Acoustic Signal Analysis in the Creeping Discharge

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Abstract. We have previously succeeded in measuring the acoustic signal due to the dielectric barrier discharge and discriminating the dominant frequency components of the acoustic signal. The dominant frequency components appear over 20kHz of acoustic signal by the dielectric barrier discharge. Recently surface discharge control technology has been focused from practical applications such as ozonizer, NOx reactors, light source or display. The fundamental experiments are carried to examine the creeping discharge using the acoustic signal. When the high voltage (6kV, f=10kHz) is applied to the electrode, the discharge current flows and the acoustic sound is generated. The current, voltage waveforms of creeping discharge and the sound signal detected by the condenser microphone are stored in the digital memory scope. In this scheme, Continuous Wavelet Transform (CWT) is applied to discriminate the acoustic sound of the micro discharge and the dominant frequency components are studied. CWT results of sound signal show the frequency spectrum of wideband up to 100kHz. In addition, the energy distributions of acoustic signal are examined by CWT.

1. Introduction

Creeping discharge is an electrical discharge phenomenon that is generated, and progresses along the boundary side of the dielectric substance. It progresses easily by the existence of the backside electrode[1],[2]. Creeping discharge on the dielectric substance surface is easy to progress more than the aerial discharge and seems to be a cause of the dielectric breakdown in the electric power equipment. Therefore, it is important to control creeping discharge in the insulation design of the electric power equipment and the electronic element.

On the other hand, the research of the positive use and application about creeping discharge have been performed including the removal of the environmental pollutant such as NOx, ozonizer and etc., and the further applications are expected[3]. The phenomenon clarification of creeping discharge chiefly examines the voltage, the current, and luminescence. The example of using the electrical discharge sound is not seen as a means of the phenomenon clarification. To examine the fundamental characteristic of creeping discharge, the voltage, the current, and the electrical discharge sound are measured, and examined the fundamental relationship between the micro discharge and the acoustic...
properties. The electric discharge sound may be considered the utilization of the monitor of the creeping discharge.

The CWT is applied to discriminate the acoustic sound of the micro discharge and the dominant frequency components. In addition, the energy distribution of the sound signal over the time-frequency plane is examined by the scalogram of CWT. CWT has better accuracy and precision than those obtained with the other time-frequency analysis method such as short-time Fourier transform[4].

2. Experimental Procedures

The creeping discharge is generated in order to understand the fundamental relationship between the micro discharge and the acoustic properties. Figure 1 shows the experimental setup of creeping discharge. The electrode is prepared to generate the creeping discharges with a flat cable electrode on the dielectric material and with a plane backside electrode. The high voltage (6kV: peak to peak voltage, 30kHz) is produced by the high frequency and high voltage power supply. The sound signal is generated by the discharge of the electrode. The current is measured through the current transformer (1kHz ~ 1MHz). The current, voltage waveforms of micro discharge and the acoustic signal detected by the condenser microphone are stored in the digital oscilloscope (Tektronix TDS3034). Data analysis is performed using MATLAB.

3. Continuous Wavelet Transform

The wavelet transform converts a signal from time domain to the time-scale domain. Wavelet analysis involves the breaking up of a single prototype function called the mother wavelet. \( \psi^{(a,b)}(t) \) is obtained by scaling the mother wavelet \( \psi(t) \) at time \( b \) and scale \( a \)

\[
\psi^{(a,b)}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right).
\]

When \( a \) becomes large, the basis function becomes a stretched version of the prototype, which can be useful for analysis of the low-frequency components of the signal. On the other hand, when the scale parameter is small, the basis function will be contracted, which is useful for the analysis of the high-frequency components of the signal [5].

As a mother wavelet, the gabor wavelet is used.

\[
\psi(t) = \frac{1}{2\sqrt{\pi\sigma}} e^{-\frac{t^2}{\sigma^2}} e^{-i\sigma t}
\]

Equation (2) is similar to the Short Time Fourier Transform (STFT) which is used the Gaussian function in window function. So it is easy to compare with the analytical results of the STFT and the CWT. In this paper, real part of gabor function is used as a mother wavelet (\( \sigma = 8 \)).

\[
\psi(t) = \frac{1}{2\sqrt{\pi\sigma}} e^{-\frac{t^2}{\sigma^2}} \cos(t)
\]

Therefore the wavelet transform of a continuous signal is defined as:

\[
\hat{f}(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} \frac{1}{2\sqrt{\pi\sigma}} e^{-\frac{(t-b)^2}{\sigma^2a^2}} \cos\left(\frac{t-b}{a}\right)f(t) dt
\]
where the signal $f(t)$ is transformed by the mother wavelet (Equation (2)). The squared magnitude of the CWT, $\hat{f}(a,b)$ is called scalogram and can be used to obtain the energy distribution of the signal over the entire time-scale plane. The time-scale expression has an equivalent time-frequency expression, obtained by using the formal identification

$$Fa = \frac{\Delta \cdot Fc}{a} \quad (5)$$

where $\Delta$ is the sampling time of sound signal and $Fc$ is the central frequency of the mother wavelet [6].

4. Results and Discussion

The voltage is applied to the electrode in atmospheric pressure. Figure 2 shows the voltage and the current waveforms with applied voltage of 6kV and the frequency of 30kHz. The duty ratio of voltage waveform is 0.30 and the current waveform is pulse-like.

One wavelength of the voltage waveform is shown in Fig. 3 (a). The discharge current flows at 4.8μs, 22.4μs and 38.5μs. The maximum current value is 2mA. The measurement result of sound and current waveforms are shown in Fig.3 (b). When the current flows, the electrical discharge sound has been generated.

Figure 4 shows the analyzing result of the acoustic signal by CWT with applied voltage of 6kV (Duty ratio=0.30) to the electrode. The time-scalogram representation of the sound signal is shown in Fig.4(a). The values of scalogram show 0.03 at 4.8μs and 0.05 at 22.4μs, respectively. The time-frequency representation of the sound signal is shown in Fig.4(b). The values of scalogram $|\hat{f}(a,b)|^2$ are over 0.01. Figure 4(b) shows that the frequency components over 40kHz appear at 4.8μs and 22.4μs. These values by CWT are fairly good agreement with the time of discharge current by creeping discharge. The dominant frequency components at the time of 4.8μs contain from 47kHz to 137kHz. The sound signal at the time of 22.4μs has the wide frequency components from 50kHz to 143kHz.

The applied voltage keeps the value of 6kV and the duty ratio of the high frequency voltage increases
to 0.75. The CWT results of sound signal are shown in Fig.5. The values of scalogram over 0.05 show at 6.2µs, 8.6µs, 22.5µs and 26.0µs in Fig.5(a). The maximum value of scalogram shows 0.87 at 22.5µs. The peak value of the sound energy (scalogram) of 0.30 (duty ratio of applied voltage) becomes smaller than that of 0.75. The frequency components over 35kHz appear at 6.2µs, 8.6µs, 22.5µs and 26.0µs in Fig.5(b). At the time of 22.5µs, the dominant frequency components are contained between 35kHz and 150kHz.

5. Conclusions
(1) CWT results of sound signal show that the high frequency components appear over 30KHz, and the frequency range of high and low frequency components increase with the value of duty ratio for applied voltage waveform.
(2) At the case of high voltage (6kV, duty ratio=0.30) is applied to the electrode, the discharge current flow at 4.8µs and 22.4µs. CWT scalogram of sound signal shows that the frequency components over 40kHz appear at 4.8µs and 22.4µs.
(3) When the duty ratios of the power supply increase from 0.30 to 0.75, the peak value of the sound signal energy of 0.30 is smaller than that of 0.75.

References
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