Separation Methodology Investigation of the Audible Noise in AC Substations

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Abstract. Direct on-site measurement of individual noise sources in AC substations is challenging, since the measured audible noise is a mixed result of diverse noise sources in the substation. In this paper, the audible noise of substation is divided into three categories: body, cooling device and corona noises. According to the noise discrepancies in time and frequency domain, the pass- and stop-band comb filters are designed, respectively, to obtain the body noise and the mixed noise of the cooling device and corona, from which the corona noise is separated out with speech enhancement technique based on spectral subtraction for its short-time and impulsive characteristics. The methodology is validated by application in the noise separation of a 500 kV AC substation.

Introduction

The audible noise emitted by the main power apparatus in the high voltage (HV) AC substations constitutes a serious environmental problem to the surrounding community [1,2]. In order to suppress the noise and to improve the noise environment in the proximity of the substations, it is necessary to make efforts to increase the accuracy of on-site noise measurement of the individual power apparatus. In AC substations, audible noise is mostly generated by main power transformers, HV reactors and the corona generated on the power transmission structures. The noises from different sources mixed together in the propagation process, which makes the on-site noise measurement of single power apparatus deviated from the actual result.

Recently, noise measurement and its characteristic analysis of AC substations have been the focus of research in China because of the increasing social pressure from the inhabitants around the substations. The noise level, spectrum and propagation characteristics of AC substations from 110 kV to 1000 kV are measured and corresponding noise control measures and advice are addressed [3-5]. However, researches concerning noise separation of the power apparatuses in AC substations are rarely observed in the open literature.

Starting from basic principles, this paper proposed a methodology to separate different noise sources in AC substations based on their time- and frequency-domain discrepancies. Pass- and stop-band comb filters are designed to process the original noise signals of the substation. The speech enhancement technique based on spectral subtraction is employed to separate the corona and cooling device noise from the filtered original noise signals. The proposed methodology is applied in a 500 kV AC substation.

Noise Separation Algorithm in AC Substations

Characteristics Analysis of the Main Noises in Substations. The main audible noise sources in AC substations, especially in ultra high voltage (UHV) substations, are the power transformers, HV reactors and corona generated on the power transmission structures such as the transmission lines, fittings and insulators. Body noise and cooling device noise constitutes the noise of main power transformers or HV reactors. According to the available investigation, body noises generated by the power transformers and HV reactors have similar spectrum, in which the 50 Hz and its harmonic frequencies are the dominant components [6]. The cooling device noise has stable amplitude in time domain, no peak and period cycle can be obviously observed from the waveform, and the spectrum is distributed in a large range, which makes the cooling device noise has comparable characteristic of typical white noise. In comparison, the corona noise has pulsating waveform in time domain and much wider range of spectrum. It can be assumed that there are three categories of noises in the substations, which are body, cooling device and corona noise. The audible noise separation of AC substations can be conducted with the following analysis process, as shown in Fig. 1. The body noise can be separated out with direct filtering of the original noise signal. The noise frequency of the cooling device is usually below 2 kHz, in which range the noises of cooling device and corona have similar spectrum distribution. Therefore, direct analysis in frequency domain cannot realize the noise separation. In this case, the speech enhancement technique based on spectral subtraction is utilized for the different properties of the cooling device and corona noises in time domain.

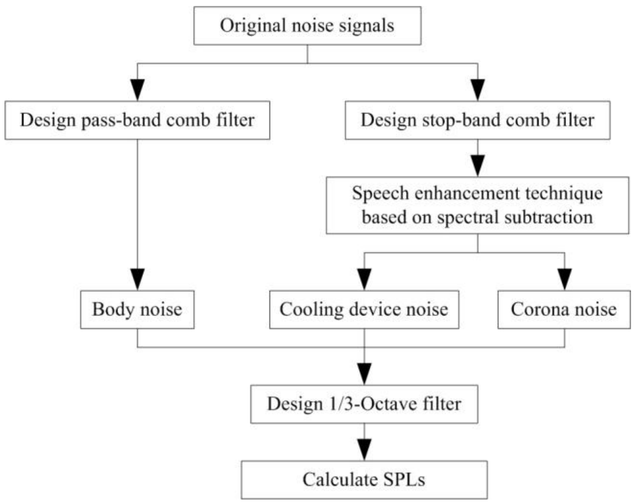


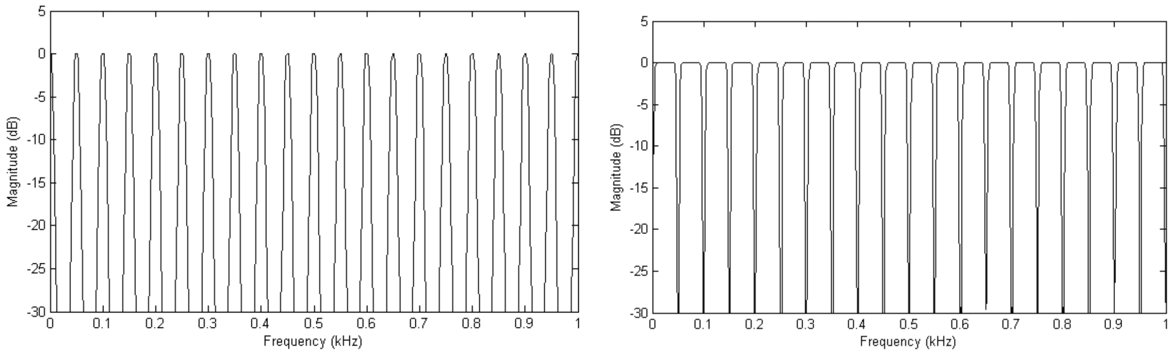
Fig. 1. Flow chart of the noise separation methodology.

Comb Filter Design. According to the characteristics of the body noise, a comb filter at the pass band of 50Hz and its harmonics is designed with a direct form II transposed structure, which can be expressed as follows:

$$y(n) = b(1)x(n) + b(2)x(n-1) + \cdots + b(n_b+1)x(n-n_b) - a(2)y(n-1) - \cdots - a(n_a+1)y(n-n_a) \quad (1)$$

where n-1 is the order of the filter, n_a is the feedback filter order, and n_b is the feed-forward filter order.

The pass- and stop-band filters used in the separation process are shown in Fig. 2. The bandwidth of both the filters is chosen to be 10 Hz referenced to the -3 dB level. The order of the filters is 1323.



(a) Pass-band filter (b) Stop-band filter

Fig. 2. Amplitude-frequency response of the pass- and stop-band comb filters.

Speech Enhancement Technique Based on Spectral Subtraction. Spectral subtraction is a traditional and effective algorithm to process wide-band noise such as the noises of cooling device and corona [7,8]. Assuming that $n(t)$ is the cooling-device noise and $s(t)$ is the corona noise, the noisy signal $y(t)$ is the sum of $n(t)$ and $s(t)$, $y(t) = n(t)+s(t)$. t denotes the sampling time. The $s(t)$ and $n(t)$ are further assumed to be independent statistically. The FFT of $y(t)$ can be written as

$$Y(w) = S(w) + N(w) \tag{2}$$

where $S(\omega)$ and $N(\omega)$ are the FFT of $s(i)$ and $n(i)$, respectively.

As $s(t)$ and $n(t)$ are independent, thus the power of noise signals can be computed as

$$P_y(w) = P_s(w) + P_n(w) = |S(w)|^2 + |N(w)|^2 \tag{3}$$

where $P_y(\omega)$, $P_s(\omega)$ and $P_n(\omega)$ are the power spectra of signals $y(t)$, $s(t)$ and $n(t)$, respectively.

The cooling-device noise keeps stationary before and when the corona noise occurs. Therefore, the silent part of the cooling-device noise can be used for power spectral estimation of the corona noise. Then, we have

$$P_s(w) = \begin{cases} P_y(w) - P_n(w), & P_y(w) \geq P_n(w) \\ 0, & P_y(w) < P_n(w) \end{cases} \tag{4}$$

Only the power spectral transform is considered in (4). As the human ear is not sensitive with the phase of noise signal, the phase spectrum of corona noise is substitute with that of the noisy signal. Then, the corona noise in time domain can be expressed as

$$s(t) = \text{IFFT}(\sqrt{P_s(w)} \cdot \exp(jY(w)) \tag{5}$$

where $Y(w)$ is the phase spectrum of the noisy signal.

Subtracting corona noise from the noisy signal, the cooling-device noise is obtained.

$$n(t) = y(t) - s(t) \tag{6}$$

According to the standard GB/T3241-2010, the 8-order Butterworth filter is used to design the 1/3-Octave filter. The SPL of the ith center frequency of the 1/3-Octave band can be calculated with the following equations:

$$p(i) = \sqrt{\frac{1}{T}\int_0^T [p(t)w_i(t)]^2 dt} \tag{7}$$

$$L_p(i) = 20\lg\frac{p(i)}{p_0} \tag{8}$$

where $w_i(t)$ is the 1/3-Octave filter, $p(t)$ is instantaneous sound pressure, $L_p(i)$ is the SPL, p_0 is the referenced sound pressure.

Noise Separation Result and Analysis.

Body Noise Separation. An original transformer noise signal is measured from a 500 kV AC substation field, as shown in Fig. 3. The sampling frequency is 65536 Hz. It can be observed that the noise near the transformer is mainly at the frequency of 50 Hz and its harmonic frequencies, but most of the sound energy is stored at the frequencies below 600 Hz. The time-domain waveform of the transformer noise is rather stable and has obvious periodicity. It seems that the transformer noise is less influenced by that of the corona. Thus, the corona noise is not considered in the next separation process of the transformer noise. Applying the proposed algorithm to the original signals, the separated body noise and cooling device noise are shown in Fig. 4. It can be seen that the body noise keeps nearly the same waveform and amplitude with the measured result. The cooling-device noise is approximately uniformly distributed in the range of 2 kHz, while the amplitude is much smaller than that of the body noise. The A-weight SPLs of the separated body noise and cooling-device noise are calculated with (6) and (7), which are, respectively, 82.7 dB(A) and 64.4 dB(A).

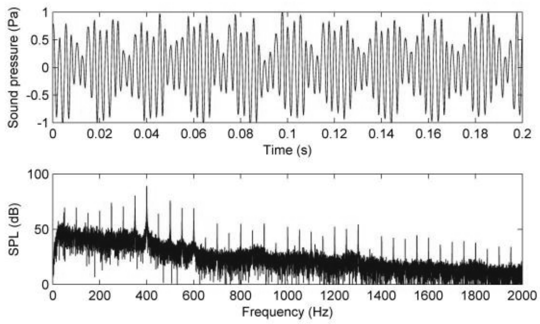
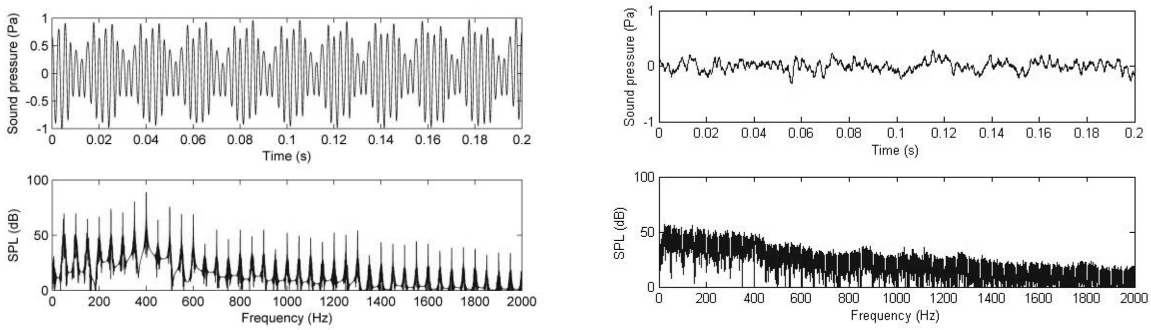


Fig. 3. Original noise signal of a 500 kV transformer.



(a) Body noise (b) Cooling-device noise

Fig. 4. Separated body noise and cooling-device noise of the transformer.

Corona and Cooling-device Noise Separation. Compared with the transformer noise, that of the corona measured under the power transmission structure is less stable, the sound pressure rises up rapidly when corona happens, as shown in the time-domain waveform pattern in Fig. 5. The spectrum of the measured corona noise is in a much wider range up to 8 kHz and the sound energy is more evenly distributed. Moreover, it can be also observed that the corona noise is affected by that of the transformer in some degree, because in the spectrum of corona noise the amplitudes at the frequencies of 100 Hz and its harmonic frequencies are prominent.

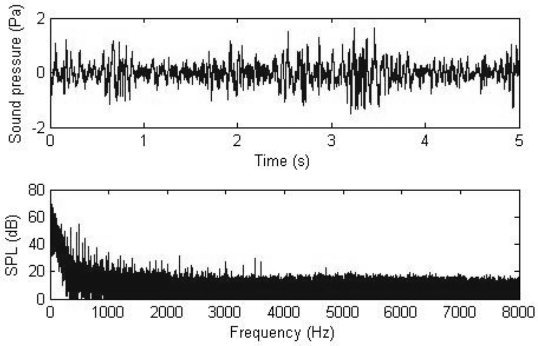
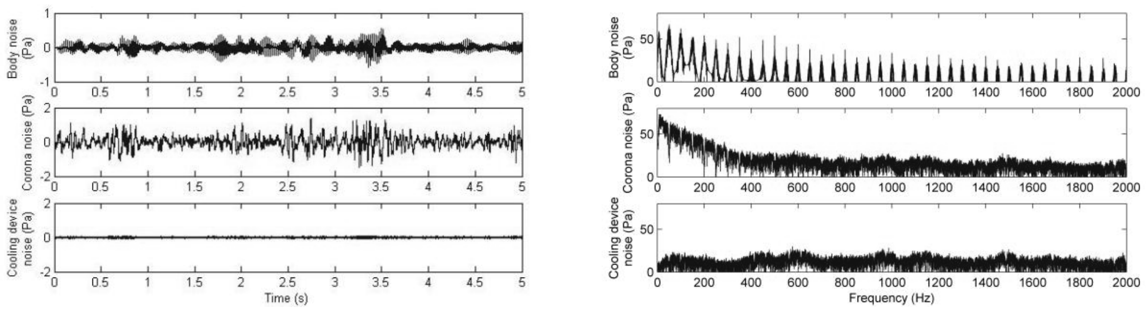


Fig. 5. Measured corona noise under the power transmission structure.



(a) Time domain (b) Frequency domain

Fig. 6. Separated noises from noise measured under the power transmission structure.

The body noise, corona noise and cooling-device noise separated from the measured noise under the power transmission structure is shown in Fig. 6. In the time domain, the corona noise occurs in short time and the waveform is impulsive, while the cooling-device noise keeps stable in the whole time range. Both of the two noises have wide and uniform spectral distribution as expected. The A-weight SPLs of the separated body noise, corona noise and cooling-device noise are 56.1 dB(A), 59.8 dB(A) and 53.4 dB(A) , respectively. The body noise is only a few decibels lower than that of the corona. Thus, it can be concluded that the transformer has a large influence on SPL of the corona.

Conclusions

The audible noises measured from the locations near the main power transformer and the power transmission structure in a 500kV AC substation have been separated with the methodology based on comb filter and speech enhancement technique. The body noise of the transformer is separated out with the comb filter with the pass band of 50Hz and its harmonics. The corona noise is separated with speech enhancement technique based on spectral subtraction. The SPLs of the separated noises are calculated. It is proved that the corona noise has little influence on that of the transformer, while oppositely the impact of the transformer noise cannot be neglected when measuring the corona noise. The proposed methodology can be further used for noise assessment and control of AC substations.

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