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A Study of the Characteristics of a Partial Discharge of SF_6 Following a Fault

Dea-Hee Yoon* · Hyun-Jig Song · Kwang-Sik Lee**

Abstract

When faults occur in the power equipment that is used a great deal in industrial sites, it may lead to fatal accidents that cause losses both economically and in manpower. In this paper, the effect of particle impact on the partial discharge of SF_6 gas was measured by simulating a partial discharge following the type of fault found in the GIS using SF_6 insulating gas as the insulating material. A spectrum analysis was performed on the radiate electromagnetic waves emitted upon partial discharge by using the UHF insulation diagnosis method. This subject of this study is insulation diagnosis by the measurement of radiate electromagnetic waves when particles exist in the GIS and power equipment insulated with SF_6 gas.

Key Words : lPartial discharge, SF_6 gas, Radiate electromagnetic wave, Breakdown

1. Introduction

Because power demand has increased recently due to the progress of the information industry, a more stable power supply is required.

To meet this power demand increase, super-high voltage, large capacity power equipment has been minimized and sealed, and its use has gradually expanded. This power equipment has emerged from the conventional air insulation model and has ensured high reliability through the use of SF_6 gas, which is an insulation medium that has the properties of being an excellent insulator, being inert and being an excellent arc-extinguisher. Reliability is also ensured by keeping the power equipment unaffected by air and the environment through the sealing of live line sections[1].

Structurally, for gas-insulated switchgears (GIS), a type piece of power equipment, the frequency of accidents increases as the use of voltage becomes higher. In the case of transformer facilities, as the quantity of GIS facilities increases, the number of accidents occurring during operation also increases[2,4]. Power equipment with super-high voltage and large capacity has such a variety of problems that the facility itself is expensive, loss of property or impacts on the

* Main author : Doctor of engineering, Department of Electrical Engineering, the Graduate School of Yeungnam University
** Corresponding author : Professor, Department of Electrical Engineering, Graduate School, Yeungnam University
Tel : +82-53-810-3953, Fax : +82-53-810-4767
E-mail : sagmak@ynu.ac.kr
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system is large when accidents do occur, repair is expensive, and a long restoration period is needed. Therefore, if the partial discharge occurring as a forerunner of insulation breakage can be detected, accidents due to broken insulation can be prevented.

As a result of recent technology developments throughout the world for the prevention of GIS facility accidents, this kind of detection is being applied in the field in advanced countries such as in Europe or Japan. But technical barriers are still great as it must correspond to technology updates. Also, there are many parts that must be supplemented for application to the field. For this reason it has not been generalized for application in all countries of the world[2].

Under these circumstances, technology for insulation diagnosis such as drastically enhanced sensitivity by X-ray irradiation to ensure the stability of power equipment such as the GIS, and enhanced signal/noise rate through the measurement of radiate electromagnetic waves in the UHF band, has been developed. These methods are being used in the measurement of partial discharge in the GIS[2].

Many scientists have proposed diverse methods for the detection of internal defects in the GIS. In consequence, a parallel use with the UHF diagnosis method as an electrical method and the sound signal diagnosis method as a mechanical method is recommended.

In this paper, radiate electromagnetic waves, which are generated through the application of high alternating voltage, were measured using antenna by means of a simulation of two cases (particles stuck to a bus bar and particles floating in an internal space) out of the internal defects that may exist within the GIS. Moreover, since electromagnetic waves generated due to a partial discharge within the GIS distribute over a wide range of frequency bands ranging from low to super-high [5][8], the discharge characteristics of SF_6 gas were measured and analyzed with the measurement of high-frequency radiate electromagnetic waves in a narrow band (150~650[MHz], 950~1,450 [MHz]). These bands exhibit a definite change among the high-frequency bands, which is advantageous in the treatment of noise among these electromagnetic waves.

2. Experimental setup and method

2.1 Experimental setup

The simulated GIS chamber was fabricated as shown in Fig. 1 to detect partial discharges occurring within the GIS when particles exist within the GIS. The outer box of the chamber consisted of a cylinder for which the internal diameter was 200[㎜] and the internal depth 340[㎜].

The internal high-voltage application electrode was a stainless steel cylinder, 270[㎜] long and with an internal diameter of 50[㎜].

It was fabricated to maintain the maximum possible voltage application of 200[㎸] and 10 atmospheric pressures. The distance between the cylindrical electrode and the outer box was 20[㎜].

One side of the chamber was made so that radiate electromagnetic waves could be easily measured in the antenna by means of a minimizing attenuation of electromagnetic waves with a Teflon window through which radiate electromagnetic waves can easily pass. The other side of the window was made with transparent acryl to enable observation of the state within the chamber.

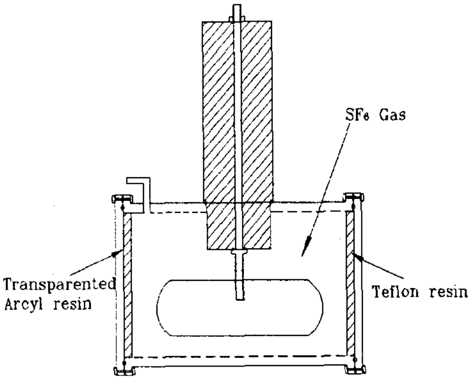
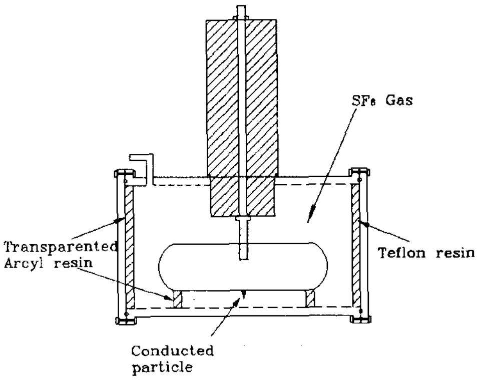
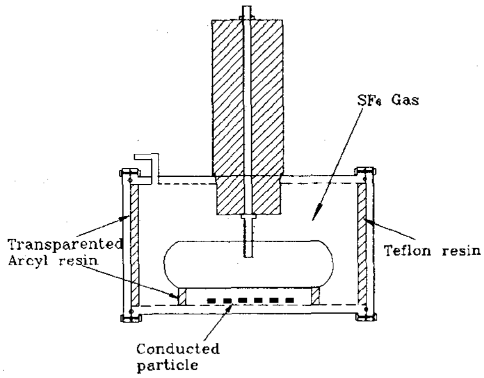


Fig. 1. Simulated GIS Chamber



(a) Particle on a bus bar



(b) Particles floating in the space

Fig. 2. Particles in the Chamber

A spacer was installed using transparent acryl at the ends of both sides of the cylindrical electrode in order to prevent particles from emerging from the gap between the cylindrical electrode and the outer box facing both window sides due to the impact of the electrical field when the particles were floated in the inner space of the GIS chamber.

To simulate defects within the chamber, particles stuck to a bus bar (Fig. 2(a), front end angle of 30[°] and curvature radius of 20[㎛]) and particles floating within the chamber (Fig. 2(b), length of 1[㎜] and diameter of 0.75[㎜], 10 particles) were artificially created and placed within the chamber.

2.2 Experimental method

Fig. 3 is a schematic diagram of the experimental setup. SF_6 insulating gas was filled at 4 atmospheric pressures into the inside of the experimental chamber (the simulated GIS) with the simulated defects as shown in Fig. 2. Then, the voltage was slowly applied in increasing increments so that partial discharges could take place within the chamber through the use of an alternating high-voltage power source (input: AC 200[V] 60[Hz], output: AC 50[kV] 60[mA]). Radiate electromagnetic waves generated via partial discharges within the simulated GIS were measured with the BiConiLog antenna (EMCO model 3142) for measurement of EMI-EMC, and frequency characteristic of the measured radiate electromagnetic waves was analyzed using the spectrum analyzer (Advantest - R3131A). In the data acquisition method of the spectrum analyzer, max-hold values were acquired by means of measuring the defined values of signals over 60 times for 30 seconds at a sweep time of 500ms. In the max-hold mode, the maximum values to be inputted for each frequency of measuring time are taken.

Since the intensity of the electric field in the frequency band set up in this study indicates greater electric field intensity than noise electric field intensity, the impact of noise cannot be neglected.

The distance between the partial-discharge power source and the antenna was 1m.

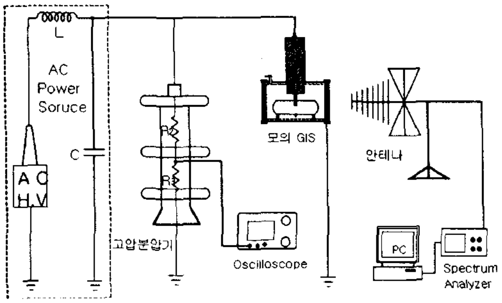


Fig. 3. Schematic diagram of the experiments setup

3. Experimental results and considerations

3.1 Particle on a bus bar

As a result of the observation of radiate electromagnetic waves over the entire frequency (30[MHz]~2[GHz]) band of the antenna while slowly increasing the applied voltage, radiate electromagnetic waves distinguished from the background noise frequency spectrum (Fig. 4) were observable at 20[kV].

As the applied voltage increased to greater than 20[kV], the average electric field intensity of the frequency spectrum increased, but exhibited a spectrum distribution of nearly similar shape.

By measuring the radiate electromagnetic waves following the rise of the applied voltage, the 150~650[MHz] band (A band) and 950~1,450[MHz] band (B band), indicating electric intensity distinguished definitely from the background noise frequency spectrum, (Fig. 4) was selected.

Fig. 5 and Fig. 6 show the results of frequency spectrum measurement in the A and B bands. As a result of measuring radiate electromagnetic waves at 35[kV] in which a continuous, stable partial discharge occurs, the average electric intensity in the A band was found to be 58 [dBμV/m], while it was 72[dBμV/m] in the B band. This indicates that greater electrical intensity is exhibited in the B band of the larger frequency bands than in the A band.

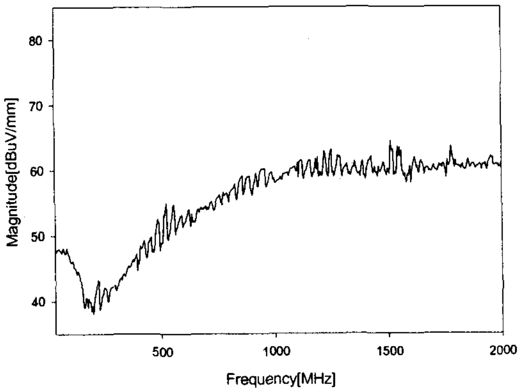


Fig. 4. Background Noise

It can be concluded that strong radiate electromagnetic waves are generated continuously over the bands of 950~1,100[MHz] and 1250~1,350[MHz] in the B band.

When particles are stuck to the bus bar, they act as a precipitation electrode for the area in which the electric field is concentrated. The inside of the experimental chamber therefore forms a bed plate shape electrode. Therefore the insulation value of SF_6 decreases significantly, and becomes a hazard.

When stuck particles exist, partial discharge can be expected due to defects created by particles stuck to the GIS inside. They can be detected through the measurement of radiate electromagnetic waves in a specific frequency band.

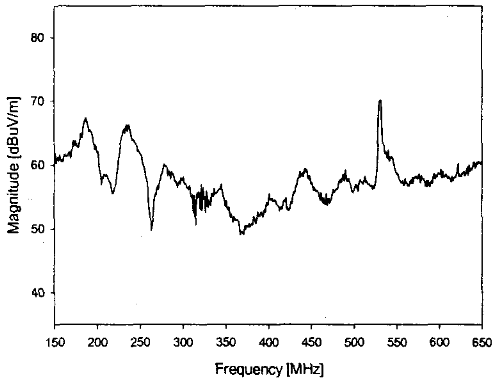


Fig. 5. Characteristics of the Frequency Spectrum in the A Band

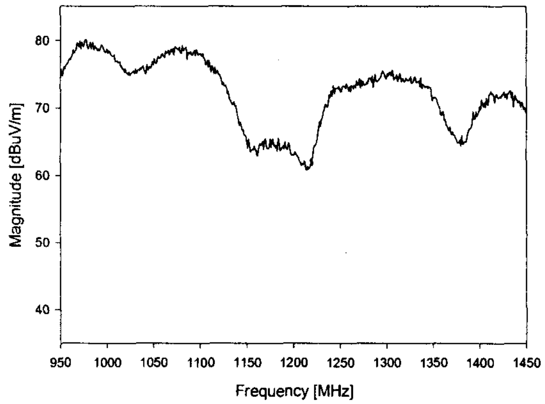


Fig. 6. Characteristics of the Frequency Spectrum in the B Band

3.2 Floating particles

Radiate electromagnetic waves were measured over the whole measurable frequency (30[MHz]~2[GHz]) band of the antenna while the applied voltage was slowly increased. As a result, the measurement of the radiate electromagnetic waves distinguished from the background noise began at the applied voltage of 25[kV](Fig. 4).

Radiate electromagnetic waves distinguished definitely from the background noise were measured at 30~80[MHz]. As it was difficult to distinguish these waves from the background noise in other bands except for this band, it was excluded in this study.

Fig. 7 shows the frequency spectrum of radiate electromagnetic waves measured at 35[kV], with unbroken insulation in the inside chamber and the generation of stable partial discharge. As the applied voltage increased, the electric intensity became greater. A spectrum distribution of a nearly similar shape was exhibited at 30[kV] or higher.

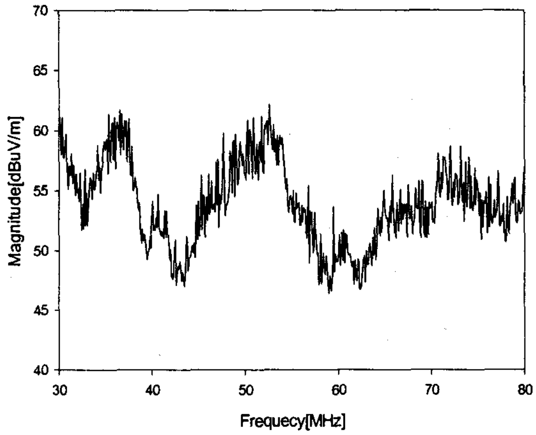


Fig. 7. Frequency Spectrum Characteristics of Floating Particles

Fig. 8 shows a conceptualized vibration of the particles floating within the chamber following the rise of the applied voltage. According to the results, vibration of these particles depends upon the Coulomb force by electric field and gravity force[2,11]. The following explains the shape of vibration of the particles by the correlation of these forces.

As shown in Fig. 8(a), since the Coulomb force is weaker than the force of gravity in the applied voltage of 25[kV], particles neither rise nor line up, but are aligned in one line on the bottom of the outer box along the cylindrical electrode. As the Coulomb force becomes gradually stronger with the applied voltage of 30[kV] (Fig. 8 (b)) and 35[kV] (Fig. 8 (c)), the particles then align.

Moreover, since the Coulomb force becomes stronger with the applied voltage of 40[kV](Fig. 8 (d)) and 45[kV](Fig. 8 (e)), the polarity of the applied voltage changes, the particles vibrate violently and part of the particles begin to rise.

In particular, the electrical intensity of the radiate electromagnetic waves increased drastically from 30[kV] at which the particles begin to vibrate. From this result, it could be concluded that particles collide with the bottom of the outer box of the chamber due to vibration, and thereby the possibility for a partial discharge to occur at this time becomes greater.

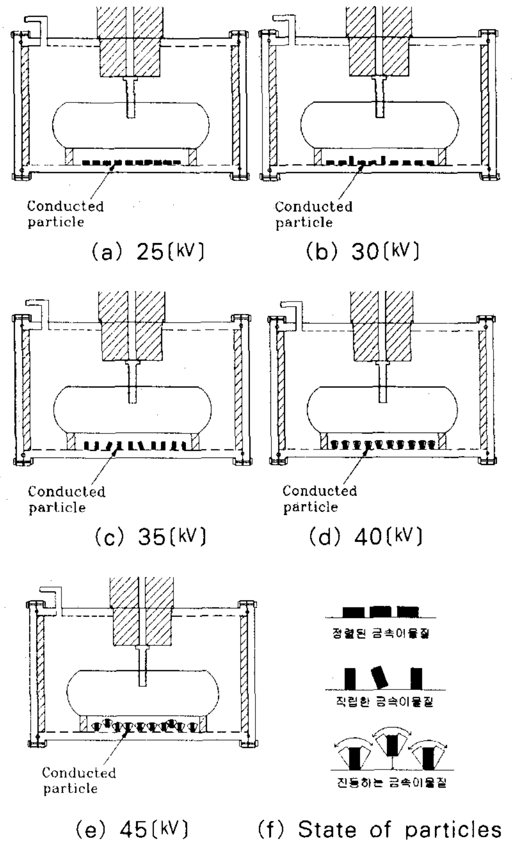


Fig. 8. Behavior of floating particles

When particles exist within the chamber, they align, vibrate and rise depending upon the applied pressure, resulting in the decrease of the gap between the cylindrical electrode and the electrode of the outer box. Particles also become a concentrated part of the electrical field, causing partial discharges, and finally resulting in insulation breaks.

When floating particles exist as explained in Fig. 7 and Fig. 8, electromagnetic waves of 30~80[MHz] appear. Therefore, partial discharges by floating particles can be detected with measured electromagnetic waves over this band.

4. Conclusion

In this study, conductive particles were recognized to be one of the main factors causing insulation breaks among the internal defects of the GIS. Accordingly, two kinds of defects (particles stuck to a bus bar and particles floating in the internal space) were simulated to study the characteristics of radiate electromagnetic waves generated upon the partial discharge of SF_6 gas when particles exist within the GIS. As a result of this study regarding insulation diagnosis by the measurement of the frequency spectrum for radiate electromagnetic waves generated upon a partial discharge due to these two kinds of defects, the following conclusions were obtained.

① Partial discharge that occurs depending upon the kind of defect has a frequency spectrum characteristic of radiate electromagnetic waves over a specific frequency band.

When particles are stuck to a bus bar, radiate electromagnetic waves distinguished from background noise were observed in the band of 150~650[MHz] and 950~1,450[MHz]. When particles float in the internal space, radiate electromagnetic waves distinguished definitely from the background noise were observed in the band of 30~80[MHz].

② When particles are stuck to the bus bar at (150~650[MHz] and 950~1450[MHz]), radiate electromagnetic waves in a higher frequency band were measured than for particles floating in the internal space of the GIS (30~80[MHz]). When a partial discharge is measured using a wideband antenna, it will be possible to apply this characteristic as a basic for the judgment of the kind of defect and for the diagnosis of insulation.

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Biography

Dae-Hee Yoon

RGraduated from the School of Electric and Electronic Engineering, Yeungnam University, in 1977. Master's of engineering from the Graduate School of Yeungnam University in 2001, Doctor of engineering from the Graduate School of Yeungnam University in 2006.

Hyun-Jig Song

Graduated from the Department of Electrical Engineering, Yeungnam University, in 1991. Master's of engineering from the Graduate School of Yeungnam University in 1993, Doctor of engineering from the Graduate School of Yeungnam University in 1997. 2001~2004: Professor in the Department of Computer and Applied Electricity of Gumi-1 College. At present: Professor in the Department of Electrical Automation, Yeungnam College of Science & Technology.

Kwang-Sik Lee

Graduated from the Department of Electrical Engineering, Yeungnam University, in 1971. Doctor of engineering from the Graduate School of Yeungnam University in 1987, 1988~1989: Invited as visiting professor to Nagoya Institute of Technology. Held posts such as a chief secretary of the study circle for discharge and high voltage, chair of the editorial committee, and vice-chair of the Korean Society of Electrical Science. Dean of the Graduate School of Industry, Yeungnam University. At present: Professor in the Department of Electrical Engineering, Yeungnam University. Chair of the Korean Illuminating and Electrical Installation Engineers.