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CORONA AUDIBLE NOISE OF 110 KV HIGH VOLTAGE OVERHEAD TRANSMISSION LINES

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Abstract: The corona discharge mechanism and the resulting audible noise of high voltage overhead transmission lines with a nominal voltage class equal or higher than 220kV is largely solved and published. In the course of reconstructing a 110kV line the local approving authority has forced the grid operator to investigate the corona noise before and after the reconstruction, especially the effect of changing from single to bundle conductor.
Therefore an experimental setup in the high voltage laboratory of the Institute of High Voltage Engineering and System Management of the University of Technology has been build and acoustic measurements on single and bundle conductor were performed. To prove the impact of typical, various weather conditions to the corona discharges field tests are also realized. With this results general predications of the corona audible noise of 110kV high voltage overhead transmission lines can be derived.

1 INTRODUCTION

At places of raised electric field strengths high voltage overhead transmission lines can produce spontaneous, pulse-like corona discharges (acoustic sound emission or A-levels) which become apparent by crackling noise. By wet or humid weather conditions a distinctive 100 hertz hum (2f or tonale emission) can appear beside the acoustic sound emission [1].

To take into account the increased awareness of the population concerning noise exposure, the local approving authority has forced the grid operator to investigate the corona noise before and after the reconstruction of an 110kV overhead line (OHL), especially the effect of changing from single to bundle conductor.

This paper describes the results of sound measurements in different conductor-configurations in a high voltage laboratory and verification of these results on the basis of field tests.

2 GENERAL DEFINITIONS OF SOUND MEASUREMENT

In this Paper the following sound pressure levels are used:

Name	Description
$L_{A,95\%}$	**Basis level in dB** In 95% of the observation time exceeded A-valued sound pressure level of any noise.
$L_{A,eq}$	**A-valued energy-equivalent long-term sound level in dB** Single indication, which describes the sound events with fluctuating sound pressure levels. It is that sound level which has the same energy concentration like the fluctuating noise by constant steady influence for a given relation time.
$L_{Z,eq}$	**Unvalued energy-equivalent long-term sound level in dB**
$L_{A,Max}$	**Maximum level in dB** The highest sound level within the measuring time

Table 1: sound pressure levels

"A-valued" means the weighting of the measured unvalued sound pressure levels with a function considering that human beings have a different frequency-dependent hearing.

3 CALCULATION OF THE CONDUCTOR-GRADIENT

Substantially for the appearance of corona discharge is the existence of effectual conductor-gradient on the conducting wire. The middle conductor-gradient of one outer conductor is generally calculated according to the equation below [2]:

$$Ei = \frac{Ci'}{2 \cdot \pi \cdot \varepsilon_0 \cdot r} \cdot [1 + 2 \cdot (n-1) \cdot \sin\left(\frac{\pi}{n}\right) \cdot \frac{r}{a}] \cdot \frac{V}{\sqrt{3}} \qquad (1)$$

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Ei	middle conductor-gradient of one outer conductor
Ci'	capacitance per unit length of the conductor i at the co-system
ε_0	dielectric constant $8.8 \cdot 10^{-12}$ F/m
V	nominal voltage (phase to phase)
a	subconductor distance of the bundle conductor
r	subconductor radius
n	number of the subconductor's

The capacity Ci' must be determined from the geometrical data of the outer conductors, the earth wire and the tower geometry. For a symmetrical line with two systems the middle capacity of one conductor can be determined by the following approximation formula:

$$\overline{C}' = \frac{2 \cdot \pi \cdot \varepsilon_0}{\ln\left(\frac{D \cdot DmRs}{r \cdot DmRr}\right)} \quad (2)$$

$$D = \sqrt[3]{D_{RS} \cdot D_{ST} \cdot D_{RT}} \quad (3)$$

$$DmRs = \sqrt[3]{D_{RS} \cdot D_{St} \cdot D_{Rt}} \quad (4)$$

$$DmRr = \sqrt[3]{D_{Rr} \cdot D_{Se} \cdot D_{Tt}} \quad (5)$$

$\overline{C}'$	middle capacitance per unit length of one conductor of the co-system
ε_0	dielectric constant $8.8 \cdot 10^{-12}$ F/m
r	subconductor radius
D_{Xy}	middle outer conductor's distance of the phase X to the phase y
DmRs, DmRr	middle outer conductor distance of different systems
D	middle outer conductor's distance of one system

By the bundle conductor the partial radius becomes the equivalent radius r_B.

$$r_B = \sqrt[n]{n + r + r_T^{(n-1)}} \quad (6)$$

r_B	equivalent radius
n	number of the subconductors
r	subconductor radius
r_T	pitch circle radius

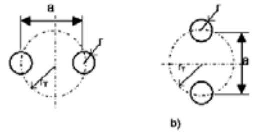

Figure 1) examples of double bundle configurations a) horizontally and b) vertically

The results of the conductor-gradient-calculation with the Al/St 240/40 wire in different configurations and various tower designs used in the field tests are shown in the Table 2. Besides, the shown voltages in tables and in the figures are phase-earth voltages.

tower design	operating voltage in kV	conductor-type	conductor-configuration	conductor-gradient in kV/cm
„ton“	68	Al/St 240/40	single conductor	9,5
	68	Al/St 240/40	2-bundle conductor	6,9
„lyra“	69	Al/St 240/40	single conductor	9,8

Table 2) calculation of the conductor-gradient

The critical conductor-gradient cited in the literature concerning annoying corona discharge emission of 16-17kV/cm were fallen short under the examined conditions (see table 2).

4 LABORATORY MEASUREMENT

4.1 Description of the high-voltage laboratory and the measuring set-up

The sound measurements on different conductor-configurations were carried out in the high voltage-laboratory of the test research institute for high voltage engineering Graz GmbH (VAH) of the University of Technology of Graz. The high voltage laboratory is located 353 metres above the sea level and is performed completely shielded to be able to measure interference-free in the hall and to not disturb the environment through unintentional hf-transmission. For the realisation of the sound measurement the high-voltage-cascade was supplied by a variable AC transformer. The connection of the specimen occurred by means of a 9kOhm resistor and a central electrode. A 3m long pipe with an external diameter of 22.5mm was taken down on the central electrode to the specimen and the conductor was connected through a T-connector electrically as well as mechanically. The basic set up of the measurements is shown in figure 2.

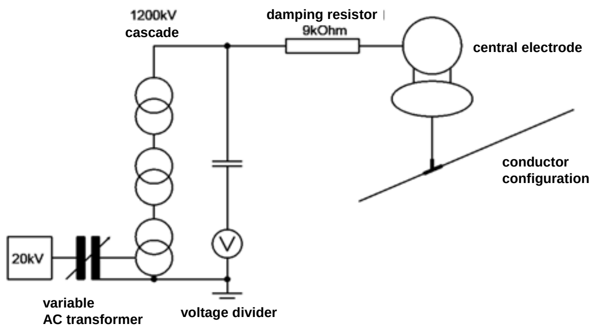

Figure 2) basic set-up

The specimen itself was mounted horizontal in the hall and stretched on both sides of the hall by means of composite insulator and chain block. Besides, the specimen's length was approx. 25 metres long. The ends of the insulator and the connectors were shielded with doubletorus (external diameter of 600mm).

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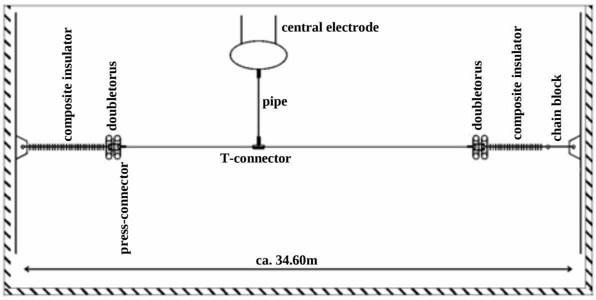

Figure 3) scheme of the single conductor configuration

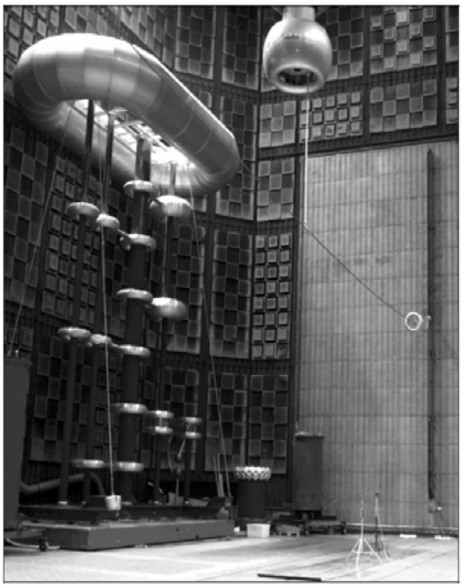

Figure 4) laboratory set-up of the single conductor measurement

In addition to fix the double bundle a plastic rope was mounted on the right double torus, so the vertical mounting orientation could be reached by the hall crane. The field distance holders were mounted at the end of the press-connectors and at the T-connector.

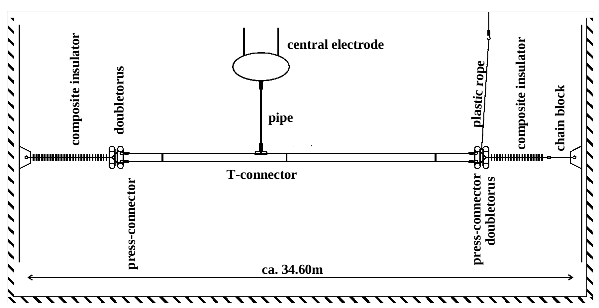

Figure 5) scheme of the double bundle configuration

4.2 Description and set-up of the sound level measuring instrument

The sound level measuring instrument 2250 of the company Brühl and Kjaer was used. The measuring microphone was mounted in a distance of 3 metres vertically below the conductor and led by shielded cables in the control room to the analyzer.

4.3 Atmospheric measuring conditions in the high voltage laboratory

During the measurements the climate in the hall was 22.4°C, 61.9% relative dampness (corresponds 11.9 g / m ³ H2O) and 1015hPa (relative air pressure).

4.4 Measurement of the quiescent noise level in the laboratory

The measurement of the quiescent level occurred with built up specimen and without supply of the cascade. Besides, possible disturbing noise and background noise just as the own noise of the measuring instruments were also detected. The quiescent noise level in the hall moved by the $L_{A,\ eq}$ between 20.4dB and 24.7dB and by the $L_{A,\ 95\%}$ between 19.0dB and 19.8dB. The evaluation of the noise emission of the transformer (transformer hum) resulted sound levels at the $L_{A,\ eq}$ from 21.7dB to 26.1dB and at the $L_{A,\ 95\%\ of}$ from 19.6dB to 20.1dB.

4.5 Measurements on the single conductor configuration

For the single conductor configuration a used wire piece from the rebuilt 110kV line Malta - Außerfragant (system number 115 / 3B and 115 / 4C) was used.
The used line conductor was a 240/40 aluminium/steel composite wire with a nominal external diameter of 21.84mm. The surface of the conductor showed cokings by the many years of use. The conductor was mounted with the T-connector at 5.9 metre height and by the microphone at a height of 6.07 metres above the hall bottom.

operating voltage in kV	$L_{A,eq}$ in dB	$L_{A,Max}$ in dB	$L_{A,95\%}$ in dB
70	22.3	33.6	19.7
120	25.5	40.2	21.5

Table 3) measurement results of the single conductor, measuring time 5 minutes

The following diagrammes show the third-octave-band unvalued frequency spectra by different operating voltages.

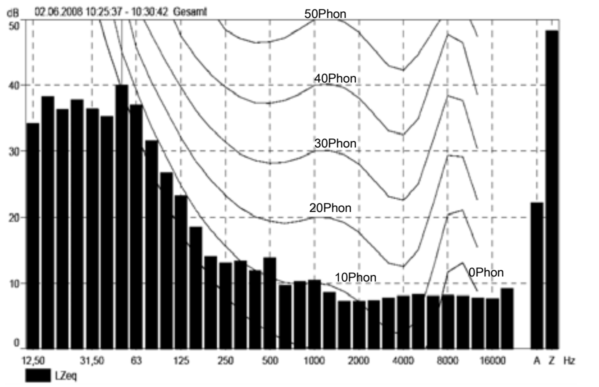

Figure 6) spectrum of the single conductor measurement with a voltage of 70kV, measuring time 5 minutes

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The envelopes mark the curves of the same volume in phon after Fletcher and Munson.

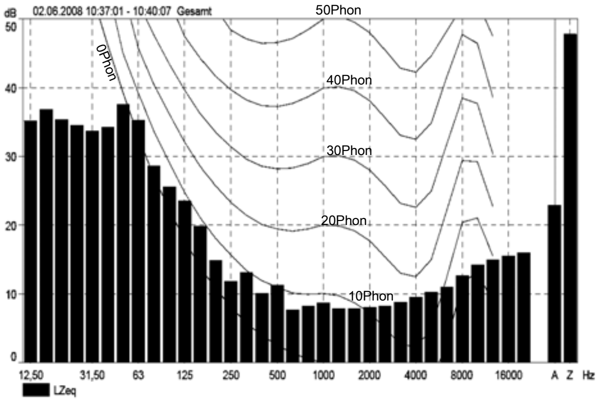

Figure 7) spectrum of the single conductor measurement with a voltage of 120kV, measuring time 5 minutes

By a voltage of 120kV a light increase of the high frequency levels is recognizable, but not audible.

4.6 Measurements on the double bundle configuration

For the double bundle configuration in vertical position (subconductor distance of 400mm) a brand new conductor was used. The height above the hall bottom of the lowest conductor was by T-connector 5.52 metres and by the microphone 5.38 metres. At the beginning of the measurements the conductors were "branded" with 200kV for 5 minutes to delete possible foulings.

operating voltage in kV	$L_{A,eq}$ in dB	$L_{A,Max}$ in dB	$L_{A,95\%}$ in dB
70	20.7	33.2	19.3
120	23.3	44.6	19.7

Table 4) measurement results of the double bundle configuration, measuring time for 70kV and 120kV in each case 5 minutes

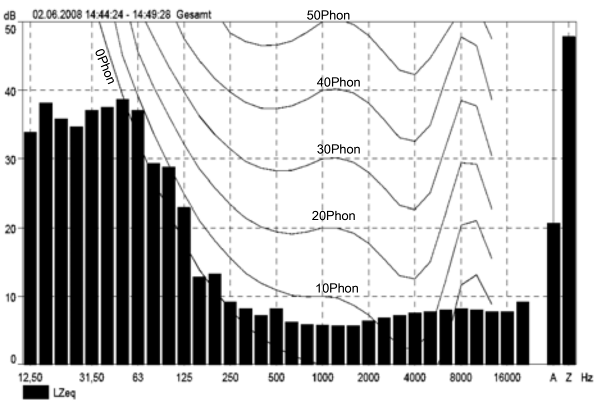

Figure 8) spectrum of the double bundle measurement with a voltage of 70kV, measuring time 5 minutes

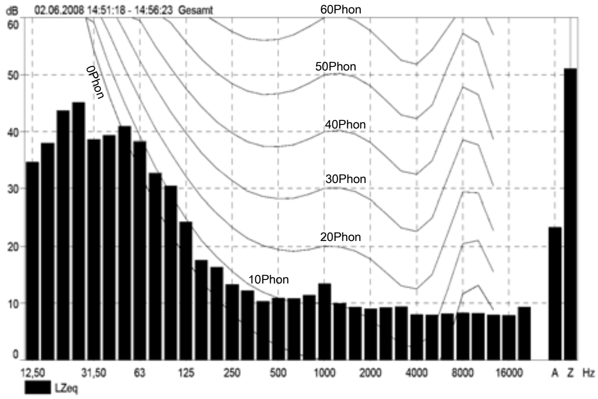

Figure 9) spectrum of the double bundle measurement with an operating voltage of 120kV, measuring time 5 minutes

4.7 Results of the laboratory measurement

With an operating voltage of approximately 70kV no essential noise emission over the quiescent level was noticed at both conductor-configurations (single and bundle conductor). The simulation of an earth-fault (increase of the phase-earth voltage in both "healthy" phases to 120kV) showed a higher noise level by the single conductor configuration than the double bundle configuration. This is a result of the conductor-gradient-decreasing-effect of the double bundle configuration.

5 FIELD MEASUREMENTS

5.1 General

To verify the laboratory-results other sound level measurements were carried out on selected 110kV overhead line locations. The sound level measuring instrument was again the 2250 of the company Brühl and Kjaer. The choice of the measuring locations occurred according to the accessibility and the quiescent level at the respective place (traffic, waters, railroad, wind, etc.). To minimize the quiescent level all measurements were hold during late night hours.

5.2 Measurement at a 110kV OHL of the type “ton-tower”

5.2.1 Description of the measuring place and the measuring set up

Measuring place:
The measuring place was located between mast No. 146 and No. 145 of the 110kV OHL “ton-tower” with the system number 112/2 (southern system) and 112/5 (northern system) near the places Projern and Dellach.

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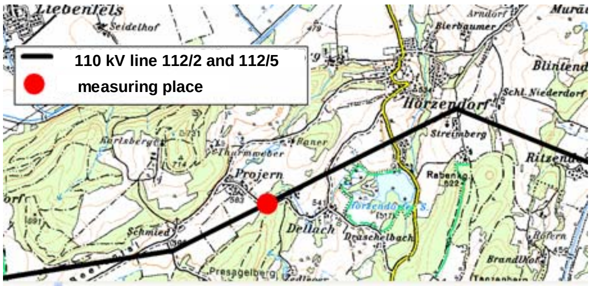

Figure 10) description of the measuring location

During the measurement the vertical distance between microphone and the tower symmetry line was 4 metres The distance between microphone (spike) and the lowest conductor (system 112/2) 5.5 metres. The measuring place is lying 517 metres above the sea level and is well protected against the wind.

Conductor and overhead earth wire:
The system 112/2 consists of an 240/40 aluminium/steel composite wire and runs between the substation St. Veit and the substation Landskron. The system 112/5 consists of an 260/40 aluminium/stalum composite wire and runs between the substation Brueckl and the substation Windischbach. The earth wire type is a 56 / E24. AlMgSI/Stalum.

Tower geometry, span field length and insulators:
The "ton-tower" consist of screwed angle-frameworks with open profiles. As insulators full-core-long-rod-insulators in double configuration with electric arc protection armatures were used.

The span field 145 - 146 measures a length of 280 metres and has in the measuring point a bottom distance of 9.42 metres (distance between the lowest conductor of the system 112/2 and the surface of the earth level).

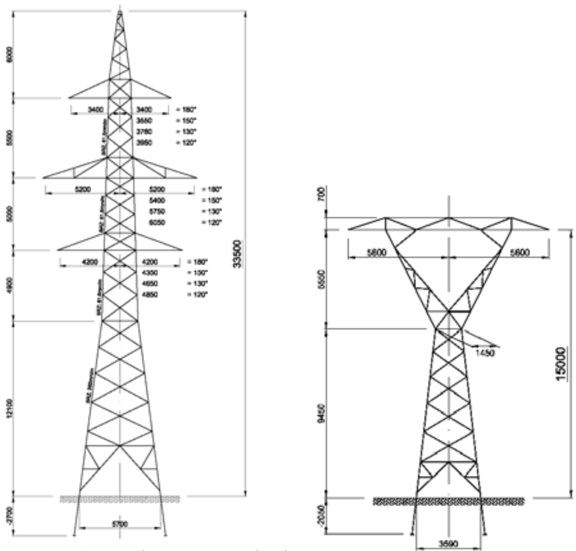
Figure 11) 110kV tower designs
(left: "ton-tower", right: "lyra-tower")

5.2.2 Atmospheric conditions at the measuring location

During the measurement the climate at the measuring place was 2.4°C, 73.8% rel. dampness (corresponds 5.4 g / m ³ H2O) and 1080hPa (relative air pressure). During the measurement it was absolutely calm.

5.2.3 Measurement at the 110kV OHL "ton-tower"

The measurement started about 22.08 CET and lasted 5 minutes. During the measurement the operating voltage in both systems was 68.13kV (phase-earth voltage).

operating voltage in kV	$L_{A,eq}$ in dB	$L_{A,Max}$ in dB	$L_{A,95\%}$ in dB
68.13	20.9	21.5	20.7

Table 5) measurement results of the 110kV OHL "ton-tower"

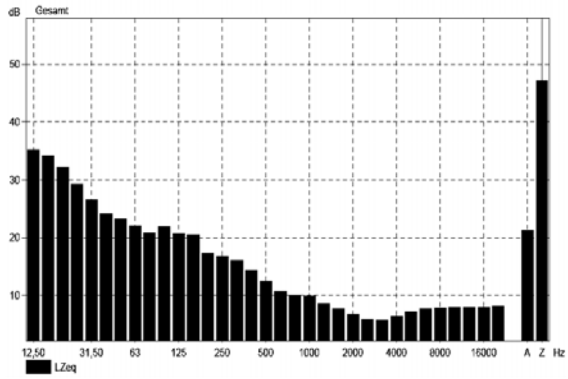
Figure 12) spectrum of the measurement of the 110kV OHL "ton-tower"

5.3 Measurement at a 110kV OHL of the type "lyra-tower"

5.3.1 Description of the measuring place and the measuring set up

Measuring place:
The measuring place was between mast No. 168 and No. 169 of the 110kV OHL "lyra-tower" with the system number 111 / 3A near the place Kras.

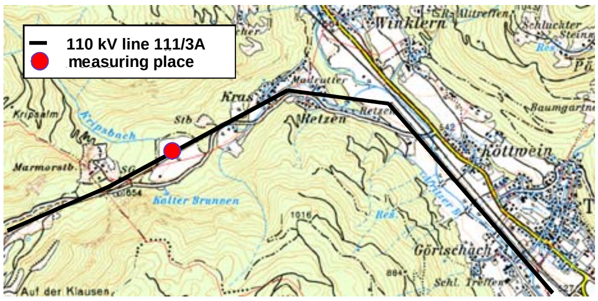

Figure 13) description of the measuring location

During the measurement the vertical distance between microphone and the tower symmetry line was 4 metres. The distance between microphone and the lowest conductor (system 112/2) 3.0 metres. The measuring place is lying 654 metres above the sea level.

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Conductor:
The system 111 / 3A consists of an 240/40 aluminium/steel composite wire and runs between the substation Landskron and the substation Gummern.

Tower geometry, span field length and insulators:
The "lyra-tower" consist of screwed angle-frameworks with open profiles. As insulators full-core-long-rod-insulators in double configuration with electric arc protection armatures were used.

The span field 168 - 169 measures a length of 250 metres and has in the measuring point a bottom distance of 10.10 metres.

5.3.2 Atmospheric conditions at the measuring location

During the measurement the climate at the measuring place was 0.3°C, 72.0% rel. dampness (corresponds 3.6 g / m ³ H_2O) and 1113hPa (relative air pressure). The measurement was influenced strongly by wind caused sounds.

5.3.3 Measurement at the 110kV OHL "lyra-tower"

The measurement started at about 00.25 CET and lasted 5 minutes. In the system 111 / 3A the operating voltage during the measurement was 68.7kV (phase-earth voltage).

operating voltage in kV	$L_{A,eq}$ in dB	$L_{A,Max}$ in dB	$L_{A,95\%}$ in dB
68.7	33.8	48.8	32.6

Table 6) measurement results of the 110kV OHL "lyra-tower"

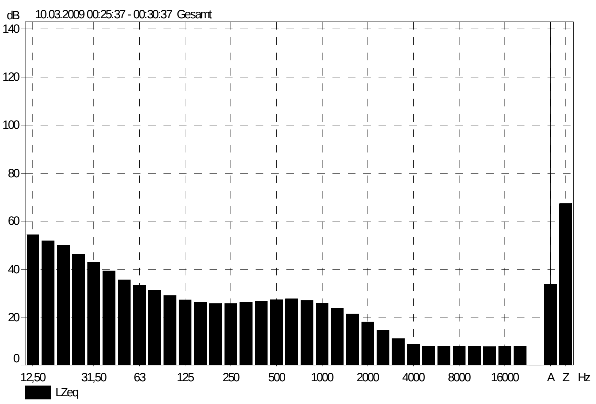

Figure 14) spectrum of the measurement in the 110kV OHL "lyra-tower"

5.4 Results of the field measurements

In comparison to the laboratory measurement the biggest problem with the field tests was the relatively high quiescent sound level. However, laboratory conditions could be reached by the transfer of the measurements during the night hours. Nevertheless, it turned out that also with favourable measuring conditions the background noise was always stronger than a possible corona discharge noise of the line itself.

Also the analysis of the spectra could not deliver any indication of corona discharge noise (no striking 100 hertz level and no audible broadband increase of the sound level between 1kHz and 16kHz).

6 CONCLUSION AND VIEW

Several measurements were executed in the laboratory as well as in the field to investigate the corona discharge emission from 110kV overhead lines. Nevertheless, the analyses of the measurement-results showed that under the prevailing climatic conditions and an operating voltage of 69kV phase-earth voltage (phase-phase voltage of 120kV) the phenomenon of corona discharge emission could not be attested neither in the laboratory nor in the field test.
Also the critical conductor gradients cited in the literature concerning annoying corona discharge emission of 16-17kV/cm were fallen short by the examined conductor-configurations, conductor-types and the tower-configurations by far.

All field measurements were executed under dry weather conditions. In addition to these investigations further field measurements on 110kV overhead lines under humid air conditions are planed.

7 EXPRESSION OF THANKS

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