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PREDICTION OF THE AUDIBLE NOISE GENERATED BY CORONA DISCHARGE ON A POWER TRANSMISSION LINE: A MODEL VALIDATION

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In the last few decades, the largest Italian Transmission System Operator has been developing novel designs for overhead power transmission lines to comply with the strict national limits regarding human exposure to low frequency electric and magnetic fields. Some of these configurations are characterised by higher voltage gradients if compared to those of traditional lines, leading to air ionisation around the conductors and to local electric discharge phenomena, also known as “corona effect”. This results in the generation of audible noise that can reach annoying levels under particular conditions, which must therefore be controlled and minimised when the transmission lines are close to residential buildings. A number of prediction methods are available in the technical literature on the subject, developed mainly in the ’60s-’80s by electrical utilities or research institutes. However, none of these methods is suitable as it is to describe complex line geometries or to take into account important parameters such as weather conditions and directivity. An analytical model available in the literature has been implemented and fine-tuned on the basis of a preliminary measurement session performed on a real transmission line. The model is based on the calculation of the electric field and of the sound power as a function of the voltage gradient around the conductor, which, in turn, is a function of the line geometry and of the cross section of the phase conductors. Improvements include the possibility to perform the computation for extended areas and frequency domain analysis. Aim of the paper is to show the potentiality of the model by comparing the code predictions with the results of an extended measurement campaign carried out at different distances from the transmission line.

Keywords: power line, corona discharge noise

1. Introduction

In recent years, the largest Italian Transmission System Operator, TERNA, has developed special designs for overhead power transmission lines (compact lines, non-conventional double circuit configurations) to comply with the very stringent national limits regarding human exposure to low frequency electric and magnetic fields [1]. These non-conventional solutions are generally characterised by higher voltage gradients on the conductors compared with those of conventional lines. Higher corona effects (visible corona, radio-interference, corona loss, acoustic noise, ozone production) are then expected, considering that the voltage gradient is the most important parameter influencing the corona effects. Accurate evaluation methods are therefore necessary to verify the conformity to the limits specified by the relevant legislation, if any, as in the case of acoustic noise, and to comply with the rules of best practice from both technical and economic point of view. A number of prediction methods are available in the technical literature on the subject, developed mainly during the ’60s to the ’80s by electrical utilities or research institutes of various countries; they have been compared and deeply discussed within international organizations, like CIGRE and IEEE. However, some uncertainties still remain in the application of these methods to very complex line geometries and in the assessment of the noise levels with respect to the atmospheric conditions affecting the line.

After analysing and improving some aspects of the available prediction methods, a general purpose code has been developed in MATLAB to predict the electric field, radio noise and sound propagation. The code has been tested on a real case, and the preliminary results have been recently proposed [2] for a single measurement point at a given distance from the power line.

The aim of this paper is to present the outcomes of audible noise simulation as compared to the results of an extended experimental campaign carried out for several weeks at different distances from the power line.

2. Audible noise

2.1 General

The calculation of the sound pressure level at a specific position placed at a certain distance from the overhead transmission line starts from the determination of the sound power level generated by the acoustic source. Each phase has been considered as a line source. The sound pressure level L_p at a certain distance x from a line source having a sound power level Γ_A in dB(A) *re* 1 μW can be computed according to the following formula:

$$L_p(x) = \Gamma_A - 10\log(x) - 52 \tag{1}$$

Since the ground causes reflections, it is necessary to consider the mirror sources from which the contribution of the reflections can be computed. The effect of the ground absorption is taken into account by assigning a lower power level to the mirror sources according to the formula:

$$\Gamma_{A,mirror} = \Gamma_A + 10\log(1-\alpha), \tag{2}$$

where α is the sound absorption coefficient of the ground. Finally, the sound pressure level in a particular position is given by the incoherent energetic sum of the sound pressure level contribution from the main and mirror sources.

2.2 Prediction methods

The prediction methods for audible noise were especially developed in the ’60s-’80s, when in many countries researches on UHV lines were extensively conducted.

For audible noise the formula describing the sound power level is of the type:

$$\Gamma_A = f_1(g) + f_2(d) + f_3(n) + K_A \tag{3}$$

K_A is a generic constant coming from numerical simplifications. Among the different formulations available in the literature, the one given by the CIGRE guideline [3] has been adopted. The sound power level for heavy rain conditions (*HR*) is computed according to Eq. (4):

$$\Gamma_{A,HR} = -\left(\frac{650}{g}\right) + 40\log(d) + 15\log(n) + 25 \tag{4}$$

and expressed in A-weighted decibels referred to 1 μW/m.

The formula is valid under given ranges of the parameters g, d and n.

The CIGRE guideline [3] gives directions to compute also the sound power level for average rain (*AR*) and fair weather (*FW*) conditions, being the three conditions *HR*, *AR* and *FW* defined according to laboratory parameters. In particular, the sound power level in average rain conditions is computed as

$$\Gamma_{\mathrm{A},AV} = \Gamma_{\mathrm{A},HR} - \Delta_0 + \Delta_{\mathrm{c}} , \tag{5}$$

being Δ_0 and Δ_c two empirical correction factors, while the value for fair weather conditions can be obtained as

$$\Gamma_{\mathrm{A},FW} = \Gamma_{\mathrm{A},AV} - 17 . \tag{6}$$

Categorising weather conditions in each of these three groups may not always be straightforward. For example, the absence of rain does not necessarily imply *FW* conditions, since the higher the relative humidity, the wetter the conductors. It is therefore essential to monitor different environmental parameters to be able to define the actual boundary conditions for the simulation. In this respect, cross-checking weather information with measurement results can provide the ultimate direction.

3. Simulation code for the audible noise

The MATLAB code developed on the basis of the previous models allows to consider any configuration of high voltage power lines (single circuit, double circuit, split phase), with any distribution of the towers and conductor catenaries.

Since the calculation of the sound power level of the sources depends mainly on the voltage gradient, the sensitivity analysis carried out for the radio noise applies also for the audible noise. Moreover, the audible noise depends also on the humidity of the air. This parameter has been monitored during the validation measurements to check its influence on the radiated audible noise. In addition to CIGRE [3] prescriptions, some other factors have been accounted for, according to [4], such as:

- The spectrum of the emitted noise;
- The reflections of the terrain;
- The absorption of the air.

The model considers each phase discretised into a sequence of point sources and then generates the mirror sources symmetrical to the ground surface. The shape of each phase is defined by the catenary equation, and the distance of each point source from the grid of the receivers placed at a certain height above the ground can be easily determined. The location and height of the conductors, modelled in the software according to the catenary equation suitably corrected by temperature and current intensity, have been checked by measuring the geometrical parameters with high precision instruments at a certain temperature and voltage condition, finding fair agreement.

The attenuation given by the air and eventually by an acoustically "soft" ground is taken into account. At the end all the contributions from the different sources and different frequencies are A-weighted and summed up together. Since the sound pressure level spectrum is computed at each measurement position, the software can easily predict the presence of audible tonal components typical of the corona noise. All the computations are made for the 1/3 octave frequency bands from 20 Hz to 20 kHz.

The 3D colour contour plot of the predicted sound pressure level in the space around the conductors is shown in Fig. 1.

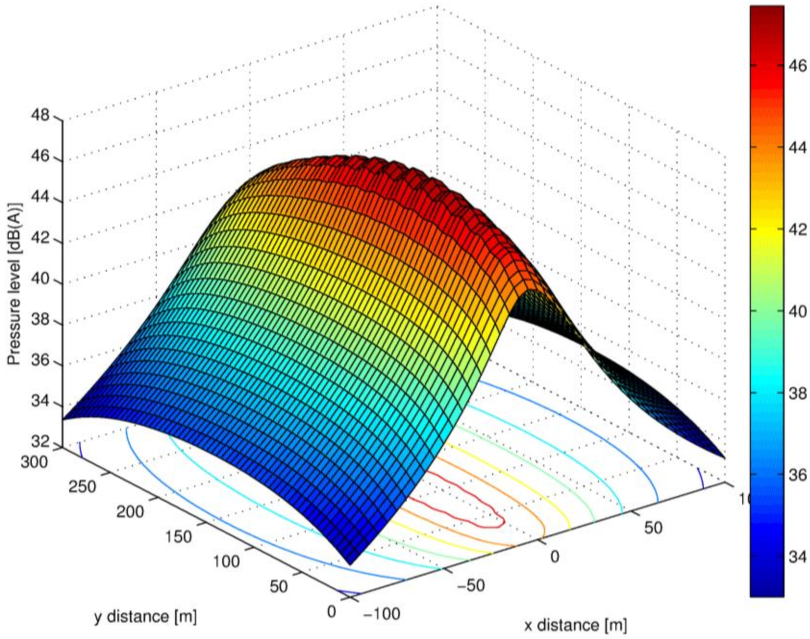

Figure 1: 3D colour contour plot of the predicted pressure level as a function of the distances from the overhead power line.

4. Experimental campaign

In order to validate the program, an acoustical experimental measurement campaign has been carried out on a single circuit, double sub-conductor 380 kV transmission line. The diameter of the sub-conductors is 29.3 mm, the span is 400 m and the ground clearance is 12 m.

Since the sound level meters are equipped with condenser microphones which are sensitive to humidity, the transducer has been fitted to a special outdoor protection system. The problem of the background noise is a decisive factor for the choice of the site where the measurements have to be performed. For this reason, a place far from traffic noise sources, towns, railways and airports was chosen as a measurement site. Fig. 2 shows a picture of the place where the acquisition system for long term measurements has been set-up. The microphone has been placed at 10, 20, 40, 60 and 80 m from the projection on the ground of the external sub-conductor, at 2 m height.

Measurements have been performed in the autumn of 2016, during rain-free days mainly characterised by high relative humidity. The acquisition system is formed by a PCB Piezotronics Type 2541 Class I microphone fitted into a PCB EPS2116 outdoor microphone protection system. A Larson Davis type 824 Class I sound level meter has been placed within a waterproof cabinet protecting the apparatus. A solar panel is used to charge the battery powering the sound level meter.

The parameters measured by the sound level meter are the 1/3 octave band noise in a frequency span ranging from 20 Hz to 20 kHz, the maximum and minimum values of the SPL, the equivalent level and the percentile levels, describing the value of the sound pressure level exceeded for a certain percentage of the acquisition time. This last set of data is very important because for non-steady noises the A-weighted value of the 95 percentile is usually a descriptor of the background noise. In order to determine the actual emissions of the overhead transmission line, the background noise has indeed to be subtracted from the equivalent level measured when the audible noise is active. The parameters have been stored every 10 s.

Figure 3 shows the colour contour plots describing the evolution of the sound pressure level in 1/3 octave bands over time at different distances from the power line.

Figure 2: Sound level metering equipment (left) during the test campaign at the chosen measurement site.

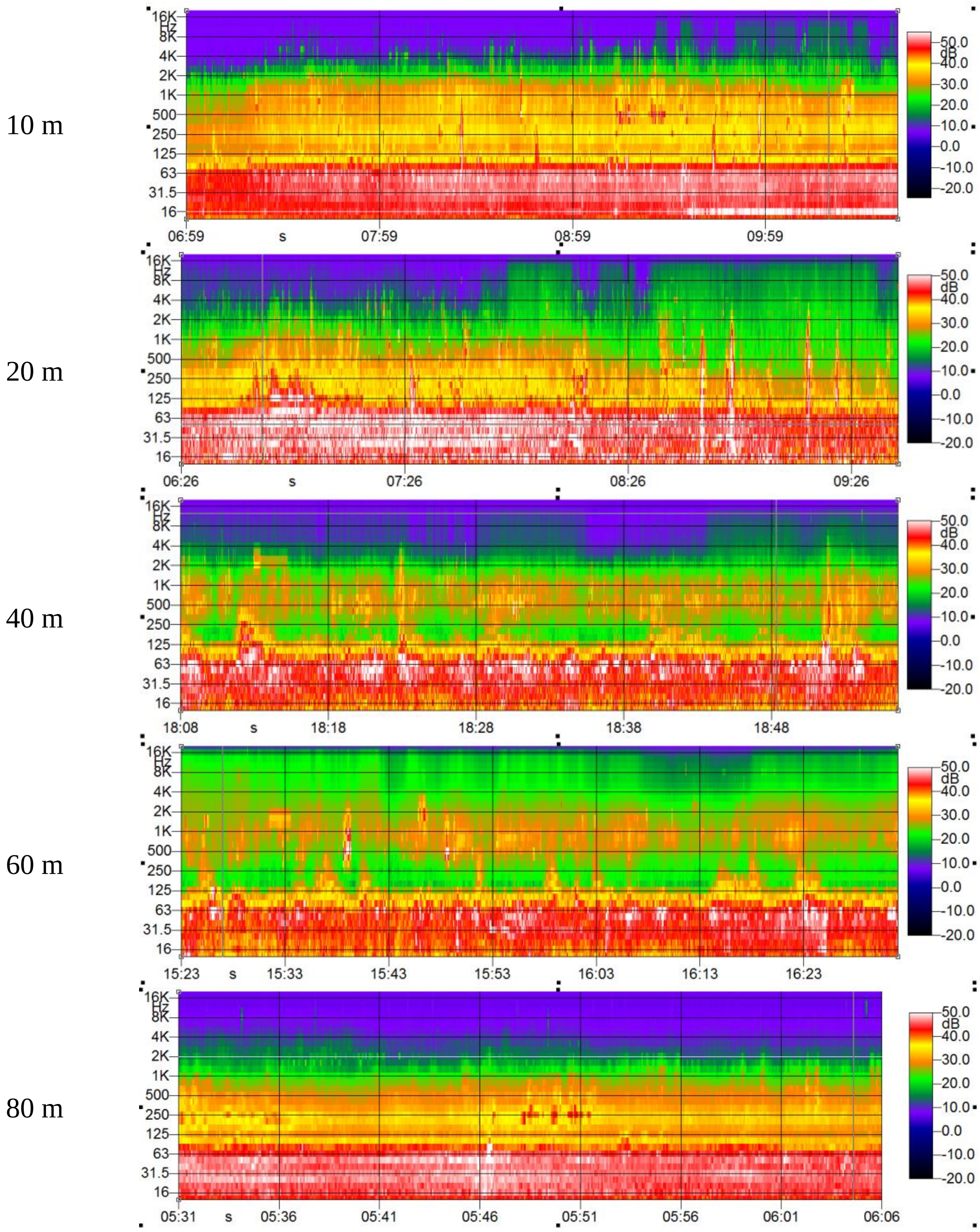

Figure 3: Colour contour plots of the pressure levels measured on site at different ground distances (left) from the overhead power line. Sound pressure level in dB(L).

It is worth noting that, in order to validate the code, it is necessary to extract the acoustic noise of the overhead transmission line from the measurements, by neglecting all the contributions coming from unwanted sources.

The result of the measurement extraction is the sum of the contributions of the acoustic corona discharge noise and the background noise. However, the code only computes the noise emission of the line, so the background noise must be subtracted from the extracted measurement. To this aim, long-term measurements have been carried out to validate the code.

The environmental noise, as well as the main parameters and results of the measurements, are summarised in Table 1.

Table 1: Summary of measurements performed at different ground distances from the power line.

Duration [h]	Distance [m]	L_{eq} [dB(A)]	Background noise L_{AF95} [dB(A)]	Measured emission [dB(A)]
21	10	44.8	29.0	44.7
48	20	42.3	32.0	41.9
8	40	39.1	22.0	39.0
23	60	38.9	32.0	37.9
22	80	36.2	30.0	35.0

5. Comparison between simulation and measurements

The comparison between code predictions and experimental measurements is reported in Fig. 4.

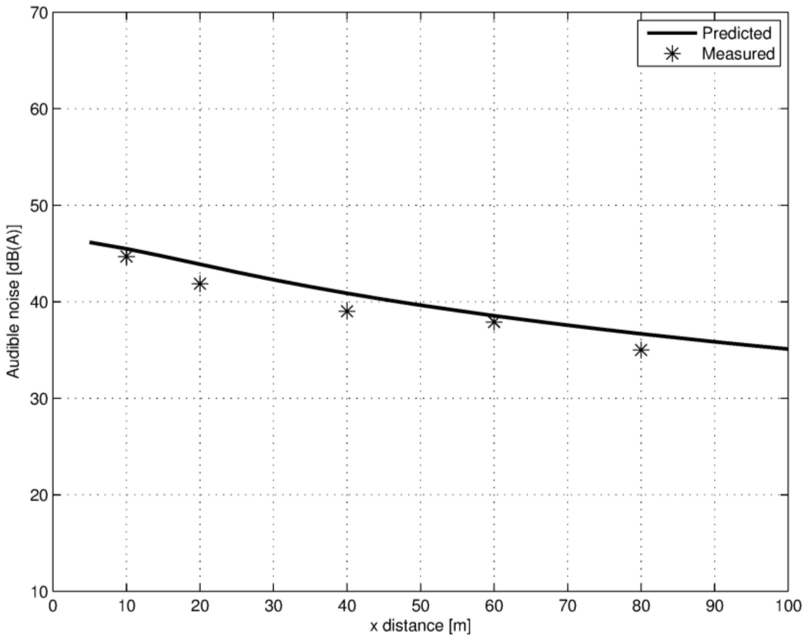

Figure 4: Comparison between predicted (solid line) and measured (star markers) sound pressure levels as a function of the ground distance from the centre of the power line.

It can be observed that the code correctly predicts the slope of the sound pressure level as a function of distance. However, the calculated values are slightly overestimated, with an average difference of about 1.5 dB.

6. Conclusions

The acoustic noise generated by an overhead electric power transmission line can be an issue when new infrastructures have to be built in very quiet environmental conditions or close to sensitive receivers. In the present study, a code, developed on the basis of CIGRE guidelines and improved to account for additional variables, has been used to compute the audible noise generated by an overhead transmission line on a wide area placed around the source. The results of the simulations have been validated by means of experimental measurements performed at different distances from a real transmission line. The comparison provides encouraging results, with an average difference between measured and predicted sound pressure level of 1.5 dB.

The study only examined the case of one 380-kV-line configuration in a weather condition characterised by high relative humidity, that was simulated with wet-conductor model. Further analyses on the influence of weather parameters and an extension of the study to other line configurations would therefore be worthwhile in order to complete the evaluation of the code capabilities.

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