Indonesian Journal of Electrical Engineering and Computer Science
Vol. 7, No. 1, July 2017, pp. 18 ~ 28
DOI: 10.11591/ijeecs.v7.i1.pp18-28

Chemical by-Product Diagnostic Technique for Gas Insulated Switchgear Condition Monitoring

Visa Musa Ibrahim*[1], Zulkurnain Abdul-Malek[2], Nor Asiah Muhamad[3]
[1,2]Institute of High Voltage and High Current (IVAT), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM) Johor Bahru 81310 Malaysia
[3]School of Electrical and Electronic Engineering, Universiti Sains Malaysia (USM),
*Corresponding author, e-mail: visaibrahim@gmail.com[1], zulkurnain@utm.my, norasiah@utm.my[2]

Abstract

Chemical by product diagnostic technique is an efficient, cost-effective and reliable diagnostic technique for gas insulate switchgear condition monitoring in view of its high sensitivity and anti- internal and external electromagnetic interference and noise. In this research paper, coaxial simulated gas insulated switchgear chamber and four different types of artificial defect were designed to cause partial discharge that will simulate the decomposition of sulphur hexafluoride gas in the chamber when energize. Fourier transform infrared spectrometer was used as the method of chemical by-product technique to detect the SF_6 decomposition product and its concentration. Different numerous by-products were detected (SO_2, SOF_2, SO_2F_2, SO_2F_{10}, SiF_4, CO, C_3F_8, C_2F_6) under this experiment using four different types of defect and the by-products differs with the type of defect and the generation rate. Gas insulated switchgear health condition can be feasibly diagnosed by analyzing the decomposition products of SF_6 to identify its fault.

Keywords: *Gas insulated switchgear, Decomposition products, Chemical diagnostic technique, FTIR spectrometer, Condition Monitoring*

1. Introduction

Gas insulated switchgear is a requisite high voltage equipment that is used in power system during the process of transmission and distribution of electrical energy for the purpose of controlling, protecting and isolation of other electrical power system equipment. It is used because of its compact in nature, high performance and reliability, outstanding compatibility with the environment, low maintenance requirement and ability to interrupt fault current in power system network thus it serves as the backbone of modern power system [1, 2].

Sulphur hexafluoride gas (SF6) is used in gas-insulated switchgear as its insulant and coolant due to its good thermal transfer characteristics and high dielectric properties with excellent arc quenching ability compare to vacuum and air [3-5]. Despite the fact of SF6 excellent characteristic in GIS, it deteriorate due to the activities of partial discharge caused by small defects such as metallic protrusion, free conducting particles, fixed contamination on the surface of the spacer and gap at electrode/epoxy interface [4], [6-8], thereby causing the GIS to fail and such failure are sometimes sudden and catastrophic that will lead to irreversible internal damage of the GIS causing power outages in the entire system network which will paralyze economic and other activities, cause personal and environmental hazards and high cost of replacement. Therefore this critical asset (GIS equipment) should be monitored closely and continuously using a reliable and effective technique in order to evaluate its operating condition and to ensure its maximum uptime.

Studies carried out by researchers shows that the presence of partial discharge in GIS will yield to different types of SF6 decomposition product with different concentration at generated rate such as SOF2, SO2F2, SOF4, S2F10, CF4, CO2, S2F2, SF2, SF8, SF4, C3F8, C2F6, CO, COS, H2S, HF, SO2, and SiF4 Etc [9, 10]. The detection of the SF6 decomposition products and its concentration in GIS can give adequate information about the property, type and the level of internal deterioration of insulation in the equipment prior to its failure. This type of detection is called chemical by-product diagnostic techniques of GIS condition monitoring.

Received March 30, 2017; Revised May 24, 2017; Accepted June 8, 2017

The international methods used in chemical by-products techniques to detect SF6 decomposition products are the detector tube, gas chromatography, gas analyzer and Fourier transform infrared spectrometer (FTIR). These methods are effective because it is not affected by internal and external interference (noise and electromagnetic interference) and it has the potential of becoming the most powerful diagnostic technique to be used in GIS to ascertain the condition of its health.

Detector tube uses chemical reaction in a special test tube for its detection and it can only detect few gases such as SO2, SOF2, SO2F2, and HF. The detector tube precision can reach up to 1ppmv but its stability can be affected by humidity, temperature, and cross interference [11- 13]. Gas chromatography is a process of separating a mixture of gases into its individual components. It can only detect few gases such as SOF2, SO2, SO2F2, CF4,CO2. etc. and its detection accuracy can reach up to 1ppmv but it takes a long time in the injection of the sample and analysis, also the chromatographic column has to be clean regularly and it is not suitable for online monitoring [,9-11], [13-18]. The gas analyzer is used to detect few SF6 decomposed components such as H2O, SO2 and O2 only. It has the advantage of high efficiency and speed during operation but the sensor that is used in the gas analyzer can be poisoned after a long period of used due to the chemical reaction between the gas sensor and the gas to be detected, thereby affecting the sensitivity and the detection precision of the gasanalyzer [11-13], [15, 19].

Fourier transform infrared (FTIR) method used for the detection of SF6 decomposition product has high detection precision, high detection speed, ability to detect numerous types of decomposition product, with strong resistance to internal and external interference and also has the ability to detect sample repeatedly. It is also suitable for online GIS monitoring with the powerful prospect of becoming the most powerful SF_6 by-product method of chemical diagnostic technique. In this research quantitative study of SF_6 decomposed product was conducted based on the FTIR method of chemical diagnostic technique to ascertain the health condition of GIS under four different artificial designed defect. [11, 12, 15,19]

2. Experimental Study

The experiment was conducted in the lab of High voltage and High current institute (IVAT) in the faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM). The experiment was setup by connecting the experimental facilities as shown in Figure 1. The gas chamber was entirely cleaned with white spirit then artificial defects were placed in the gas chamber and sealed. The chamber was subjected to a vacuum pump then filled with pressurized SF_6 gas at a pressure of 2bar. High voltage was applied to the chamber and the artificial defects generate partial discharge that simulates the decomposition of SF_6 then the decomposition products were detected by Fourier transform infrared spectrometer.

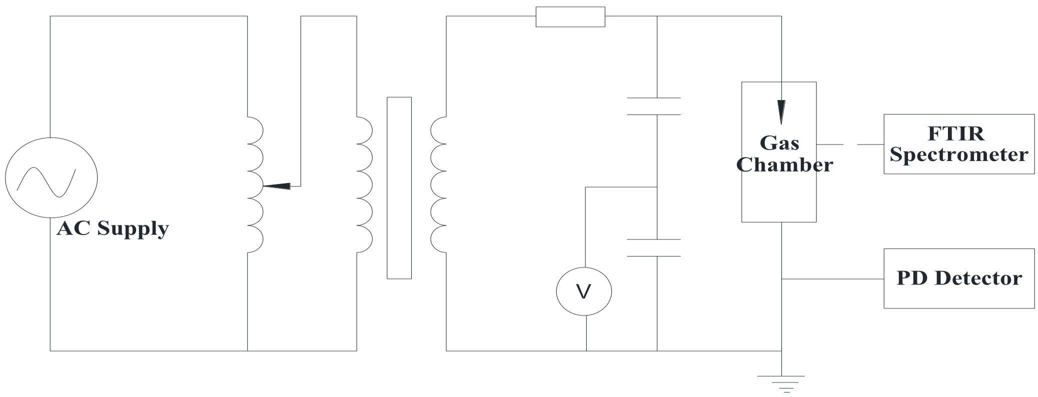

Figure 1a. SF_6 decomposition and detection system schematic diagram

Figure 1b. SF_6 decomposition system in IVAT lab UTM

2.1. Decomposition Gas Chamber

SF_6 decomposition gas chamber is a coaxial or concentric cylinder with a flat flange and cone cover at end of the both side respectively as shown in Figure 2a and 2b. It is a sealed container with a volume of about 10litres ($0.01m^3$) and a tolerance pressure and voltage of about 6bar and 60kv respectively. The coaxial gas chamber is made up of (Cr/Ni/Fe) Austenitic stainless steel designation of AISI 300 series for good weldability and corrosion resistance. It has gas inlet and outlet that is used to fill and reclaim pure and decomposed SF_6 gas in the chamber before and after the experiment respectively. Also viewing window and pressure gauge was attached on it. High voltage electrode made up of aluminium and a spacer connected to it separates the high voltage conductor and the ground electrode made up of Austenitic stainless steel which is the tank of the chamber. The high voltage conductor is at the supply end and it is insulated with condenser graded porcelain bushing.

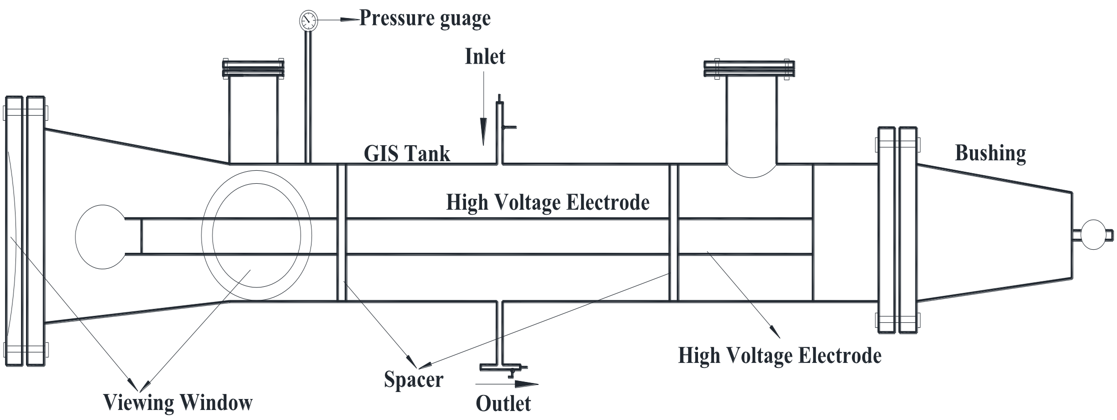

Figure 2a. SF_6 decomposition gas chamber

Figure 2b. Decomposition gas chamber in IVAT lab UTM

2.2. Artificial Defects

Four artificial defects namely metallic protrusion defect, fixed defect, gap or void defect and floating particle defect were designed in line with typical defects in practical GIS as shown in Figure 3. The artificial defects simulate the generation of PD in the system. Protrusion defect was a needle electrode with diameter and length of 1mm and 10mm respectively with a 0,2mm radius of curvature fixed on the high voltage electrode. The distance between the needle and the ground electrode i.e. the tank of the chamber is 12mm as shown in Figure 3a. The fixed defect is made up aluminium foil of 15mm x 10mm dimension attached to the surface of the spacer as shown in Figure 3b. A gap defect is a void of 1mm between the spacer and the high voltage electrode as shown in Figure 3c and the floating particle defect is made up of cutting of copper of 15mm length by 0.1mm diameter inserted in the chamber and allow to move freely as shown in Figure 3d. Aluminium was used as the high voltage conductor or electrode and Austenitic stainless steel as the ground electrode which is the tank of the chamber in order to make the simulation more practical as in real GIS.

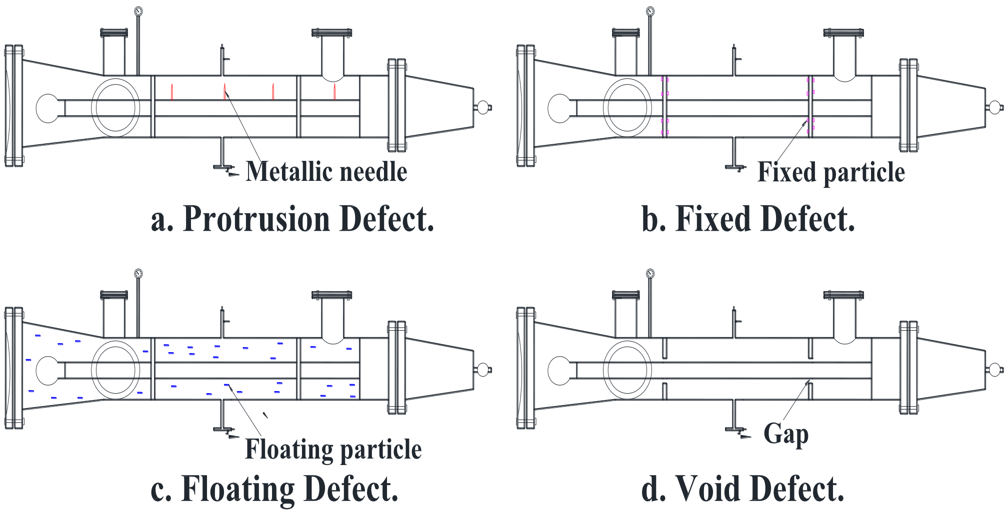

Figure 3. Designed four kinds of artificial defects

2.3. Fourier Transform Infrared Spectrometer for Detection of Sf_6 Decomposition Products

Fourier transform infrared ray (FTIR) spectroscopy was used to detect the SF_6 decomposition products and its concentration as shown in Figure 4. The decomposed gas was injected into the FTIR spectrometer which consists of a source (glowing black body), Interferometer and detector. The source emits an infrared radiation (energy) inform of a beam that passes through an aperture (mirror) which controls the amount of energy that goes to the sample and detector. The beam enters the interferometer where spectral coding takes place resulting in interferogram signal, then it passes to the sample and some of the radiation is absorbed by the sample while some are reflected then the beam finally passes to the detector which is design to measure interferogram signal. The measured signal is digitized and sent to a digital computer where Fourier transformation takes place. The final infrared spectrum was then interpreted by pop software that was installed in the digital computer then the SF_6 detected decomposition product and its concentration was extracted and printed.

Figure 4. FTIR spectrometer in TNB research institute Kajang Selangor Malaysia

2.4. Experimental Procedure

As shown in Figure 3 all the facilities of the experiment were connected. The designed artificial defect was inserted into the clean gas chamber that was subjected with a vacuum pump and filled with (99.99%) pure SF_6 at a pressure of 2bars. The gas in the chamber was checked to ensure that there was no leakage then connected to high voltage single phase supply. The PD detector type TE 571 model was calibrated with the use of KAL 451 calibrator. After the calibration high voltage was applied to the gas chamber through the high voltage conductor and increased gradually until the PD detector detects PD and allowed to for a period of 50 hours.

This experiment was conducted excluding the influence of humidity and temperature but the temperature and humidity of the laboratory were about 24^0C and 60% humidity respectively. The high voltage was disconnected and the residual voltage was discharge with earth electrode before sampling and connected after sampling. SF_6 gas was sampled every 10 hours with the use of TEDLAR-PVT sampling bag for the detection of decomposed product. The TEDLAR-PVT sampling bag (1litre) has excellent corrosion resistance. The sampling amount taken was about 90 ml and the gas chamber was not refilled because the sample amount taken is very small and it has negligible influence on the experiment. The sample gas was taken and injected into FTIR spectrometer to detect the amount and concentration of the decomposed products. The experiment lasted for 50 hours and after that, the defect was change to another one and the same experimental step and procedure was repeated for all the four artificial defects.

3. Results of Experiment and Discussion

3.1. Decomposition Product

The decomposition product of SF_6 gas and its concentration detected by FTIR spectrometer under four kinds of artificial defects that caused the partial discharge that simulate the decomposition is illustrated below.

Experiment with a Void defect was carried out at the voltage of 55KV and the SF_6 decomposition products detected using FTIR spectrometer are SO_2, SO_2F_2, SiF_4 and C_2F_6 (four numbers). SO_2, SO_2F_2 and SiF_4 are not stable SF_6 decomposition products and their concentration at 50 hours decrease respectively while C_2F_6 is almost a stable SF_6 decomposition product that its concentration oscillates with an increase in time during the period of the experiment. It was also observed that the concentration of SO_2, SO_2F_2 and SiF_2 are higher than that of C_2F_6 as shown in Figure 5a and 5b.

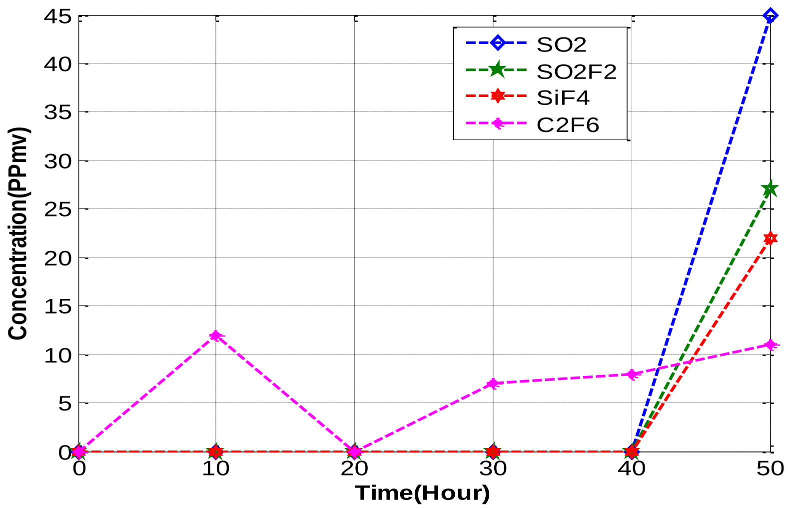

Figure 5a. Void defect concentration of SF_6 decomposition product variation with time

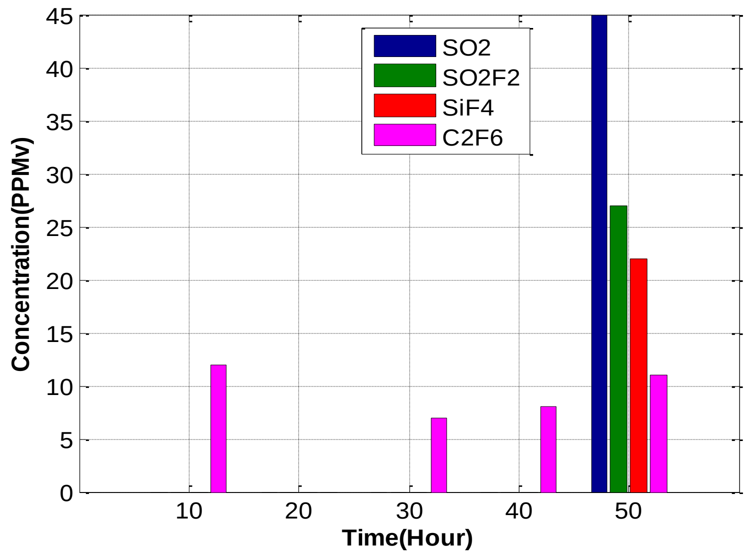

Figure 5b. Void defect concentration of SF_6 decomposition product variation with time

Experiment with fixed artificial defect attached to the spacer was conducted at the voltage of 54KV and the SF_6 decomposition products detected using FTIR spectrometer are SO_2, SO_2 F2, C_3F_8 and C_2F_6 (four in numbers). C_2F_6 is a stable SF_6 decomposition product but its concentration is undulating during the period of the experiment. C_3F_8 is almost a stable SF_6 decomposition product that slightly increases and decreases in its concentration while SO_2 and SO_2F_2 are not stable decomposition products. The concentration of SO_2 in the course of the experiment is more than that of $SO_2F_2$and that of SO_2F_2 is more than that of both C_3F_8 and C_2F_6 as shown in Figure 6a and 6b.

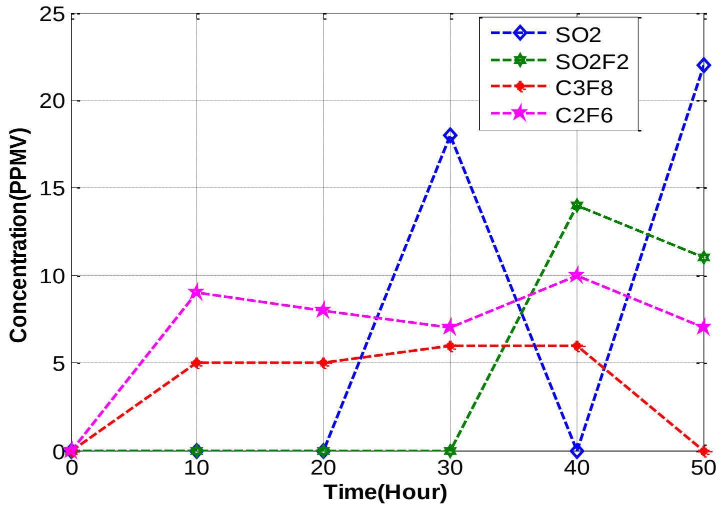

Figure 6a. Fixed defect concentration of SF_6 decomposition product variation with time

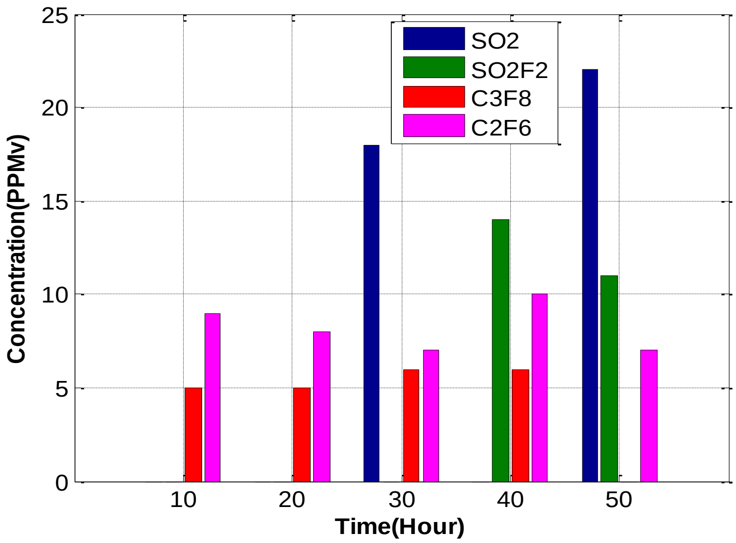

Figure 6b. Fixed defect concentration of SF_6 decomposition product variation with time

Floating artificial defect experiment was carried out at the voltage of 45KV and the SF_6 decomposition product detected using FTIR spectrometer are C_3F_8 and C_2F_6 (two numbers). C_2F_6 is a stable decomposition product that its concentration oscillates continually with variation of time while C_3F_8 is not a stable decomposition product and its concentration is less than that of C_2F_6 as shown in Figure 7a and 7 b.

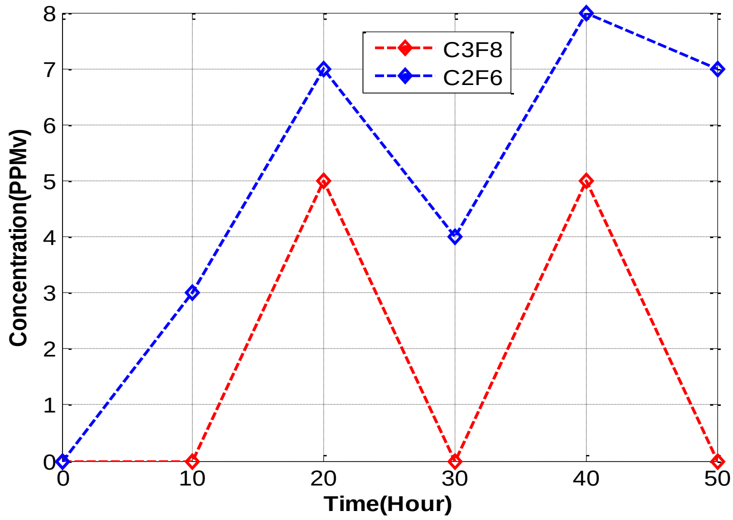

Figure 7a. Floating defect concentration of SF_6 decomposition product variation with time

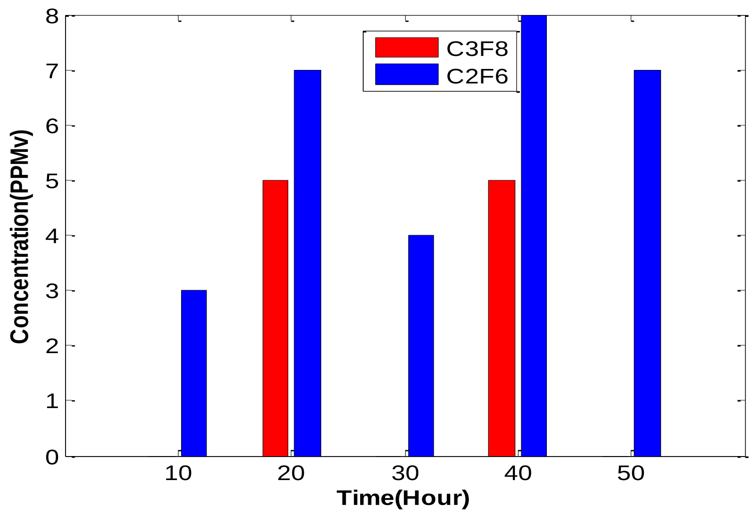

Figure 7b. Floating defect concentration of SF_6 decomposition product variation with time

Protrusion artificial defect experimental voltage is 50KV and the SF_6 decomposition products that were detected using FTIR spectrometer are SO_2, SOF_2, SO_2F_2, SO_2F_{10}, SiF_4, CO, C_3F_8, C_2F_6 (eight number). SOF_2 and SO_2F_2 are stable decomposition products that its concentration increases with variation in time and disappears, SiF_4 and C_2F_6 are almost stable decomposition product while SO_2, SO_2F_{10}, CO and C_3F_8 are not stable decomposition products. SOF_2 and SO_2F_2 have a higher concentration than the other decomposition products as shown in Figure 8a and 8b.

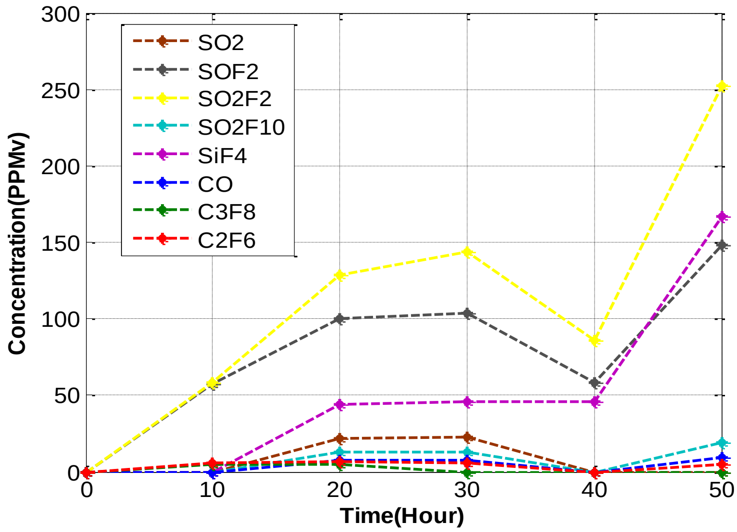

Figure 8a. Protrusion defect concentration of SF_6 decomposition product variation with time

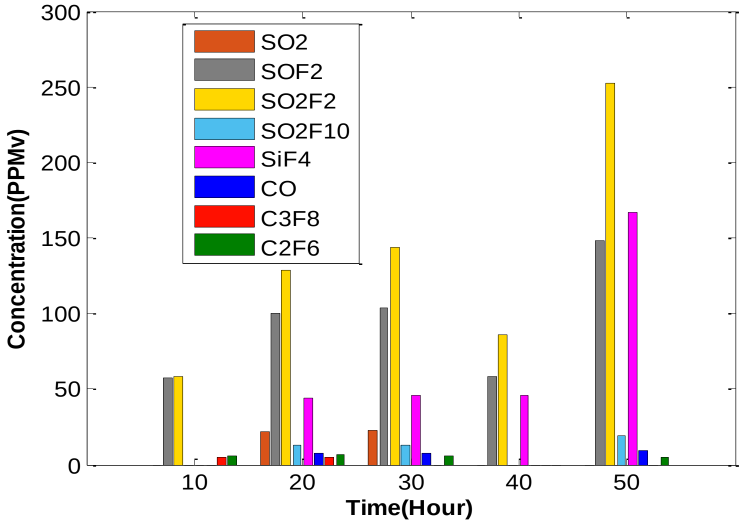

Figure 8b. Protrusion defect concentration of SF_6 decomposition product variation with time

4. Conclusion

GIS in operation suffers the challenge of insulation degradation (decomposition) and eventually failure in the presence of defects caused by partial discharge. The main SF_6 decomposition products detected by FTIR spectrometer under the four artificial defects are follows; void defect (SO_2, SO_2F_2, SiF_4 and C_2F_6), fixed defect (SO_2, SO_2 F2, C_3F_8 and C_2F_6), floating defect (C_3F_8 and C_2F_6), protrusion defect (SO_2, SOF_2, SO_2F_2, SO_2F_{10}, SiF_4, CO, C_3F_8, C_2F_6) The SF_6 decomposition characteristics under the four artificial defects are clearly different in terms of decomposition product, the concentration of decomposition products and decomposition rate during the period of the experiment. From figure 5-8 shows that protrusion defect has the highest number of decomposition products with high concentration, its effect on GIS insulation deterioration will be more than fixed defect, floating defect and void defect while fixed defect will be more than that of floating and void defects. Therefore protrusion defect is more harmful to the health state of GIS followed by fixed defect then floating and void defect. These acquired decomposition products and their concentration can be used to detect and identify the type and the level of fault in gas insulated switchgear before GIS failure for purpose of preventive maintenance. Also, it is attainable to recognise and classify different types of defects caused by PD when SF_6 decomposition products are analysed.

Acknowledgement

The authors wish to thank the Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (Research Vote No. 4F828) for the financial aid and also appreciate the support of TNB research institute Kajang Selangor Malaysia for providing FTIR spectrometer for the test of SF_6 decomposed by products.

References

[1] V. Aaradhi and K. Gaidhani, "*Special problems in gas insulated substations (GIS) and their effects on Indian power system*," IEEE Int. Conf. Power Syst. Technol. POWERCON 2012, pp. 1–5,

[2] MS Naidu, V Kamaraju, " High Voltage Engineering text book" Third edition, Tata Mc Graw, Hili publishing company limited, New Delhi.2005 pp. 1–19.

[3] C. Liu, S. Palanisamy, S. Chen, P. Wu, and L. Yao, "Mechanism of Formation of SF 6 Decomposition Gas Products and its Identification by GC-MS and Electrochemical methods : A mini Review. *IEEE Trans. Dielectr. insul*," 2015 vol. 10, pp. 4223–4231,

[4] R. Sarathi and R. Umamaheswari, "Understanding the partial discharge activity generated due to particle movement in a composite insulation under AC voltages," *Int. J. Electr. Power Energy Syst.*, Jun. 2013.vol. 48, pp. 1–9,

[5] W. Jiajun, H. Bin, and W. Hongmei, "Electric Insulation Detection Method for High-voltage Insulators," *TELKOMNIKA Indones. J. Electr. Eng.* 2013;11(7): 4086–4090,.

[6] Z. Weixia, Z. Xianping, Z. Shutao, Y. Hong, and W. Dada, "Study on Partial Discharge Detection of 10kV Power cable ," *TELKOMNIKA Indones. J. Electr. Eng.* 2012.;10(7):1795–1799,

[7] M. H. Ahmad, N. Bashir, H. Ahmad, A. A. A. Jamil, and A. A. Suleiman, "An Overview of Electrical Tree Growth in Solid Insulating Material with Emphasis of Influencing Factors Mathematical Models and Tree Suppression," *TELKOMNIKA Indones. J. Electr. Eng.*, 2014;12(8): 5827 - 5846

[8] Y. Wang, "SF_6 Byproducts in High-Humidity Environment: an Experimental Evaluation between 200^{o}C and 500^{o}C," *J. Electromagn. Anal. Appl.*, 2011. vol. 03, no. 06, pp. 179–183,

[9] J. Tang, F. Liu, X. Zhang, Q. Meng, and J. Zhou, "Partial Discharge Recognition through an Analysis of SF 6 Decomposition Products Part 1 : Decomposition Characteristics of SF 6 under Four Different Partial Discharges *EEE Trans. Dielectr. insul.*,,2012." vol. 19, no. 1, pp. 0–7,

[10] J. Tang, F. Liu, Q. Meng, X. Zhang, and J. Tao, "Partial Discharge Recognition through an Analysis of SF 6 Decomposition Products Part 2 : Feature Extraction and Decision Tree-based Pattern Recognition, *IEEE Trans. Dielectr. insul.*, 2012," vol. 19, no. 1, pp. 37–44,

[11] J. J. Shea, "Advances in High Voltage Engineering [Book Review]," *IEEE Electr. Insul. Mag.*, vol. 23, no. 1, pp. 53–53, 2007.

[12] F. Liu, D. Gan, S. Zhou, C. Hu, P. Liu, and X. Zhang, "*Analysis of infrared spectrum characteristic and variation trend of SF 6 PD decomposition*," 2010 Int. Conf. High Volt. Eng. Appl. ICHVE 2010, no. 2, pp. 409–412,

[13] Cigré Working Group WG B3.25, *SF6 Analysis for (AIS, GIS and MTS) Condition Assessment February 2014*. ISBN : 978-2-85873-262-3

[14] J. Tang, F. Liu, X. Zhang, Q. Meng, and J. Zhou, "Partial Discharge Recognition through an Analysis of SF 6 Decomposition Products Part 1 : Decomposition Characteristics of SF 6 under Four Different Partial Discharges *EEE Trans. Dielectr. insul.*,,2012." vol. 19, no. 1, pp. 0–7,

[15] X. Zhang, H. Liu, J. Ren, J. Li, and X. Li, "Fourier transform infrared spectroscopy quantitative analysis of SF6 partial discharge decomposition components," *Spectrochim. Acta - Part A Mol. Biomol. Spectrosc.*, 2015.vol. 136, no. PB, pp. 884–889,

[16] I. a. Metwally, “Status review on partial discharge techniques in gas-insulated switchgear/lines,” *Electr. Power Syst. Res.*, 2004 vol. 69, no. 1, pp. 25–36,
[17] Farish, O, Judd, MD, Hampton, BF & Pearson, JS 2004, 'SF6 insulation systems and their monitoring'. in AM Haddad & D Warne (eds), *Advances in high voltage engineering.* IET Power and Energy Series, 2004, no. 40, pp. 37-74.
[18] Emerson, “Fundamentals of Gas Chromatography,” *85th Annu. Int. Sch. Hydrocarb. Meas.*, 2010. vol. 43, pp. 1–8,
[19] Y. Wang, N. Wei, S. Ji, W. Ding, and K. Ma, “*Study on SF6 gas decomposition products of typical GIS defect models by infrared detection*,” 1st Int. Conf. Electr. Power Equip. - Switch. Technol. ICEPE,*2011 - Proc.*, no. 5, pp. 496–499,