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Time-Frequency Analysis of E-M Signals Emitted from a Partial Discharge Occurring in GIS using Wavelet Transform

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Abstract—Diagnostic techniques have been investigated to detect a partial discharge (PD) associated with a dielectric material defect in a high-voltage electrical apparatus such as Gas Insulated Switchgear (GIS). It's greatly requested to measure PD occurring in GIS. We propose a new method to detect the wide-band electromagnetic (E-M) waves emitted from PD using the Wavelet transform. The Wavelet transform can provide "Dynamic spectrum" in the time-frequency domain. This paper experimentally shows the "Dynamic spectrum" of the wide-band E-M waves emitted from PD. This method is shown to be useful for detecting PD occurring in GIS.

1. INTRODUCTION

It's more important to develop a diagnostic technique to maintain a function of an electrical equipment and to prevent a breakdown. It's greatly requested to measure a partial discharge (PD) which is a symptom of an insulation breakdown occurring in Gas Insulated Switchgear (GIS). Essentially, GIS is designed not to be needed the maintenance. However in case of an insulation breakdown, it takes a long period for the restoration and the breakdown causes serious damages to a system operation.

Therefore, it's very important to develop the diagnostic technique to detect PD occurring in GIS. When PD occurring in GIS is to be detected under the operation of the apparatus, a sensor is placed inside or on the surface of the apparatus for a better detection sensitivity in many cases. This internal diagnostic technique may attain a higher S/N ratio. However it's not applicable to live high-voltage apparatuses from a safe point of view. It, therefore, is important to develop a non-contact method for detecting the symptom. Especially it is generally reported that the discharge level of PD increases in case of the insulation breakdown, therefore, a continuous observation of PD leads to the prediction of the insulation breakdown.

In this paper we propose a new method to detect PD occurring in GIS using the Wavelet transform[1][2] which can provide "Dynamic spectrum" in the time-frequency domain and experimentally show the Dynamic spectrum of the wide-band E-M waves emitted from PD. This method is shown to be useful and progressive for detecting PD.

2. WAVELET TRANSFORM [1][2]

The Wavelet transform has been applied to analyze "Dynamic spectrum" of various phenomena instead of "Power spectrum" by the Fourier transform because the formula of the Fourier transform alone is quite inadequate in many applications such as analysis of non-stationary signals and real-time signal processing. The Wavelet transform of a function $f(t)$, with respect to a given admissible mother wavelet $\psi(t)$, is defined as the equation(1).

$$(W\psi f)(b,a)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty}\psi(\frac{t-b}{a})f(t)dt \qquad (1)$$

a : the scale parameter

b : the translation parameter

The mother wavelet $\psi(t)$ is scaled by the scale parameter "a" and translated by the translation parameter "b", respectively. Any finite energy signal is mapped from the time (or space) domain to a finite energy two-dimensional distribution in the scale-translation (wavelet domain). A wavelet domain coefficient $(W\psi f)(b,a)$ is computed for each the scale parameter "a" and the translation parameter "b", that is, the Wavelet transform breaks the signal $f(t)$ down into component pieces and these pieces are examined or operated on instead of the function $f(t)$. The mother wavelet $\psi(t)$ is defined as the following equation (2).

$$\int_{-\infty}^{\infty}\psi(t)dt=0 \qquad (2)$$

The mother wavelet is one that cycle (oscillate), have finite energy, and have an average value of zero. We

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regard the "$1/a$" term in the equation (1) as the following equation (3).

$$\frac{1}{a} = 2\pi f \tag{3}$$

f: frequency[Hz]

The translation parameter "b" is used to translate a time-localization window in order to cover the whole time domain for extracting local information of the function $f(t)$. The unitary refers to the energy normalization performed by the "$1/\sqrt{a}$" term that keeps the energy of the scaled mother wavelet equal to the energy of the original mother wavelet.

In this paper we use the real part of Gabor mother wavelet which is achieved by using a Gaussian function given as equation (4), where σ =8 voluntarily decided.

$$\psi(t) = e^{-\frac{t^2}{\sigma^2}} \cos(t) \tag{4}$$

We vary the frequency "f" from 20 to 200[MHz] because the frequency bandwidth of a biconical antenna used in this paper is from 20 to 200 [MHz]. As a record length of an acquired data is 2.5[μs], the time-localization window is moved from 0 to 2.5[μs] by the translation parameter "b". Hence, we observe the Dynamic spectrum of the wide-band E-M waves emitted from PD in the time-frequency domain of which time window is 2.5[μs] and frequency bandwidth is from 20 to 200 [MHz] using the Wavelet transform.

3. EXPERIMENTAL METHOD

A 77 kV, three-phase model GIS was used in the experiment to generate a corona discharge as shown in Fig.1 . The corona discharge source, which was regarded as PD, was occurred in the model GIS. Of the three-phase high voltage buses in the model GIS, one bus was provided with a needle-shaped electrode and another bus was provided with a plane-shaped electrode. The distance between the needle-electrode and the plane-electrode was 10[mm]. A single-phase A.C. voltage to ground was applied to the bus provided with the needle-electrode. No voltage was applied to the other two phase buses. The gas (SF_6) pressure was 0 [kg/cm²] (the pressure of the atmosphere).

The wide-band E-M waves emitted from PD was received by an external antenna as shown in Fig.2. The antenna was a wide-range biconical antenna (the bandwidth : 20-200[MHz], EMCO 3014C). The signal received by the antenna was inputted into a digital storage oscilloscope (DSO). The sampling interval was 2.5[ns], and the record length was 2.5[μs]. The data taken into the computer were recorded in a magnetic

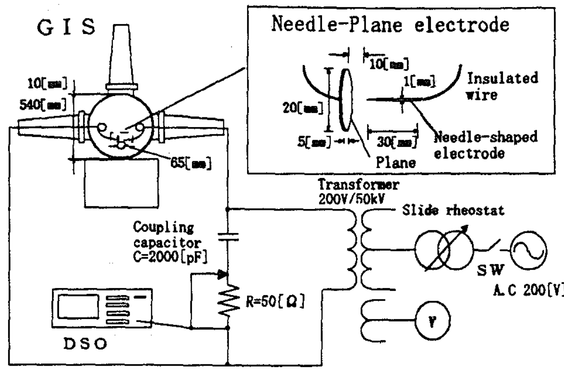


Figure 1 A 77 kV, three-phase model GIS used in the experiment. PD was occurred in the GIS using the needle-electrode and the plane-electrode.

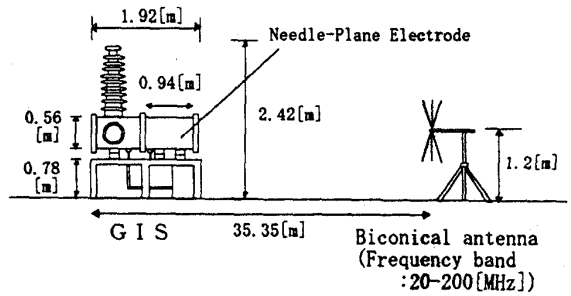
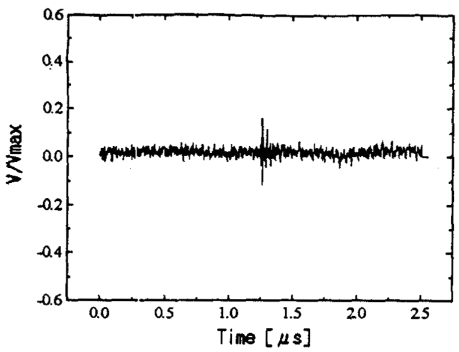


Figure.2 The measurement site of the wide-band E-M waves emitted from the PD. The antenna was wide-range biconical antenna (band-width:20-200 [MHz]).

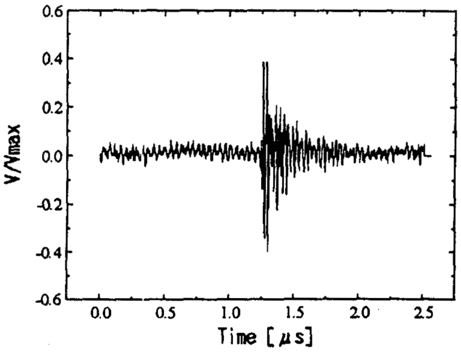
disc. A resistance (50[Ω]) was inserted in the grounding wire of the GIS and the discharge level of PD was measured by measuring the current pulse flowing through the resistance.

4. TIME-FREQUENCY ANALYSIS OF PD

The magnitude of the applied voltage was varied to change the discharge level of PD. Fig.3 shows the wide-band E-M waves received by the antenna arranged at 35.35[m] (voluntarily decided) from PD when the discharge levels were at 500 [pC] and 2000 [pC]. It is difficult to estimate the discharge level by measuring the amplitude of the E-M waves emitted from PD, because the amplitude is decreased by a factor of the distance (:1/ distance) and is attenuated by the weather such as rain, snow and so on. If there are many PD sources, the amplitude is affected because the E-M waves emitted from them are interfered each other.



(a) 500 [pC] (Applied voltage : 2.5[kV])



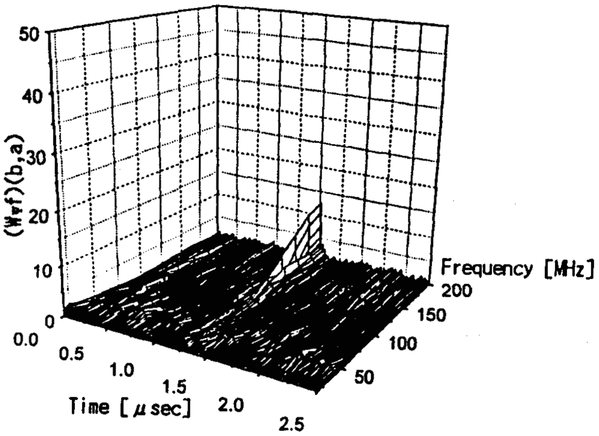
(b) 2000 [pC] (Applied voltage : 8.0[kV])

Figure 3 The wide-band E-M waves emitted from PD. The discharge levels of PD are at (a) 500 [pC] and (b) 2000 [pC], respectively.

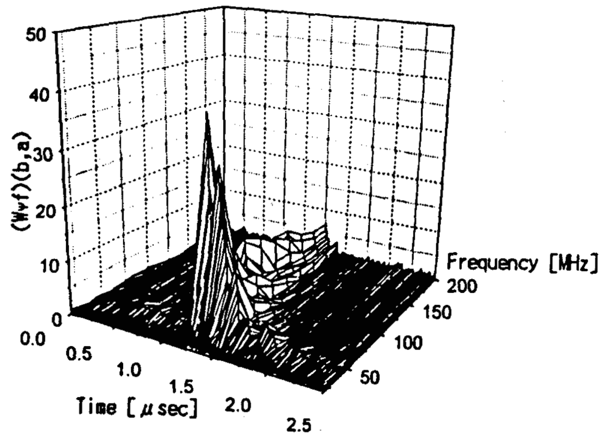
Fig.4 shows the Dynamic spectrum of the received signal which was transformed by the Wavelet transform. The Dynamic spectrum is represented as the absolute value. The time window is 2.5[μs] and the frequency bandwidth is from 20 to 200 [MHz]. Clearly, when the discharge level of PD is at 500 [pC], the main component of the frequency of the E-M waves is the high frequency band (120 - 200 [MHz]). On the other hand, the main component of the frequency shifts to the lower frequency band (20 - 80 [MHz]) at 2000 [pC]. Furthermore, when the discharge level is increased, the duration-time of the lower frequency band becomes more longer. Therefore it is important to detect the component of the lower frequency band (20 - 80 [MHz]) of the E-M waves in the point of view of the insulation diagnosis.

5. DETECTING E-M WAVES OF MINUTE PD BURIED UNDER FM RADIO

It's needed to detect a minute PD in the range of a few hundred [pC] in case of the application of the system to



(a) 500 [pC]



(b) 2000 [pC]

Figure 4 Dynamic spectrum of the wide-band E-M waves emitted from PD. This figure shows the Dynamic spectrums of PD at (a) 500 [pC] and (b) 2000 [pC], respectively which are transformed by the Wavelet transform.

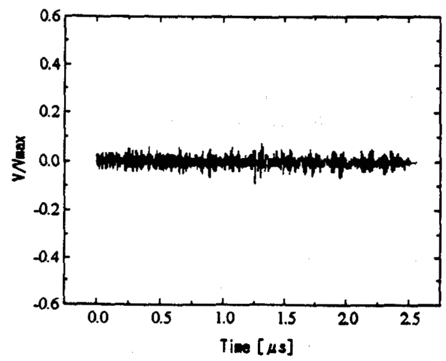
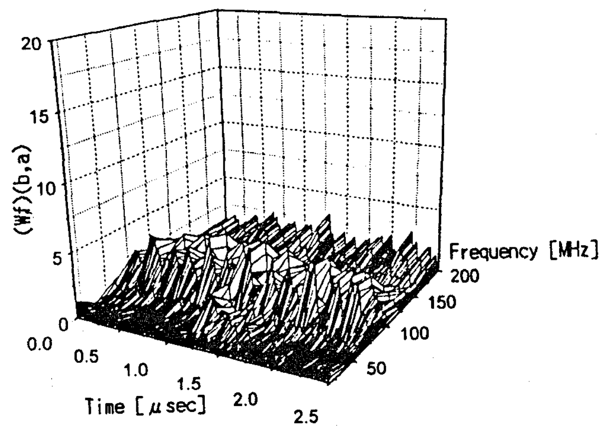
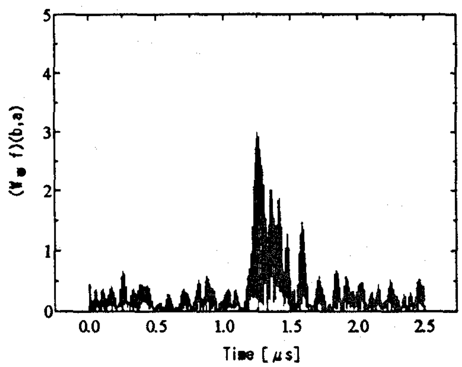


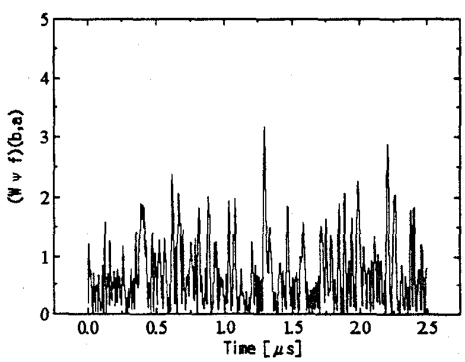
Figure 5 The E-M waves emitted from minute PD. The discharge level of PD was 170[pC] buried under the continuous wave (FM radio).



(a) Dynamic spectrum



(b) Duration-time of 40[MHz]



(c) Duration-time of 200[MHz]

Figure 6 The Dynamic spectrum of the E-M waves emitted from minute PD buried under the continuous wave such as FM radio. The E-M waves of PD can be clearly distinguished from FM radio.

the practical insulation diagnosis of GIS. Furthermore it's needed to detect the E-M waves emitted from the minute PD buried under continuous wave such as FM radio.

Fig.5 shows the E-M waves emitted from the minute PD of which discharge level was 170[pC]. The distance between the fault point and the antenna was 3.36[m] which is voluntarily decided. It is hard to distinguish the E-M waves of PD from other signals by the amplitude. Fig.6 shows the Dynamic spectrum of the received signals using the Wavelet transform. This figure shows that the occurrence-time of PD is about 1.25[μs] and the PD signal can be clearly distinguished from the continuous signal which is FM radio (about 80 [MHz]). Therefore, this system is very useful for detecting the E-M waves emitted from minute PD buried under the continuous wave such as FM radio.

6. CONCLUSION

We proposed a new method to detect a partial discharge (PD) occurring in GIS using the Wavelet transform which can provide "Dynamic spectrum" in the time-frequency domain. As it is important to develop a non-contact method for detecting the insulation fault, we analyzed the E-M waves emitted from PD.

Clearly, there was a correlation between the discharge level of PD and the Dynamic spectrum of the E-M waves emitted from PD. The results demonstrated that, when the discharge level was low, the main component of the frequency of the E-M waves was high frequency band (120 - 200 [MHz]), and as the discharge level was increased, the component shifted to the lower frequency band (20 - 80 [MHz]) and the duration-time of the lower frequency band increased.

The minute PD in the range of a few hundred [pC] could be clearly distinguished from the continuous signal such as FM radio. Therefore, this system was very useful for detecting the symptom of the insulation breakdown occurring in GIS.

7. REFERENCES

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[2] Laura J. Pyrak-Nolte,David D.Nolte,"Wavelet analysis of velocity dispersion of elastic interface waves propagating along a fracture",Geophysical Research Letters,Vol.22,No.11,June,1995