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Diagnosis of Gas Insulated Switchgear Based on Detection of CF4 as an SF6 Decomposition Gas

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論文名：Diagnosis of Gas Insulated Switchgear Based on Detection of CF_4 as an SF_6 Decomposition Gas
（SF_6分解ガス CF_4の検出によるガス絶縁開閉器の診断）

区　分：甲

論 文 内 容 の 要 旨

The power system, concluding generation, transmission, and distribution, is one of the most complex networks in modern society. The rapid evolution of its size and diversity and the emergence of the smart grid have brought many challenges, including stability and reliability issues and the subsequent occurrence of blackouts. The failure cause is faulty equipment or human error, shown at 31.8%. Apparently, the electrical apparatuses need to be improved continuously as well as power system protection. Nowadays, there is an electrical power substation everywhere. The power substation is one of the essential parts of power system reliability. The study on the power substation and the equipment installed inside should be necessary for power system improvement. As described above, the power system needs a high degree of reliability. Therefore, the electrical equipment will be essential to make high quality and capacity in future. In the last two decades, the evolutionary development of gas-insulated switchgear (GIS) has resulted in the higher integration of several new technologies to enhance performance and reliability by reducing defects, having more compact designs. GIS has been operated for more than 50 years with a low failure rate due to high-reliability levels. However, some evidence shows the failure related to defects caused by a circuit breaker, disconnector, and bus duct and interconnecting parts. Therefore, when any failure occurred in GIS, the insulation level would decrease. So far, GIS diagnosis should be the essential method for monitoring and investigating the stability and reliability of GIS. The partial discharge detection techniques are classified based on parameters measured by sensors and other equipment. Each detection scheme has its detection range and physical quantity that limits its application. Diagnosis techniques can be divided into five techniques: the electrical detection techniques, the electromagnetic detection techniques, the ultra-high frequency (UHF), the acoustic detection techniques, and the chemical detection techniques. This thesis proposes a new chemical detection-based GIS diagnosis method based on condition-based monitoring (CBM). When SF_6 is exposed to PD or breakdown, it dissociates, then a part of the dissociated species recombines. Since the recombination occurs imperfect, many decomposition products such as HF, SO_2, CO_2, CF_4, SiF_4, SOF_2, SO_2F_2, S_2F_{10}, and SF_4 are generated. These decomposition products can be an indicator of PD, breakdown, or insulation failure in the system. CF_4 is one of the decomposition products of SF_6. CF_4 has attracted attention as an indicator for the GIS diagnosis because CF_4 accumulates in the GIS vessel for a long time. This is because CF_4 is hard to be removed by an absorbent generally placed in the GIS. Therefore, the CF_4 detection can be considered as the failure indicator of the GIS. CF_4 is generated when the reactions with the discharge involve carbon-including materials such as insulator solids and grease. In the practical application, it has been revealed that most of the decomposition gas is removed and controlled using an absorbent. However, the absorbent or filtration cannot effectively remove CF_4. Typically, GIS manufacturers put the absorbent to the gas compartment. Other decomposition gases are removed. But CF_4 still remains in the gas compartment. For these reasons, the unique diagnosis of CF_4 is we can apply CF_4 detection to any gas compartment in GIS, with and without the absorbent. In the real world of GIS, based on the critical value of CF_4, the critical CF_4 concentration can be calculated to be 30 ppmv (detection target). In this research, two types of CF_4 detection methods are considered. The first one utilizes nanomaterial-based gas sensors fabricated by dielectrophoresis (DEP). The another uses non-thermal plasma application. The former, nanomaterial-based gas sensors fabricated by DEP, SnO_2, ZnO, and CNT were investigated for the ability of CF_4 detection. The results show that three kinds of semiconducting nanomaterials, carbon nanotube, SnO_2 nanoparticle, ZnO nanowires, were integrated on a microelectrode by dielectrophoresis fabricate a gas sensor. It was found that the SnO_2 gas sensor showed the highest response to CF_4 gas at 10000 ppm concentration in SF_6. The conductance of the SnO_2 sensor gradually decreased with elapsed time after exposure to the CF_4 gas, depending on the operating temperature. The latter, the indirect CF_4 detection by CF_4 conversion into CO and CO_2 by DBD application. The concept is the sampled gas mixed with O_2 additive, then DBD-treated to generate CO and CO_2. The generated CO and CO_2 can be detected with gas sensors. In GIS, CF_4 is major decomposition gas containing a carbon atom. Even if CO and CO_2 have already existed in the sample gas, the proposed method should work by evaluating the increment of these gas concentrations after DBD treatment. This implies that CO and CO_2 detection in plasma-treated sample gas can be regarded as an alert for the possible accumulation of residual CF_4 in the GIS. The results show that the limitation of CF_4 conversion was limited at 100-ppm CF_4. Moreover, the performance of the commercial CO sensor was tested in the experimental environment, and it had a similar trend as FT-IR. Especially, further works investigated nanomaterial combinations for the CF_4 gas sensor fabricated by DEP. Recently, the challenges in hybrid material-based gas sensing is the key attention. This technique was selected and applied to fabricate NO_2 gas sensors by two-step dielectrophoretic assembly. It appeared the sensitivity enhanced when the mixture ratio and materials of the combination were suitable. The combination technique might be the essential key to develop CF_4 detection in future work.

This dissertation is presented as follows:

Chapter 1: introduction to world electricity consumption. How necessary of liability of the power system leading to power system improvement. GIS is one crucial key of the power system. Explanations of increasing the number of GIS substations, fault types and possible defects that occurred in the system, and diagnosis methods are the essential background knowledge to understand the real-world situation of GIS and to find the way to improve GIS in the future.

Chapter 2: research objective and concepts. This chapter describes the background of this research, including both direct and indirect CF_4 detection concepts.

Chapter 3 direct CF_4 detection by using several kinds of nanomaterial-based gas sensors fabricated by the DEP process. Experimental results of CF_4 detection using several gas sensors are reported. Discussion about the sensitivity for practical application is shown.

Chapter 4: indirect CF_4 detection by CF_4 conversion into CO and CO_2 by DBD application. The new proposed schemed is examined. The possibility and limitation of the detection system are discussed.

Chapter 5: new DEP-based nanomaterial sensor fabrication technique. This chapter shows the new DEP-based nanomaterial sensor fabrication technique and evaluation of the fabricated sensor. The new technique enables producing highly sensitive and new function gas sensors because the technique enables the assembly of several kinds of nanomaterials quickly. The technique can be used to produce the sensor which has the suitable property to detect CF_4 directly.

Chapter 6: summary of the dissertation and future works.