Acoustic Model and Detection Method of Corona Discharge Noise

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Abstract A study gives rise to a new angle of the on-site detection method for the classic audible noise due to corona discharge. Based on a fundamental acoustic model, which describes major acoustic characters of the N-type wave with the consideration of the gradual distortion of the propagating sound wave, difference of Gaussians method combined with frequency comb filter is adopted for detecting corona discharge noise. The preliminary test is given to confirm the effectivity of the proposed method in more practical conditions. The research work may be helpful to the construction of new power transmission grid in China.

Keywords Corona · Discharge · Detection method · Pulsed signal · N-type wave

1 Introduction

In today's China, the problem of corona discharge on transmission line and its associated audible noise has been emerging extensively as a concern, especially in which the projects of ultra high voltage (UHV) power transmission lines are constructed. It is known that tiny protrusions such as burr, particles, water drops, snow, or ice on the conductors or connectors of high voltage overhead line facilities may

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S. Feng et al. (eds.), *Low-carbon City and New-type Urbanization*,
Environmental Science and Engineering, DOI 10.1007/978-3-662-45969-0_9

increase the electric field strength in the vicinity to reach the values where corona discharges set in. In most conditions, the sound resulted from corona discharge is perceivable as a group of crackling and hissing noise, which is situated mainly in a broad frequency range from 1 up to 20 kHz (Taylor and Chartier 1969). Moreover, corona noise generally contains an additional component of the low tones at twice the main frequency and its higher harmonics. With the rise of voltage, corona discharges may become more frequent and intensive in the new power grid, which gives rise to more problems of environmental noise, energy loss, and security implications. Hence, the monitoring, detection, and analysis of corona noise become increasingly notable for the construction of power transmission grid in China (Tang et al. 2010).

The research into the field of corona noise has never lost its topicality since the period of 1960s–1980s, when the implementation of UHV AC transmission over 1,000 kV was initially being considered (Perry 1972). As far as known, a lot of contribution to corona noise focused on the sound components in frequency domain or just in A-weighted level (Comber and Nigbor 1976; Tanabe et al. 1996; Comber et al. 1987), and yet few works concerned the details of the noise signal in time domain, which is important to detecting and monitoring corona discharge in real conditions.

2 Methodology

2.1 Fundamental Model of Corona Discharge Noise

When corona discharge occurs, the high voltage increased over a certain level, generates a high electric field that allows an efficient electron impact ionization and the production of highly reactive species, where the ions produced in the ionization-zone drift along the electrical field lines. During this progress, a significant part of the energy stored in the electronically excited gas molecules is transferred into kinetic energy of the heated gas. As a consequence, a micro-source of shock wave is initiated, of which the simplified spherical model can be described by Taylor's theory (Comber et al. 1987). During a short time in the microsecond level, a shock wave, which can be characterized by jumps in the air density, pressure, and velocity of its wavefront, propagates radially at the Mach number approximate to 1. Behind the shock wavefront, a low density region is formed with a pressure less than the atmospheric pressure. This depletion is a consequence of the air displacement due to the velocity induced by the shock wave. A classic N-type wave in the initial period is plotted in Fig. 1.

After a little time of the initial period, with rapid decrease in the pressure and velocity of wavefront, the propagating shock wave become to be an acoustic pulse temporally in a N-type waveform, of which the wave equation is given by

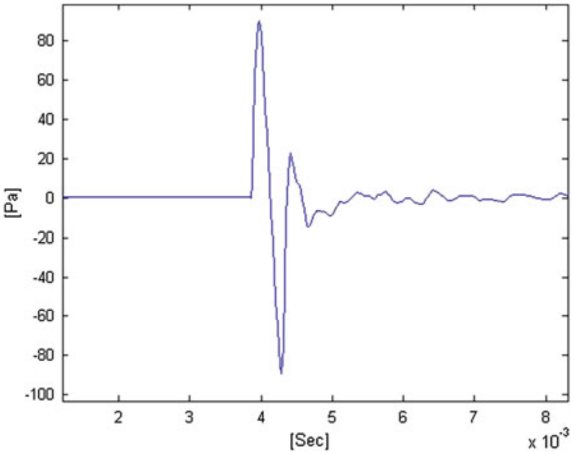

Fig. 1 Initial N-type shock wave

$$\frac{\partial v}{\partial r}+\frac{n}{2r}v-\frac{\beta}{c_0^2}v\frac{\partial v}{\partial r}=\frac{b}{2\rho_0 c_0^3}\frac{\partial^2 v}{\partial \tau^2} \tag{1}$$

where v, r, β, b are the particle velocity, the radius of wave front, the nonlinear coefficient, and acoustic absorption coefficient of air, while the transferred variable τ of time delay is expressed by

$$\tau=t-\frac{r-r_0}{c_0} \tag{2}$$

With further expansion of the wavefront due to the wave propagation, correspondingly the amplitude of the acoustic pulse becomes to be small enough so that the nonlinear wave term is negligible. In this condition, the degenerated acoustic wave equation can be solved approximately:

$$v\approx\sum_i v_0(\omega_i)\frac{r_0}{r}\exp[-\alpha(r-r_0)]\sin(2\omega\tau) \tag{3}$$

where the attenuating factor is defined by

$$\alpha\equiv\omega^2 b\left(2\rho_0 c_0^3\right)^{-1} \tag{4}$$

The equations above clearly indicate that the attenuation of higher frequency components of corona discharge noise will be exponentially increased in far field. A noise pulse initiating from an ideal N-type wave would be gradually transforming to be more smooth in the propagation process such as illustrated in Fig. 2.

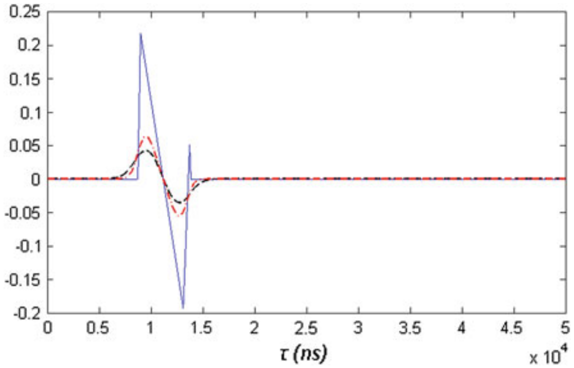

Fig. 2 Transformation of a N-type wave

2.2 Detection Method of Corona Discharge Noise

Unluckily, it is often difficult to directly extract perfect pulsed signals and detect a standard N-type wave of corona noise in real conditions. A series of unideal factors may have impacts on the on-site measurement or detection. First of all, the amplitude of $2f$ harmonic components associated with corona discharge noise is always considerable. Secondly, the sampling rate of standard acoustic measurement may be not high enough to catch the exact values of peak locations. Thirdly, different ambient disturbance extensively occurred in various environments will lead pulsed signals not as perfect as theoretical analysis.

Being motivated by the recognition method that is based on local scale-invariant features (Lowe 1999). In order to fit shock wave in real data, a developed N-type wave model is proposed as follows:

$$y(t) = \begin{cases} k_1 t, & -L_2 < t < -L_1 \,(a) \\ f_1(t), & -L_1 < t < -L_0 \,(b) \\ -k_0 t, & -L_0 < t < L_0 \,(c) \\ f_2(t), & L_0 < t < L_1 \,(d) \\ k_2 t, & L_1 < t < L_2 \,(e) \end{cases} \tag{5}$$

In Eq. (5), k_0 stands for the major descending edge of shock wave, k_1 and k_2 stand for rising edge before and after the distorted N-type wave's descending edge, and Eq. 5(b) and (d) represent N-type wave's corrupted peak and valley corresponding to the plots in Fig. 3.

As mentioned above, there may be two main kinds of unwanted sound waves contained in a period of measured signals for the detection of corona discharge noise. To get rid of the impact from the $2f$ harmonic components, a type of frequency comb filter will be applied. To minimize the impact of other stochastic audio disturbances, a type of difference of Gaussians (DoG) method is adopted, which can be utilized to distinguish them for detecting general signals of corona discharge noise. Being used by other researchers in different fields (Corrant et al. 1976), DoG method is

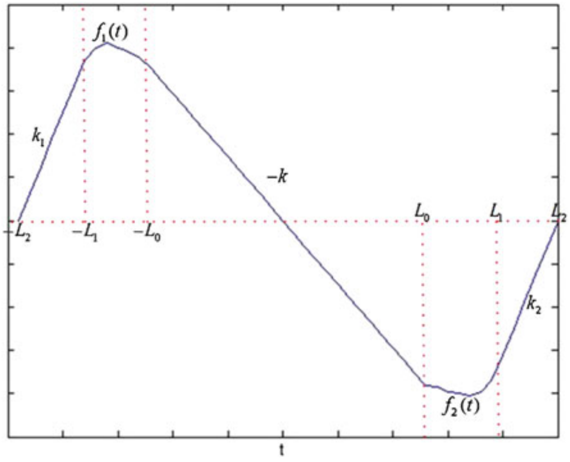

Fig. 3 Developed N-type wave model

mentioned to extract features in different scales as well as suppress noise. Motivated by their work, DoG method herein is adopted to detect shock wave and muzzle blast quickly and accurately. This method can be majorly described as follows:

$$D(t,\sigma,k) = \frac{1}{\sqrt{2\pi}\sigma}\mathrm{e}^{-\frac{t^2}{2\sigma^2}} - \frac{1}{\sqrt{2\pi}k\sigma}\mathrm{e}^{-\frac{t^2}{2k^2\sigma^2}} \tag{6}$$

In principle, the detection procedure includes two major steps. Firstly, measured sound signals are convoluted by $D(t,\sigma,k)$ in different scales in which wave signals of corona discharge noise have the biggest response. Then thresholds can be used to detect the discharge noise.

3 Detection Test and Results Analysis

3.1 Acoustic Separation of Corona Discharge Noise

Here, a period of practically measured sound data that contain corona discharge noise and $2f$ harmonic noise components, which is plotted in Fig. 4a, and is tested by implementing the separation algorithm, and the results are presented in Fig. 4b, c.

As shown in Fig. 4b, the additional noise mainly consisting of the $2f$ harmonic components can be filtered well so that another part of major signals consisting of the corona discharge noise is extracted as the wave plotted in Fig. 4c.

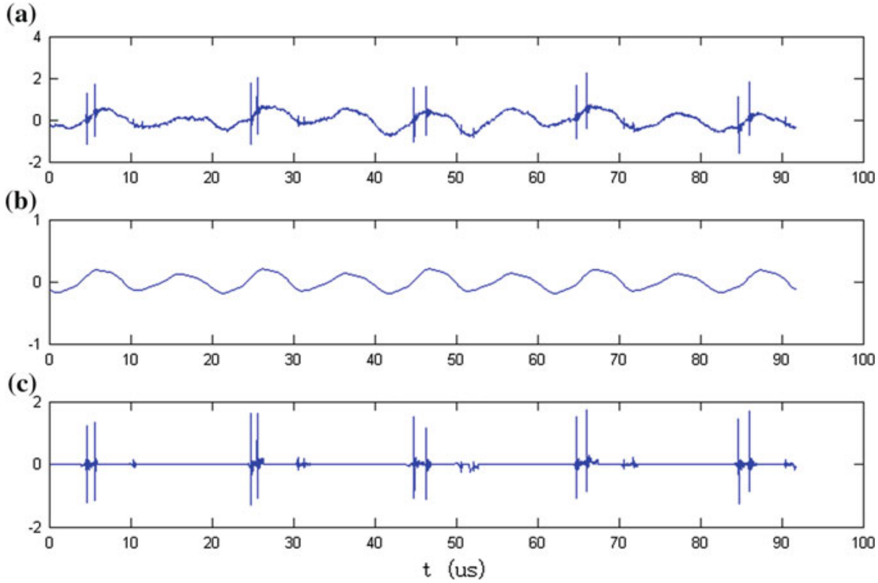

Fig. 4 Test of separation algorithm for corona discharge noise

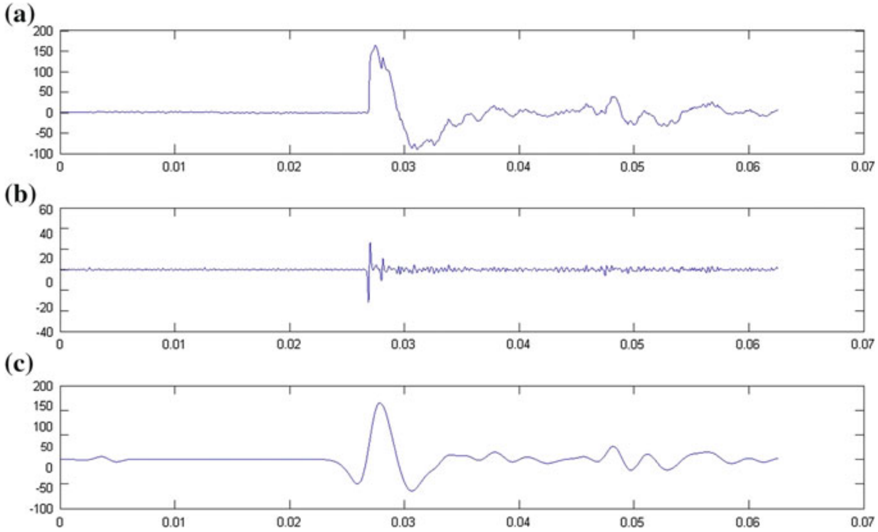

Fig. 5 Test of detection method for corona discharge noise

3.2 Detection of Corona Discharge Noise

After the procedure of noise separation, then the last step for the detection of corona discharge noise should be implemented. A period of the separated sound wave that contains the pulse signal of a distorted N-type wave together with the signals of a series of disturbance is used as shown in Fig. 5a. The DoG method is applied for the noise detection, and the characteristic noise signals resulted from the detection method are presented in Fig. 5b, c.

Obviously, as shown in Fig. 5b, c, the characteristic signal of a N-type wave is quite effective, of which the features are easier to be utilized for detecting corona discharges.

4 Conclusion

In this work, the classic audible noise due to corona discharge is fundamentally studied by giving rise to an acoustic model, which describes the major acoustic character of the N-type wave considering the gradual transformation with the sound propagation.

Further, a named difference of Gaussians method combined with frequency comb filter is adopted as the detection method of corona discharge noise. The last part of this work confirms the effectivity of the proposed detection method for corona discharge noise in more practical conditions.

On the whole, the study of our work gives rise to a new angle of sight that may be helpful to detecting and monitoring corona discharges on power transmission lines in real on-site cases.

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