ARCHIVES OF ACOUSTICS
36, 1, 151–160 (2011)
DOI: 10.2478/v10168-011-0011-2

Technical Note

Diagnostic Symptoms of Corona Audible Noise in Continuous Monitoring Systems

Tadeusz WSZOŁEK

AGH University of Science and Technology
Department of Mechanics and Vibroacoustics
Al.Mickiewicza 30, 30-059 Kraków, Poland
e-mail: tadeusz.wszolek@agh.edu.pl

(*received April 30, 2010; accepted January 12, 2011*)

Random nature of corona processes in UHV power lines and the accompanying noise is the reason that in practice the best determination of acoustic parameters, necessary for the noise evaluation, is obtained from the continuous monitoring procedure. However because of considerable fluctuations (both the useful signal part and the interfering components), careful selection of monitored parameters is necessary to enable a possibility of automatic determination of the parameters that are required for long-term evaluation of corona noise.

In the present work a practical realization is shown for estimation of corona noise parameters, based on the data obtained from continuous monitoring stations, making use of the statistical spectra measurement and characteristic features of corona process acoustic signal.

Selected results are presented from continuous monitoring of corona noise generated at a 400 kV power line, with special attention focused on definitions of the measured quantities, which enable automatic estimation of the basic factors required for noise evaluation. Accompanying monitoring of environmental conditions, including humidity, precipitation intensity and fog density, that are well correlated with the corona process intensity, which might definitely increase the filtration efficiency of environmental disturbances and on the other hand, it enables verification of calculation methods applied to corona noise.

The paper also contains a description of practical approach to selection signal parameters of corona noise in continuous monitoring stations.

Keywords: corona audible noise, power lines, continuous monitoring systems, noise indicators, statistical levels.

1. Introduction

It gives birth to many problems with estimation of basic factors that are used in corona noise evaluation (Tanabe, 1991; Wszołek, Tadeusiewicz, 2005) both in the short-time sample estimation, when the risk of unrepresentative signal sample is encountered, and in long-term measurements (continuous monitoring), when the parameters can be overestimated because of insufficient filtration of disturbances, in particular in time periods when the signal-to-noise ratio is rather small.

For the case of UHV power lines, such a situation is frequently encountered in the good weather conditions, when the corona noise signal is rather weak and the environmental disturbances are enhanced, e.g. because of intense social and homestead activity. Such a situation also frequently occurs during daytime in bad weather conditions, when the corona acoustic signal is relatively high, but in addition to the disturbances from the homestead activity other disturbances from the wind and falling rain are registered (Hardie *et al.*, 2008). Then the measurement is carried out by time elimination of disturbances, aided by statistical methods applied to short-time but representative samples of the examined signal (Wszołek, 2008).Studies of corona noise in good weather conditions, in spite of its relatively low level, are also important because of long exposure times (more than 90% of time) and on the other hand, they can be essential for the diagnostic aspect (Wszołek, Tadeusiewicz, 2006). Extraction of corona acoustic signal becomes particularly important in continuous monitoring systems, when there is a risk that the long-term level value will be affected by various environmental disturbances, that are hard to eliminate. It results from the fact that monitoring stations are usually installed in noise-protection areas, in locations where protection from external intrusion can be provided and the required power supply is available; therefore in locations where normal human activity goes on, being the source of many disturbing events (Wszołek, 2009).

Because of the continuous signal recording and great volume of the stored data, an automated interference filtration is required. It is also essential to select a proper time resolution for the data recording, because on one hand one has to avoid information loss when too long time-step is selected and on the other hand, to avoid problems with storage and processing of extensive data files. However irrespective of the particular objective and the selected means of further data processing, more efficient preliminary signal filtration is always necessary.

In the present work statistical levels measurement method has been applied as a primary interference filtration method in the continuous monitoring systems. The levels have been measured in 1/3-octave bands, and from the results, the A-weighted sound levels have been determined.

Such methods are particularly efficient when the examined signal in the selected time period is steady, and the corona acoustic signal can be treated as such, while the disturbances are of random nature and additionally, they occur in various (random) frequency bands (Wszołek, 2008), as e.g. swoosh of the trees, barking of the dogs, car passage or airplane flight. The method is not so efficient in elimination of continuous interference (in a given measurement time period), e.g. lawn-mower operation, when the signal recognition methods based on artificial intelligence algorithms are much more suitable.

2. Research determinants

In the spectrum of corona acoustic signal, two characteristic components can be distinguished: (1) tonal components of basic harmonic frequency equal to doubled network frequency and (2) noise component in frequency band above 1 kHz (Engel, Wszołek, 1996; Transmission Line Reference Book – 345 kV and Above [EPRI], 1982, pp. 267–316). As shown in Fig. 1, in real conditions these two features can be overshadowed by environmental interference, even when the acoustic signal from the corona process is relatively strong. For evaluation of A-weighted sound level of the corona noise in such cases, the noise component can be usually used, as the one that is best correlated with the required sound level. Certain underestimation of the result can be expected, which can be corrected by application of an appropriate correction procedure (Wszołek, 2009). However for the diagnostic purposes, the tonal components are more useful, the identification of which is also necessary when applying A-weighted tonal correction as specified by the ISO 1996-2 standard.

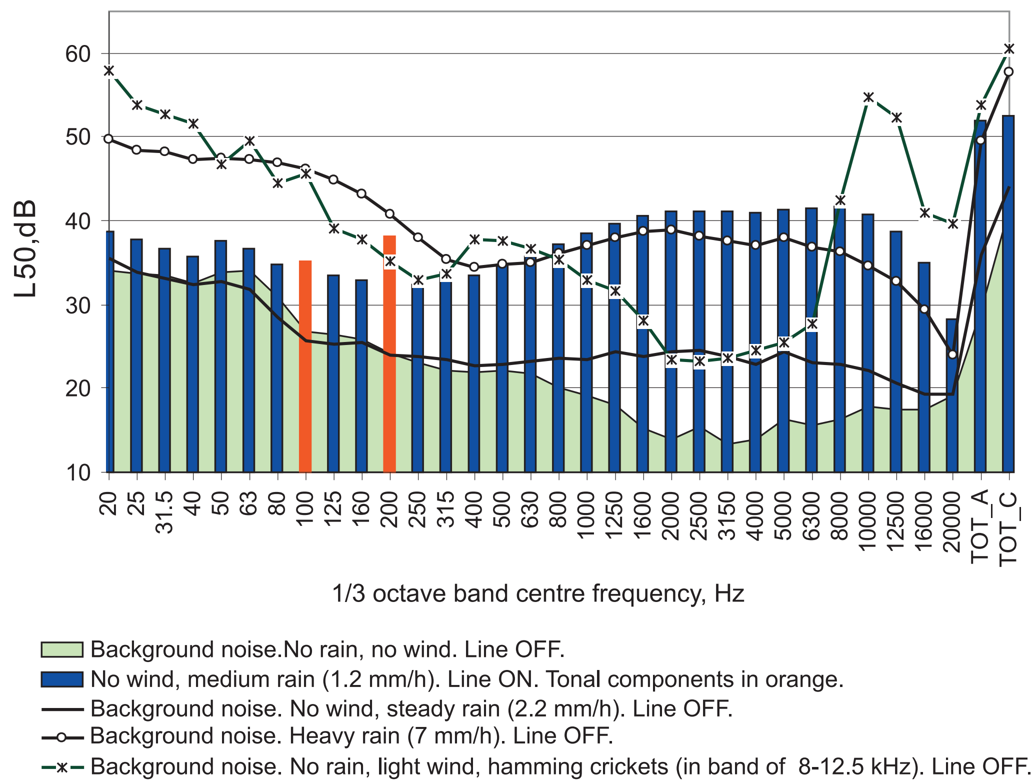

Fig. 1. Various tendencies in spectral distributions of corona acoustic signals and background noise, depending on weather conditions.

There is one question left to be answered: whether the "overshadowed by environment" (therefore inaudible) acoustic signal of the line should be treated as a noise, irrespectively of the sound level of its emission. In the systems of continuous monitoring and automatic extraction of the noise indicators this remains a key question.

The parameters that should be determined from the registered monitoring data are long-term indicators L_{DEN} and L_N (Directive/2002/49/WE, 2002; Wszołek, Tadeusiewicz, 2005) as well as 24-hours indicators $L_{Aeq,D}$ and $L_{Aeq,N}$ (Environmental Law Act, 2001). The L_{DEN} level is a day-evening-night time level, while L_N level is a strictly night-time level. These levels are determined taking into account all 24 h periods of the year. This brings about the necessity to average the registered values over all daytime, evening and night-time periods of the year. The $L_{Aeq,D}$ and $L_{Aeq,N}$ levels are equivalent (L_{Aeq}) A-weighted sound levels, averaged over 16 daytime hours and 8 night-time hours and they refer to a single day.

In the quoted legal acts there are no algorithms specifying the selection procedure of a single day to be used, nevertheless the registered monitoring data should allow the calculation of the above-mentioned levels from an arbitrary 24 h period of the year.

The long-term levels L_{Dr}, L_{Er} and L_{Nr} (L_{LTr}) for measurements of corona noise in continuous monitoring, because of its time variation depending on the weather conditions, are determined according to the following formula:

$$L_{LTr} = 10 \log \left[\frac{1}{N} \left(\sum_{i=1}^{n} 10^{0.1(L_{ti}+K_{ti})} + \sum_{j=1}^{m} 10^{0.1 L_{wtj}} \right) \right], \tag{1}$$

where L_{LTr} – long-term A-weighted sound rate level, determined for all periods of the daytime (L_{Dr}), evening (L_{Er}) and night-time (L_{Nr}) all-over the year, with application of appropriate tonal correction; L_{ti} – equivalent A-weighted sound level in the i-th time sample (e.g. 15 minutes period) with the identified tonal component, as specified by the ISO 1996-2 standard, dB; L_{wtj} – equivalent A-weighted sound level in the j-th time sample (e.g. 15 minutes period) without tonal components, dB; n – number of samples in a year with identified tonal components, m – number of samples in a year without tonal components, N – total number of samples in a year.

3. Experiments procedures

The data are collected using the SVAN 210 monitoring station, based on the SVAN 959 analyzer. This analyzer, due to a swappable external memory (pendrive), enables the storage of extensive volumes of data and its easy transfer to the base computer. Additionally the station is equipped with Fardata hardware controller, which enables the connection of a video recorder as a fog sensor and registration of a compressed acoustic signal in MP3 format, what facilitates the identification of interference signal sources.

In the standard setup the station is equipped with a pre-polarized $1/2$" free field microphone (GRAS, 40AE type) with SV-200 all-weather shield and WatchDog, 2900 series weather station, or in the Fardata controller version an integrated Vaisala WXT520 weather module, with extended high sensitivity module for rainfall intensity measurements with 0.1 mm/h resolution. In the standard version the station is equipped with specialized modules for measurements of air pressure, temperature, humidity, wind speed and direction, including wind gusts. The data from the weather module are registered in time synchronization with the acoustic data by the Fardata controller. All the data from the monitoring station can be sent on-line using the GSM cellular network systems or (with better efficiency) using the internet connection. Depending on the data transfer capacity of the connection, the data volume is limited accordingly.

Taking into account the minimal time extension of a transient disturbance signal (from a few to several seconds), and on the other hand – the real capacity of extensive data file processing of modern PC class computers, the basic spectrum registration in the data buffer was carried out every 10 s. Independently the averaged spectrum and statistical spectra with the accompanying weather data were recorded every 15 minutes in the external memory. Such a recording time-step has been selected after necessary observation of weather conditions variations, which are essential in the aspect of corona process stimulation.

All the essential working parameters of the monitoring station are listed below:

Buffer: 1/3 octave RMS spectrum registration in the audio frequency band with time-step equal to 10 s.

Main results: spectrum registration in 1/3 octave bands from 20 Hz to 20 kHz and the A and C-weighted levels – with RMS, MAX, MIN values – as well as statistical levels (percentiles) 1%, 5%, 10%, 20%, 30%, 50%, 80%, 90%, 95%, 99%, with time-step equal to 15 minutes.

The spectrum registration is realized in time synchronization with the weather data. Then the data are "packed" in 24 h cycles (22:00 to 22:00) and monthly cycles. It enables easy determination of parameter values, which has been mentioned above, and the averaged (long-term) levels are estimated from the statistical spectra L_{50} (or other percentiles, depending on nature and level of the interference signal) calculated for 15 minutes time periods.

Exemplary plots of week sections of selected acoustic and weather parameters are shown in Fig. 2. The monitoring station in the Fardata controller version is shown in Fig. 3.

Acoustic signal spectrum registered during an intense corona process is dominated by the high-frequency contribution, which is usually absent in a typical environmental noise, dominated by the low-frequency components. It can be used for estimation of the A-weighted sound level directly from the 1.6–8 kHz band. Additionally, monitoring of the average value and the respective component dis-

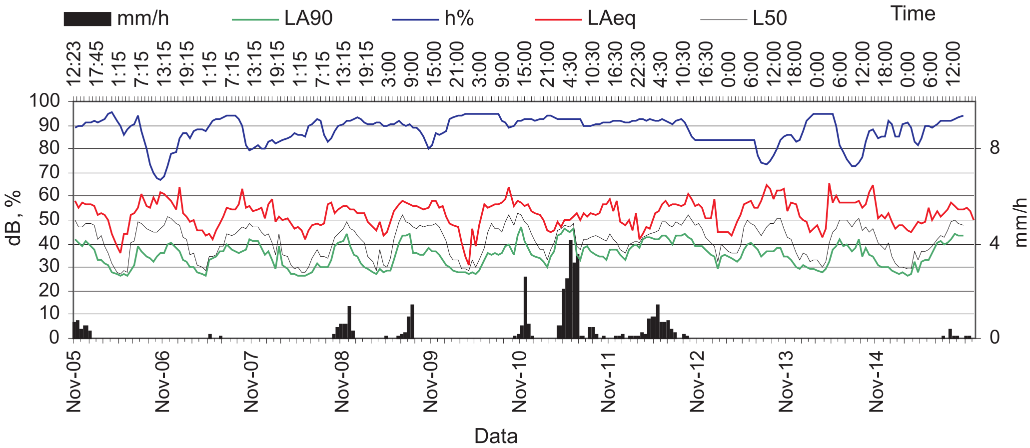

Fig. 2. Plots of selected acoustic and weather parameters registered by the monitoring station in near vicinity of a 400 kV power line with triple sub-conductor bundle 3×350 mm^2 (the station itself is shown in Fig. 3). November 2009.

Fig. 3. General view of the acoustic signal continuous monitoring station (ENVIRO131) in vicinity of two circuits of 400 kV power line with triple sub-conductors bundle, 3×350 mm^2.

persion is useful for identification of the acoustic signal source – noticeable enhancement of that component with accompanying decrease of the dispersion is characteristic for the corona acoustic signal, see Fig. 4 (Wszołek, 2008).

Further Fig. 5 presents the plots of statistical levels L_{A50} and L_{A80} in relation to the L_{Aeq} level and the rainfall intensity. The L_{Aeq} and L_{A50} parameters –

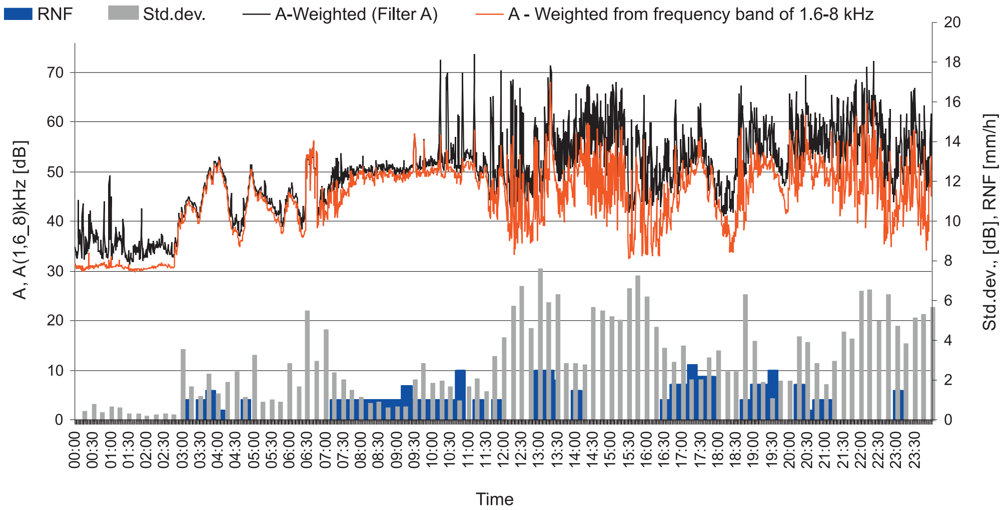

Fig. 4. Plots of selected components of the corona acoustic signal (from the buffer) – A-weighted levels for the full acoustic band and determined from the 1.6–8 kHz band, rainfall intensity (RNF), standard deviation of the A-weighted level (1.6–8 kHz).

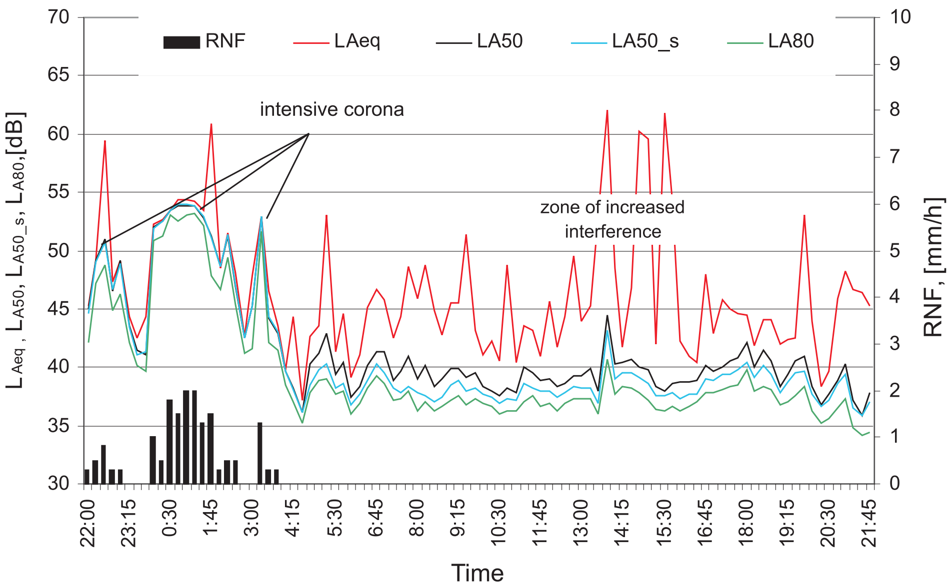

Fig. 5. Plots of the L_{Aeq} level and the statistical levels for the corona acoustic signal – L_{A80}, L_{A50}, and L_{A50_s} (A-weighted level determined from the statistical spectrum L_{50}) and rainfall intensity (RNF).

basic input data for calculations of the L_{DEN} parameter – clearly diverge when any disturbances are noticed or in general, the signal-to-noise ratio goes down. During rainfall, in intense corona process conditions, all the parameters take similar values, thus any parameter is a good estimator for the equivalent level of corona noise.

When the disturbance level goes high, a rapid increase of the L_{Aeq} level is noticed, accompanied by much slower increase of the L_{A50} level (and even slower increase of the L_{A80} level). Such a tendency has been observed in earlier works (Wszołek, 2009) as well as in the other samples in the gathered data. Further effectiveness improvement in the automatic filtration of interference signals can be achieved by calculating the A-weighted level from the L_{50} statistical spectrum (L_{50_s} level in Fig. 5), assuming that the disturbances are distributed at random in various frequency bands. Depending on the nature of the disturbances, a better estimator for the equivalent level (L_{Aeq}) can be A-weighted level determined from the statistical spectrum with higher percentile index.

The average difference between L_{Aeq} and L_{A50} levels for rainy an low wind speed conditions during nights (it means for low interferences) have been shown in Table 1 whereas long-term levels (L_{LT}) calculated for "night" and "all day" conditions have been shown in Table 2. These data relate to a period of two months, when the line was often turned off. This enabled an evaluation of the average values of background noise in similar weather conditions and, as a consequence, calculation of the emission levels for bad and fair weather conditions ($L_{LT(em)}$). As one can see in Table 2, the all-day level for bad weather conditions ($L_{LT(bw)}$) is 1.8 dB higher than the night one, mainly due to higher interferences during the day hours. In case of fair weather ($L_{LT(fw)}$) this difference equals 4.5 dB.

Table 1. Full year average difference between L_{Aeq} and L_{A50} for bad weather and low interference conditions (nights & wind gust < 5 m/s), [dB].

L_{Aeq}–L_{A50}	0.76
St. dev	1.30
U_{ex} (expanded standard uncertainty)	2.6

Table 2. Long term levels for bad ($L_{LT(bw)}$) and fair weather ($L_{LT(fw)}$) conditions [dB].

	All day (line on)	Night		
		Line-on	Line-off	$L_{LT(em)}$
$L_{LT(bw)}$	51	49.2	40	48.6
$L_{LT(fw)}$	42.8	38.3	36	34.6

As it has been shown in paper (Wszołek, 2010), the dominant factor of uncertainty in the estimation of long-term noise indicators for corona noise in continuous monitoring stations is accuracy of the background noise measurement, especially for a small distance between the tested signal and the background. In this paper (Wszołek, 2010) one can find more details according to some other uncertainty components in continuous monitoring stations. Partial uncertainty caused by estimation of the long term level by L_{A50} might be assessed using standard uncertainty of the distance between L_{Aeq} an L_{A50} levels, calculated for no-interference conditions, as in Table 1.

4. Conclusions

In the paper, partial results are shown for continuous monitoring measurements of corona audible noise in the vicinity of a 400 kV power line with double 2×525 mm^2 or triple 3×350 mm^2 sub-conductor bundle, focused on the problem of automatic extraction of the acoustic signal parameters generated in the corona process in real conditions in the monitoring station location.

It has been confirmed that in most cases the application of the L_{50} value for estimation of the long-term levels leads to satisfactory results, however in the enhanced interference conditions, that are often encountered in the daytime hours, the increase of filtration effectiveness can be obtained by calculation of averaged A-weighted levels (L_{A50_s}) from the statistical spectra L_{50} (or spectrum with higher percentile index, e.g. L_{80} or even L_{90}). The method is particularly effective in cases with random disturbances occurring in various frequency bands, i.e. from the various sources of interference.

Satisfactory levels of statistical effectiveness of the method obtained in two different positions, Meteorological Station indicates a certain universality of the method, which can be applied in other cases

Calculation of the A-weighted sound level from merely the noise component of the acoustic signal also gives quite good results. However because of possible underestimation of equivalent level values, it can be applied only as a supportive tool in the extraction of the signal. The equivalent level underestimation can be corrected by introduction of a respective correction terms, determined experimentally.

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