV/cm. The maximum surface voltage gradients for a twin-conductor bundle (horizontal arrangement) were calculated to E_{max} = 7.21 kV/cm resp. E_{max} = 6.31 kV/cm.

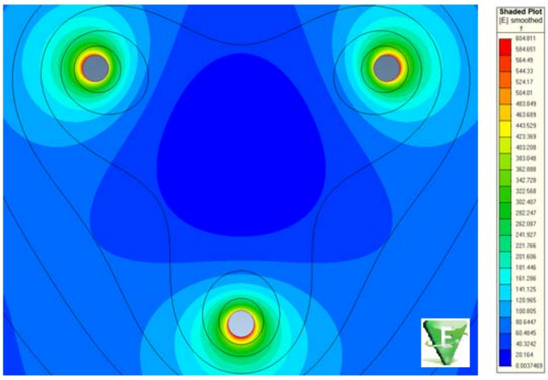

Fig. 1: Electric field distribution of a three-conductor bundle calculated by FEM method

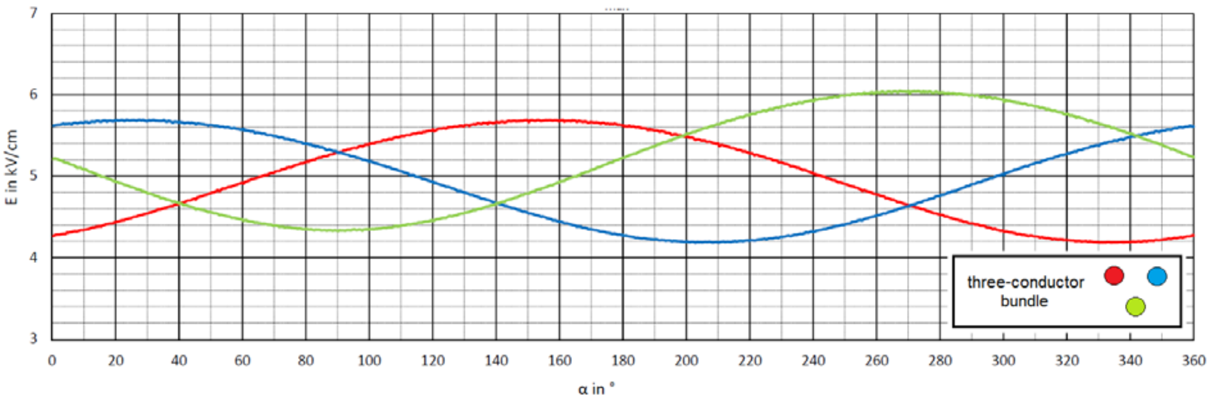

Fig. 2: Surface voltage gradients for conductors of a three-conductor bundle

The surface voltage gradients can be influenced by the conductor diameter. A maximum surface voltage gradient of E_{max} = 5.36 kV/cm is given by a three-conductor bundle at a height above ground of 3 m with conductor diameters of 42 mm. An increase of 16.7 % for the conductor diameter (42 mm vs. 36 mm) results in a reduced surface voltage gradient of 88.7 % (5.36 kV/cm vs. 6.04 kV/cm).

Consideration of the real outer strands shape will increase the calculated surface voltage gradients by a factor of up to 50 % [4].

CONDUCTOR SURFACE

OHL conductors can show different strand shapes and surface conditions. However, the strands are usually made of aluminum with a round or trapezoidal shape. New standard conductors without any treatment are characterized by a smooth metallic surface which enables the presence of prominent water drops under foul weather conditions (Fig. 3). The water drops increase the electric field strength and promote corona discharges and audible noise.

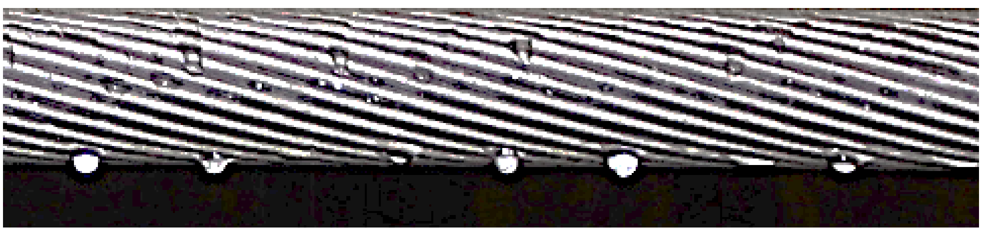

Fig. 3: Conductor surface with prominent water drops (new standard conductor)

Old conductors with several years in operation show a reduced audible noise level (reduction of about 8 dB(A)) in comparison to new conductors of the same type. This phenomenon results from the aged conductor surface showing water films under foul weather conditions instead of water drops. The aged conductors develop a hydrophilic surface, which can be prepared for new conductors by coating or increasing of surface roughness (e.g. blasting with glass beads). OHL conductors with hydrophilic surfaces are under investigation and are already in use on some pilot projects [6, 8, 9].

AUDIBLE NOISE MEASUREMENTS IN THE LABORATORY

Up to now no standardized test procedures exist for the audible noise measurements on OHL conductors and different test arrangements and test procedures have been used in the past. The present investigations are based on a two-step test procedure, which was used for the comparison of different conductors and bundle arrangements.
The A-weighted audible noise is first measured under foul weather conditions (artificial rainfall) in dependence of the test voltage resp. conductor surface voltage gradient (step 1). The test voltages need to cover all conductor surface voltage gradients which exist on related OHL in the transmission grid. After rain stops audible noise is measured for a set time period at constant test voltage while the conductor starts drying (step 2). Different rainfall rates can support the characterization of the conductor performance. The AN measurements are supported by measurement of radio interference voltage and partial discharge, and visual inspection.

Figure 4 shows the laboratory test arrangement for audible noise measurements on OHL conductors. The main dimensions of the laboratory test arrangement, the performed measurements and artificial rain were as follows:

- conductor length: 10 m
- height of conductor bundle above ground: 3 - 7 m
- distance to walls and other equipment in the laboratory: > 5.5 m
- measurements: audible noise, radio interference voltage, partial discharge
- visual inspection: corona camera, digital camera
- number of microphones: up to 4
- rain: pre-wetting, artificial rain with defined rainfall rate: 1 - 15 mm/h

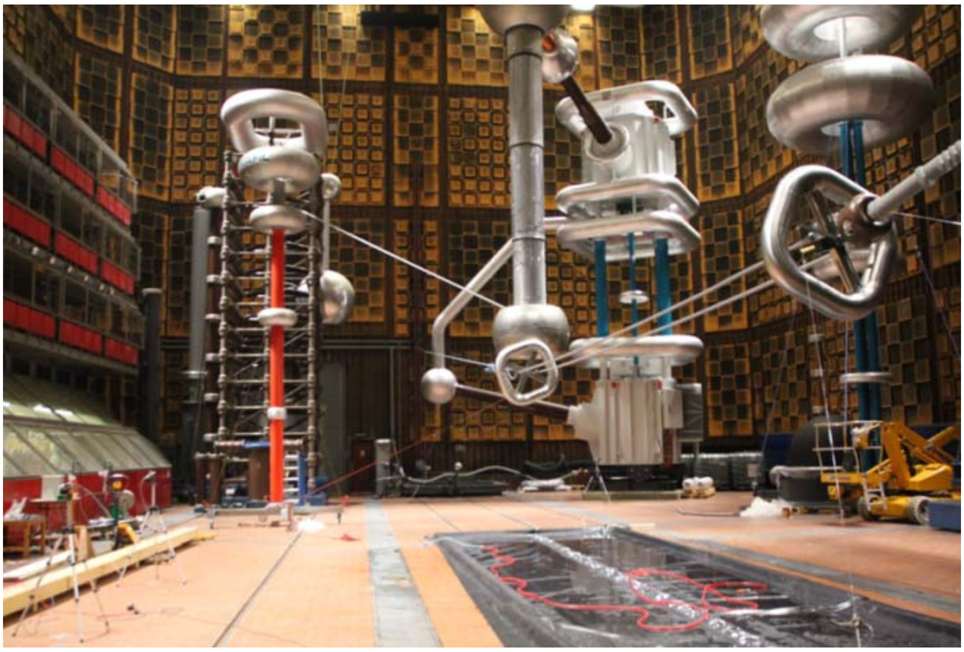

Fig. 4: Single phase laboratory test arrangement for OHL conductors

Bundles with twin conductors in horizontal arrangement and bundles with three conductors are used for the experiments (bundle spacing = 400 mm, conductor diameter = 36 mm). Table 1 describes the test parameters of the experiments. Conductors with different surfaces were investigated:

- bare surface (new, bare, untreated)
- aged surface (old, about 20 years in operation)
- hydrophilic coating (new, treated)

Table 1: Test parameters for audible noise measurement on OHL conductors

Step 1	• conductor bundle height above ground: 7 m • constant artificial rain with defined rainfall rate of 6 mm/h • range of test voltage: 180 - 300 kV • voltage steps and time of each voltage step: 20 kV, 30 s • measurements at each voltage step: AN, RIV, PD and visual inspection
Step 2	• pre-wetting of conductors • test voltage to a defined magnitude for set time period: 240 kV for 15 min • measurements at 1 min and 15 min: AN, RIV, PD and visual inspection

Figure 5 shows the audible noise measurement results from the single phase laboratory tests ($L_{A,eq}$ sound pressure levels). It can be seen that for step 1 of the investigation AN of twin-conductor bundles is in general higher in comparison to the three-conductor bundles due to different surface voltage gradients for the same test voltage. The audible noise of old conductors has always been lower in comparison with the new standard conductors (about 6 dB(A) for the twin-conductor bundle at voltages up to 240 kV and about 10 dB(A) for the three-conductor bundle at voltages up to 260 kV). The coated conductors with hydrophilic surfaces show the same, or often better AN performance compared to the service-aged old conductors.

The results at step 2 (drying period after rain stop) for a test voltage of 240 kV show the expected decrease of AN with time, i.e. less corona with reduced number of water drops based on drying of conductor surface. The coated conductors show always a better AN performance as old conductors. Further data evaluation will also consider the hum noise at 100 Hz ($L_{f,100}$) and 200 Hz ($L_{f,200}$).
The results shown in Fig. 5 also demonstrate that calculation of audible noise is difficult due to its dependency on conductor surface. Experimental investigations are necessary to check the audible noise performance of OHL conductors under foul weather conditions.

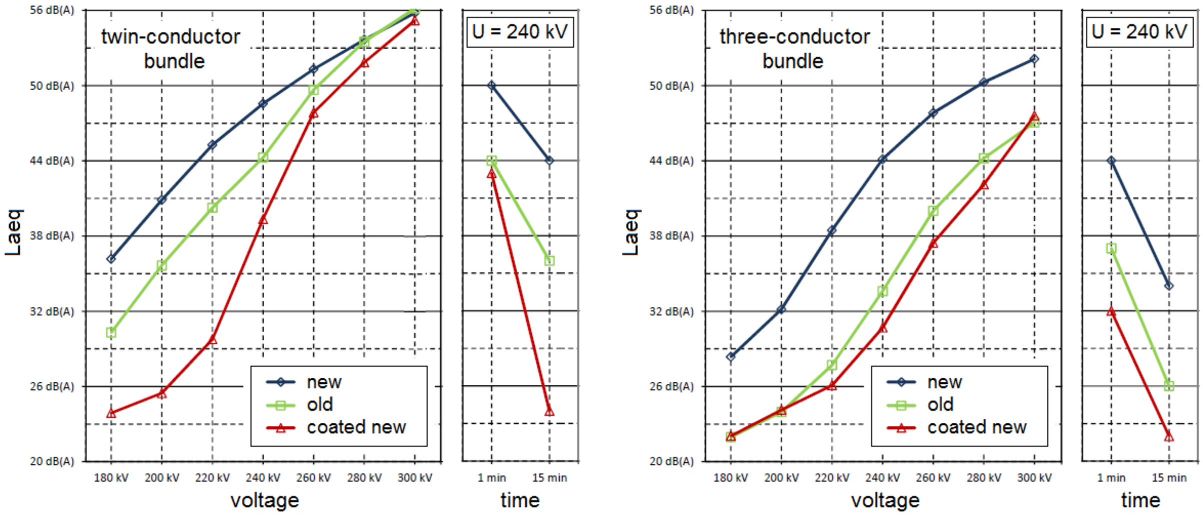

Fig. 5: Audible noise in dependence of test voltage and during drying period for twin-conductor bundles and three-conductor bundles with different conductor surfaces

The results of visual inspection show the corona activity of the OHL bundles with different conductor surfaces and support the evaluation of the audible noise test results (Fig. 6).

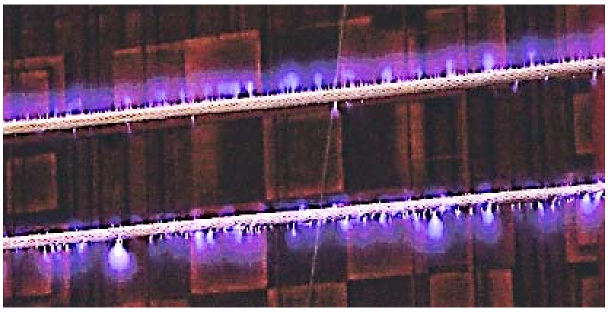

Fig. 6: Visible corona on OHL twin-conductor bundle under foul weather conditions

CONCLUSION

The AN of different OHL conductors under foul weather conditions was investigated. The surface voltage gradients and conductor surface are important factors for audible noise from OHL. A FEM software tool was applied for the calculation of surface voltage gradients.
A defined test procedure was used for AN measurements in laboratory. The single phase laboratory tests on twin-conductor bundles and three-conductor bundles with different conductor surfaces show an AN reduction of up to 10 dB(A) at typical operating voltages for coated conductors with hydrophilic surface in comparison to new standard conductors. The coated conductors show a similar and often better AN performance to that of service-aged standard conductors. The available equations for the calculation of AN levels need to be improved to consider different conductor surfaces.

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