A Study on Partial Discharge Diagnostic System for Power Cable using RLCR

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Abstract

This system is a diagnosis system that checks whether it causes a partial discharge of a power cable or not. It is to classify normal from abnormal-normal, PD (Partial Discharge) sound through analysis of RLCR (Relative Level Crossing Rate) and spectrogram energy algorithm. Partial discharge diagnostic system has a function that stores PD sound and analyzes the data. The wave shape of PD sound is similar to noise and is systematically generated by partial discharge. Therefore, in this paper, we could discriminate between normal and abnormal case using relative level crossing rate (RLCR) and spectrogram of frequency energy rate.

Keywords : PD(Partial Discharge), RLCR(Relative Level Crossing Rate), spectrogram energy rate, normal-abnormal

I. INTRODUCTION

Currently, the need and high reliability for the electric power supply with 765 kV of power transmission voltage are increasing. Accordingly, error diagnosis that detects abnormal conditions in electric power equipment to prevent accident and disability becomes more important.

For diagnosis methods for modern power equipment, chemical detection via gas analysis, mechanical detection via ultrasound measure or vibration measurement, RF measurement for detecting partial discharge, and electrical detection such as UHF measurement method are suggested.

The diagnostic algorithm for chemical detection is an analysis on changes and trend of certain chemical substances. The algorithm of mechanical detection and electrical detection is usually comparing Vpp values of signal, measuring pulse frequency, and analyzing based on status [1][2].

However, the existing diagnostic algorithms don’t detect partial discharge frequency generated from the equipment accurately. Also, it has difficulties in separating and analyzing external noises.

In this study, it offers a FBDS (Frequency Band Detecting Sensor) developed to detect partial discharge of power cable and EBG accurately. By applying this FBDS, RLCR and spectrogram of frequency energy algorithm, it analyzes partial discharge data in the domain of time and frequency.

It also has the partial discharge diagnostic system with the collected data that FBDS analyzes monitoring the system, and in case of abnormality, it secures the safety of the system via alarm and prevents any error in the system in advance.

II. DETECTION OF PARTIAL DISCHARGE SIGNAL

A. Frequency Band Detection Sensor (FBDS)

A partial discharge is an electrical discharge or spike that bridges in a small portion of the insulation between two conducting electrode. PD activity can occur at any point in an insulation cable (Fig. 1).

When Partial Discharge activity occurs within high voltage switchgear or cable insulation, it generates electromagnetic waves in the radio frequency range. The signal can travel through insulating materials or components, though the signal attenuation increases with each surface or medium that it traverses. Essentially, the majority of the electromagnetic pulses produced by these Partial Discharge ‘sparks’ is conducted away by the surrounding metalwork, but a small proportion impinge onto the inner surface of the casing [6].

Partial Discharge activity can be quantified and recorded in several ways, depending on the sensor technologies employed such as ultrasonic, TEV (Transient Earth Voltage) and UHF (Ultra High Frequency) etc.

However, due to its closed structure, it is very difficult to detect any abnormal condition from outside. Any belated detection may lead to a serious accident. So, many internal diagnostic apparatuses have been utilized to detect sign of error inside indirectly through various sensors [3].
If the connection of EBG or power cable, the most important part in power transmission, has partial discharge, it may cause power interruption and serious accident. The electric field generated by EBG’s partial discharge is very high.

Thus, this study offers a FBDS (Frequency Band Detecting Sensor) to measure partial discharge of EBG or power cable and analyze, diagnose the data collected from it. Fig. 2 displays the diagram of the FBDS. The reason for the multiple band antenna is that the frequency range variations (47-1000 MHz).

In order to detect abnormal condition inside of EBG and power cable, it consists of FBDS to collect data. FBDS detects abnormal signal sound generated from the EBG or power cable, and it detects discharge frequency induced by electric field. FBDS detects the induced current through several band antennas, amplifies it, and converts the current to voltage to send to peak holder. And it holds a fixed reference voltage or more and then the voltage is transferred to microprocessor.

The microprocessor performs Fourier transform (FFT) of bigger signal voltage among the two, and ANR (Ambient Noise Rejection) by covering it with Hamming Window. The filter bank selects the optimum PD signal to transform in digital format (ADC) (Fig. 2, 3). This data is sent to the computer in order to analyze and diagnose at time and frequency domains in real time.

B. PD Sound Data Collection and Experiments

For collecting PD Sound Data, the system in Fig. 3 utilized partial discharge sound analysis software designed via Visual C++ in Fig. 4 to gather data from the detected digital signal through the system in Fig. 3. Partial discharge sound entered by the sensor pass through the hard filter in the PD detecting system in Fig. 3 and then, through ADC to the USB port of the computer while being converted from analog to digital. In here, the data was recorded in 16 bit, 20 kHz. The prototype partial discharge data collection system installed in Sin-gal automatic substation of KEPCO (May, 2014) collected EBG data and PD data in Jeonju University Lab. to analyze.

The data on partial discharge sound generated from three phases (A, B, and C) was collected for analysis and diagnosis. Fig. 5 represents the normal status (no partial discharge), the wave form of frequency domain, and its spectrogram. Fig. 6 shows the time domain during partial discharge, its wave form of frequency domain, and its spectrogram. Based on this, it confirms that partial discharge can be detected in real-time.

Fig. 7 is configured to test the partial discharge of spark instead of power cable and Fig. 8 shows the position setting of FBDS. Fig. 9 and 10 are the PD waveform shown by the test results above Fig. 7 and 8.

III. DATA ANALYSIS

Looking at the abnormal sounds collected in the EBG and power cable sound data, it divides into two groups; continuous sound and discontinued sound. The continuous sounds in the EBG and spark data are from regular partial discharge and machine vibration. These are sounds at low frequency. The data are displayed in Fig. 5 and 6 as graphs.

The graph at the bottom is continuous sound of EBG in
normal condition at the time domain. It shows regular amplitude, and the middle section is a graph magnified the EBG sound at the time domain. The top section represents the EBG sound at the time domain as an energy at the frequency domain. In normal circumstances, the frequency part shows regular pattern (basic frequency generated from EBG).

In case of partial discharge (Fig. 6), the time domain shows high amplitude while the frequency domain shows strong energy. The frequency for this case is about 800 Hz-4 kHz in this sound analysis. This frequency energy is called spectrogram. Fig. 6 represents the spectrogram of abnormal EBG sound widely distributed from 0 to 4000 Hz, and the concentrated energy band in red on the section 800-4000 Hz.

The intensity of the energy displays in colors by its levels, ground color, blue, yellow, orange, and red in order. That means, red is the strongest energy level detected.

Compared to the wave form and spectrogram from Fig. 6, the spectrogram distribution created a shape of band between 0-4 kHz in the section of 109.5-113.5 sec while the level cross rate is increasing.

Also, it is confirmed that the partial discharge can be detected at three positions (or phase position) by Fig. 9 and Fig. 10 in the experimental Lab.

In order to analyze the EBG and sparks sound data, the process in Fig. 11 was performed. Hamming window was utilized as window and its size is 256 samples for one frame. The frequency analysis used 65,536 point FFT.

As for the Relative level cross rate (RLCR), it set a threshold figure for each frame, and counted the number of the signal wave form crossed the threshold as shown in Eq. (1).

\[
R(m) = \sum_{m=m-N+1}^{m} \frac{|sgn[x(n)-L_{th}] - sgn[x(n-1)-L_{th}]|}{2} w(m-n)
\]

\[
sgn[x(n)] = \begin{cases} 
1 & x(n) \geq 0 \\
-1 & x(n) < 0 
\end{cases}
\]

In this formula, \(N\) is the number of the samples in the section to be analyzed, \(R(m)\) is the RLCR of current sample \(m\), \(L_{th}\) is the constant experimentally determined, \(w(n)\) is Hamming window constant, and \(x(n)\) is the signal to obtain RLCR. Also, the frequency range is divided into three steps for spectrogram analysis of EBG and spark sound data.

First, in the EBG and spark sound data, the frequency energy in the low range 0-2 kHz was set as Low spectral energy, and the frequency energy in 2-5 kHz was set as Medium spectral energy.
The frequency energy in the range of 5-10 kHz was set as High spectral energy. With the spectral energies set as above, Eq. (2) extracted the parameters of $\text{db}_{\text{ML}}$ and $\text{db}_{\text{HL}}$.

$$\text{db}_{\text{ML}} = \frac{\text{Medium Spectral Energy}}{\text{Low Spectral Energy}}$$

$$\text{db}_{\text{HL}} = \frac{\text{High Spectral Energy}}{\text{Low Spectral Energy}}$$

(2)

Based on these parameters of $\text{db}_{\text{ML}}$ and $\text{db}_{\text{HL}}$, it determines $\text{db}_{\text{ML}}$ parameter and $\text{db}_{\text{HL}}$ parameter calculated from the sound signal of normal condition as normal or abnormal whether the figures exist in the error range or not. The determined parameters were shown in color (spectrogram).

### IV. RESULTS AND DISCUSSION

Fig. 12 is the FBDS collecting sounds of the three domains (A, B and C) in EBG. With the data collected from EBG’s A domain, the formula (1) calculated RLCR figures in order to display in the graph (Fig. 13). Fig. 13 confirms that the RLCR values of normal EBG and RLCR values from partial discharge condition. And, Fig. 9 and 10 shows red graph of RLCR figures for partial discharge generated from the FBDS in the three position. In here, the normal sections and the sections with partial discharge in each domain are clearly appeared.

Table 1 displays RLCR values in the normal section and abnormal section (where partial discharge (PD) occurred) in terms of the three positions (System 1, 2 and 3). RLCR values in the normal spark data frame were ranged from 7.8 to 10.2 in reference 574, and the RLCR values in the abnormal section (PD) were ranged from 12.2 to 14.8 in the system 1. If the check in the same way, it is possible to confirm that the difference in system 2 and 3. Reference 574, 2874 and 4024 means relative variable levels and it can be adjusted. Fig. 14 is the graph that compares the RLCR figures of three positions. In this graph, it confirms that the partial discharge was occurred according to the RLCR values in real time.

And Fig. 15 displayed the spectrogram of spark sounds in the frequency range. In the spark sound data analysis flowchart in Fig. 11, the energy figures in the three domains were calculated.
V. CONCLUSION

In terms of the realization, the system designed to analyze and diagnose the PD and the FBDS in Fig. 2 is constructed in Fig. 16. In this research, it investigated a constant diagnosis for EBG and spark sounds based on the normal EBG, spark data and the analysis of the data from outside noise and discharge inside of EBG and spark. In order to identify the sounds of normal condition and partial discharge condition, it utilized RLCR values for the time domain, and the parameters of dbML and dbHL for the frequency domain. As a result, it found out that the average RLCR has high values over 7.8-10.2 in reference 574. Also, by determining partial discharge in real-time, it is expected to contribute to the prevention and preservation of electric power. The RLCR algorithm determines the abnormal conditions of EBG or other machine in real-time. According to the frequency band, it is confirmed that the partial discharge is detected reliability by setting a different (relative) value. Further research aims to apply the algorithm to other systems of the power system. In addition, it expects to utilize the algorithm to the system for monitoring & diagnosis the electric system by building the database on the basis of the data collected.

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REFERENCES

[1] F. H. Kreuger, E. Gulski and A. Krivda, "Classification of Partial Discharges", IEEE Trans. on Elect. Insul., Vol. 28, No. 6, pp.917-931, 1993.
[2] K.Y. Park, J.H. Lee, S.J. Cho, H.K. Choi and E.B. Jung, “A study on a intelligent GIS monitoring system using the preventive diagnostic technology”, Journal of IEEK, Vol. 51, NO. 6, pp1372-1379, June 2014.
[3] Momiyama Giyoaki, "Development of a high performance portable PD detection device", Product and Electrics, 2006. 12.
[4] Harrop, P. J., “Dielectrics”, Butterworths, London, 1972.
[5] H. Kawada, M. Honda, T. inoue, and T. Amemiy a, “Patrial discharges automatic monitor for oil-filled power transformer”,IEEE Transaction on Power Apparatus and System, Vol. PAS-103, No.2, pp. 422, 1984.
[6] iobhan Gorman, “Electricity Grid in U.S. Penetrated by Spies”, The Wall Street Journal, Page A1, April 8, 2009.
[7] http://www.eatechnology.com/