International Journal of Engineering & Technology, 7 (4.30) (2018) 59-63

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Empirical Investigation on Breakdown Characteristics of Air – CO_2 Gas Mixtures Under AC and DC Voltages

N. Azizol[1], M. S. Kamarudin[1*], M. F. M. Yousof[1], N. A. M. Jamail[1], R. Abd.Rahman[1], N. A. Othman[1], M. N. R. Baharom[1], J. M. Wari[2]

[1]*Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.*
[2]*Indkom Engineering Sdn. Bhd, 40200 Shah Alam, Selangor, Malaysia*
** Corresponding author E-mail: saufi@uthm.edu.my*

Abstract

For years there have been countless efforts to find an environmental-friendly gas or gas mixtures to minimize SF_6. Researchers have been ongoing to find its alternatives where there are few gasses used to minimize SF_6, such as carbon dioxide (CO_2) and air. This paper aimed to study the effects of field uniformity towards breakdown characteristic of air-CO_2 gas mixtures under AC and DC voltage. Two types of electrodes were used in this experiment which are sphere-sphere electrode (D=5cm) and the rod-rod electrode. Other than that, there are five level of gap distances (0.5cm-2.5cm) with three mixing ratios (100% air–0% CO_2, 70% air–30% CO_2, 50% air-50% CO_2) in 2 bar (abs). The results show the breakdown voltage (U_{50}) of the sphere-sphere electrode is higher than the rod-rod electrode under AC and DC voltage. Besides, as the U_{50} goes higher, the E_{max} will be decreasing in any mixing ratio under AC and DC voltage. As for the results, the sphere-sphere electrode is more uniform field than the rod-rod electrode. Moreover, the sphere-sphere electrode has shown the highest withstand capacity of breakdown since they have provided less stress to the field gaps.

Keywords: *Air; breakdown voltage; CO_2, field utilization factor; maximum electric field.*

1. Introduction

Recently, people were concerned about the environmental impact to the world as the result of human activities. From the global environment side, there is an impact of potential climate change due to the increase of greenhouse gases to the atmosphere. In applications, SF_6 is considered as a greenhouse gas even though it has been extensively applied in large capacity electric power equipment such as gas-insulated switchgear (GIS) and gas circuit breakers (GCB). According to Kyoto Protocol (COP 3) in 1997, SF_6 has been identified as a global warming potential (GWP) with a long lifetime as long as 3400 years [1][2]. The GWP of SF_6 is 23900 times that greater than of CO_2 [3].

At present, previous researchers have been giving intense efforts to find an environmental-friendly gas such as air [4] and CO_2 [5] to substitutes SF_6. CO_2 is a relatively good interruption performance and much lower GWP than SF_6. Besides, CO_2 also has a lower boiling temperature than SF_6 and remain gaseous at low temperature ranges down to -40℃ at a high gas pressure of 1.0 MPa-abs [6]. In addition, CO_2 can be obtained relatively cheaply and is available from must gas manufacture. Although CO_2 has a weak electron attaching property, research is carried out as it is an environmental-friendly gas.

On the other hand, air the simplest form of insulator that is used in high voltage application. Although SF_6 is regarded as the best gas insulation for high voltage application, air is still widely used to ease maintenance of property.

Researchers have been investigating on mixtures of air and CO_2 since these two gases are easy to be found. Martin Seeger reported the results of CO_2 measurements are significantly lower compared the results of Cohen in his paper [7]. The results of minimum breakdown electric field strengths are in the range 200 to 300 kV/cm and when the pressure above 2.0 MPa there is no increase of breakdown electric field strength if the lowest values are compared [8]. Zhexin Chen investigated the reduced critical breakdown fields of the hot CO_2 and CO_2-based mixtures [9]. Hideto Mashidori examined the sparkover characteristics of air-CO_2 mixed gases. In his journal, when CO_2 concentration increased from 0% to 2%, the sparkover voltage decreased around 20 kV under a positive DC voltage [10]. Although other researchers have been investigating more expensive gasses [11], [12], [13], CO_2 and air are still being used as part of the gas mixtures.

This paper aims to investigate the performance of the breakdown voltage (U_{50}) and the electric field of CO_2 and air in view to minimize SF_6 gas as an insulator in high voltage equipment. These gasses will be mixed with three types of mixing ratios and pressure is fixed at 2 bar (abs). Other than that, the electrodes used are sphere-sphere and rod-rod configurations under AC and DC voltages. Perhaps a gas-insulated transmission line (GIL) with CO_2 gas mixtures will be able to replace HVDC cable [14] and solve magnetic field problems in overhead transmission lines [15].

2. Experimental Setup

All experiments were carried out in a laboratory gas chamber consists of a Plexiglass cylinder fixed with top and bottom flanges which are connected to high voltage and ground potential respectively. The tests were performed in two types of electrode configurations which are sphere-sphere configuration (D-5cm) and rod-rod configurations. Three type of mixtures ratios of air and CO_2 are used which are 100% air–0% CO_2, 70% air–30% CO_2 and 50% air-50% CO_2. The tests only focus in two types of voltages,

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

which are: (1) AC (U_{rms}) rated up to 100kV; (2) DC rated up to 140kV. The gap distance is adjusted in five level 0.5, 1, 1.5, 2, 2.5 (cm) under the gas pressure of 2 bar (abs). The surfaces of the spheres are polished before starting with several breakdown initiated to remove any dust particles. In addition, FEMM software is used to show the electric field stress around the electrodes. FEMM software also able to show the magnitude of the electric field and solve the complex finite element analysis depends on electrode configurations. The test circuit as shown in Figure 1.

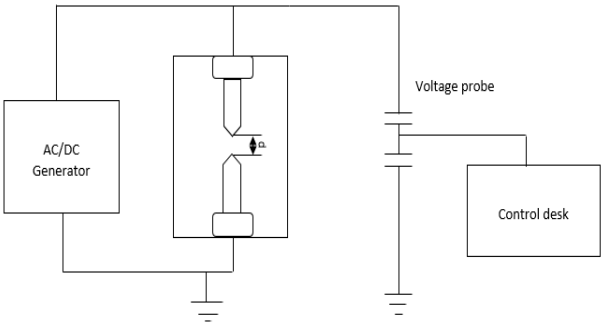


Fig 1: Test circuit for AC and DC

2.1. Electrode Configurations

There are two electrode configurations used in this experiment which sphere-sphere and rod-rod configurations. The diameter for sphere is 5cm while rod has a tip radius of 0.1cm. Figure 2 shows both of the electrode configurations.

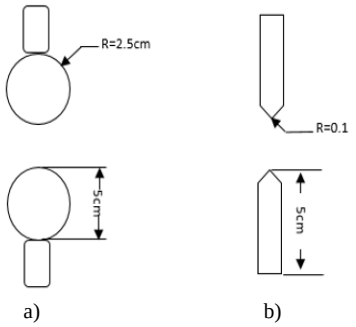


Fig 2: Electrode configurations. a) Sphere-sphere b) Rod-rod

2.2. 50% breakdown voltage (U_{50})

Based on the Standard [16], the U_{50} is a breakdown voltage by applying 20 shots at a timed interval of 120 seconds

2.3. The simulated models

Simulation techniques are carried out to obtain the maximum electric field, E_{max} as in [17], and field utilization factor, η for each electrodes configuration [18]. The field utilization factor is calculated using equation:

$$\eta = E_{mean}/E_{max} \quad (1)$$

While, E_{max} is a maximum electric field for each electrode configuration, simulated using Finite Element Method Magnetics (FEMM) as shown in Figure 3. E_{mean} can be defined as:

$$E_{mean} = v/d \quad (2)$$

Where d is the gap distance between electrodes while v is the applied voltage, which is similar to U_{50} obtained in laboratory works.

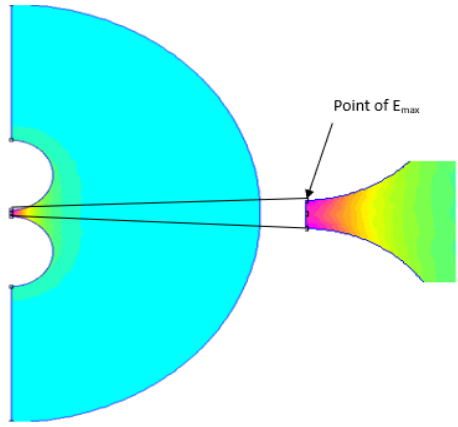


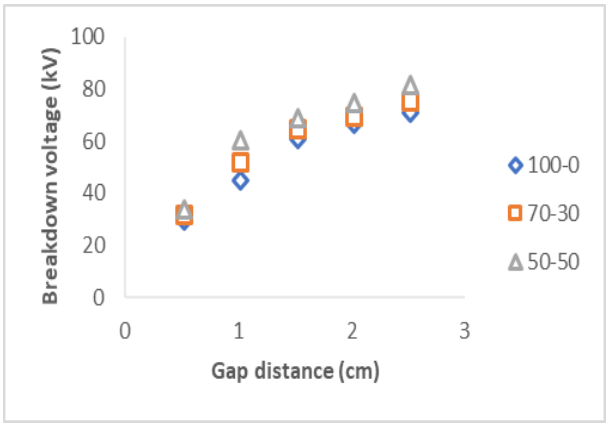
Fig 3: Maximum electric field of sphere-sphere configuration

3. Experimental Results

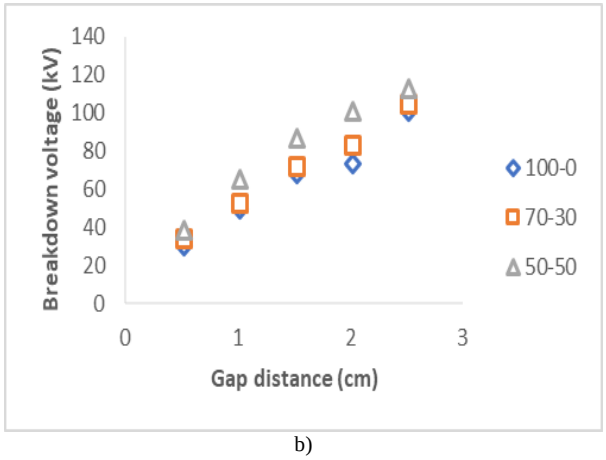
This section describes the results obtained with the sphere-sphere and rod-rod configurations under AC and DC voltages. First results are about sphere-sphere configuration which is focuses on U_{50}, maximum electric field, E_{max} and field utilization factor, η. Then followed by rod-rod configuration with same focusing.

3.1 Sphere-sphere configuration

Figure 4 shows the same approximately increasing trend with an increase of gap distance for both AC and DC voltage. The biggest gap distance in this experiment is 2.5cm while the lowest is 0.5cm. The U_{50} of 50% air-50% CO_2 is highest while second highest is a 70% air–30% CO_2 where the difference between both mixtures is 2% to 5%. When the tests were carried out with pure air which is 100% air–0% CO_2, the U_{50} dropped 12%. In this sphere-sphere, the U_{50} for AC is lower than the DC voltage. The trend of this figure is similar with researcher F. Sadaoui [19]. As mentioned, the U_{50} of 5 level gap distance of AC for 100% air–0% CO_2 is 30.64–72.20 kV, 70% air–30% CO_2 is 32.91–81.18 kV and 50% air-50% CO_2 is 34.77–82.55 kV. For the DC voltage, 100% air–0% CO_2 is 31.62–102.51 kV, 70% air–30% CO_2 is 35.1–106.36 kV and 50% air- 50% CO_2 is 39.88–114.5 kV. The results show the U_{50} of insulating medium are strongly depend upon the electrode configurations.



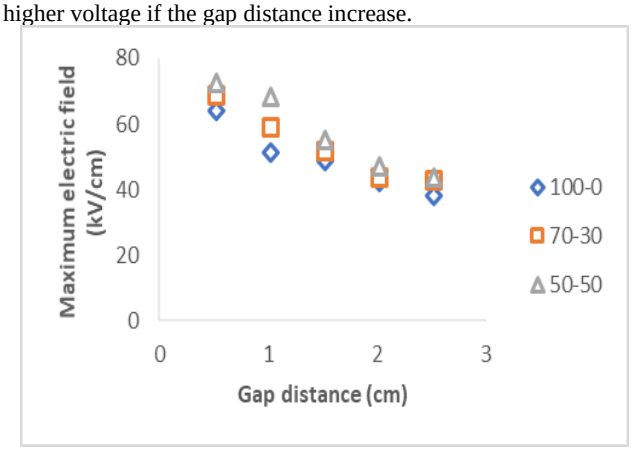
a)



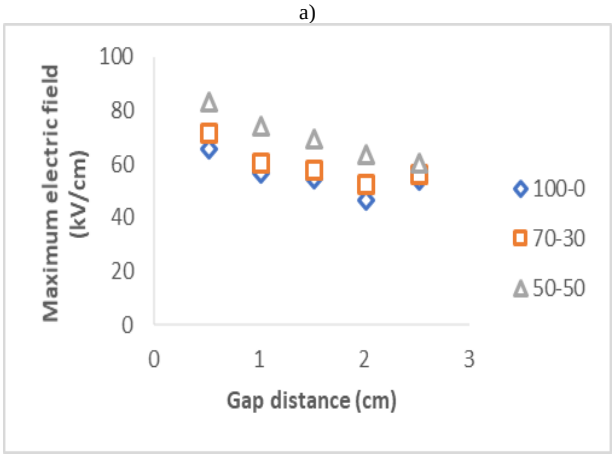
b)

Fig 4: Breakdown voltage against gap distance. a) AC, b) DC

By referring to the Figure 5, the maximum electric field, E_{max} decreases when the gap distance increases for the three of different mixtures in AC and DC voltage. In fact, when the electrodes are in uniform field approaching 1, the gap distance increase, the breakdown voltage also increase while the E_{max} will be decreasing. E_{max} for 50% air-50% CO_2 is lowest than 70% air–30% CO_2 and 100% air–0% CO_2 in gap distance for both voltages. Apart from that, the graph also shows the E_{max} of DC voltage is lower than the AC voltage where for gap distance 2.5cm, 50% air–50% CO_2 is 61.50 kV/cm while AC voltage is 43.61 kV/cm with a difference is 28%. It shows the sphere-sphere configuration can withstand higher voltage if the gap distance increase.



a)

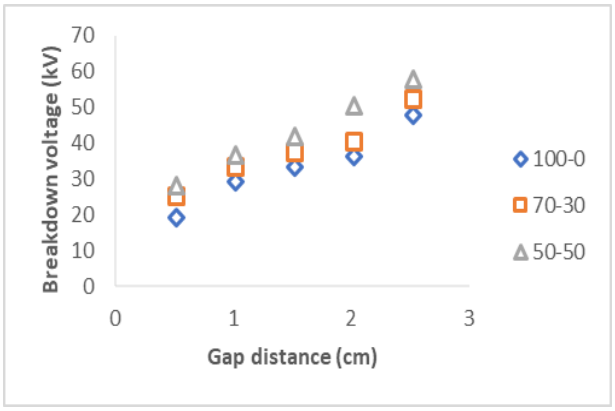


b)

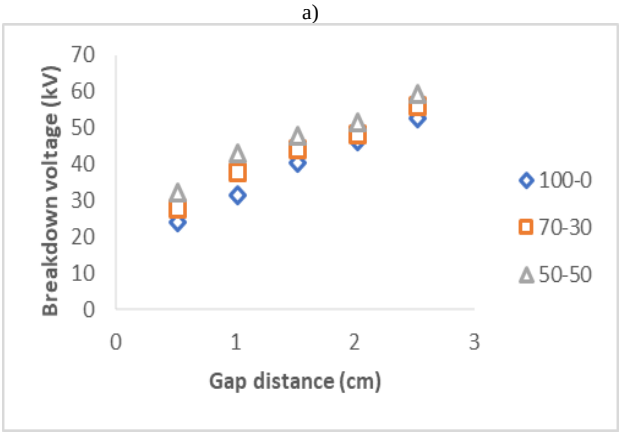
Fig 5: Maximum electric field against gap distance. a) AC, b) DC

3.2. Rod-rod configuration

Based on the Figure 6, the pattern of U_{50} rod-rod configuration is similar to a U_{50} of sphere-sphere configuration. The difference between these two configurations is about 34%, where lower voltages are obtained with rod-rod configuration. This happened due to rod-rod configuration only required less voltage to reach its breakdown. Rod-rod configuration has a smaller tip radius, and hence higher electric field with the same voltage as compared with sphere-sphere configuration. Hence, lower voltage is required for breakdown to happen. The U_{50} for AC is lower than DC voltage but the result not much different. In 5 level gap distance, the U_{50} of AC is 100% air–0% CO_2, 20.1–48.53 kV, 70% air–30% CO_2 is 25.96–53.22 kV and 50% air-50% CO_2 is 28.9–58.88 kV. For the DC voltage, 100% air–0% CO_2 is 24.72–53.31 kV, 70% air–30% CO_2 is 28.62–56.95 kV and 50% air-50% CO_2 is 32.95–60.28 kV. Therefore, the difference of breakdown between AC and DC is around 10%.



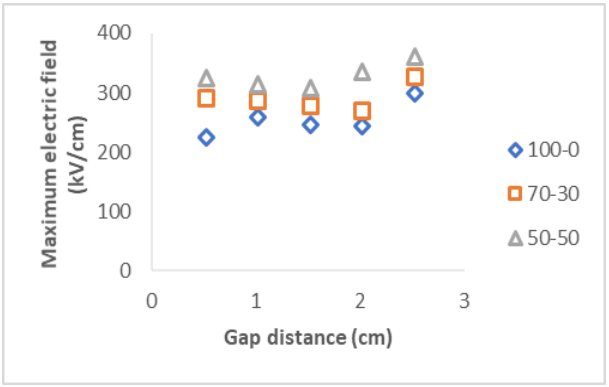
a)



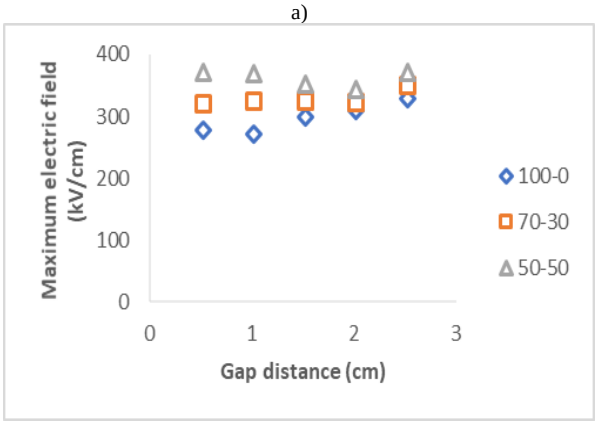
b)

Fig 6: Breakdown voltage against gap distance. a) AC, b) DC

Figure 7 shows the E_{max} for AC and DC voltage of rod-rod configuration. It is different with sphere-sphere configuration where E_{max} is higher due to the geometry of the electrode. Even though the rod-rod configuration is a symmetric arrangement, the E_{max} between the rods is much more non-uniform than in the sphere-sphere configuration. The other reason was found that E_{max} produced by uniform fields is lower than the non-uniform field. This is because the lines of the electric field is more spread out towards a weaker electric field. In addition, the other reason is about that E_{max} could be caused by the space charge where a uniform field with a space charge may not remain uniform ideally [20]. Breakdown voltage of AC for 100% air–0% CO_2 is 228.55–302.40 kV/cm, 70% air–30% CO_2 is 295.19–331.62 kV/cm and 50% air-50% CO_2 is 328.62–365.02 kV/cm. For the DC voltage, 100% air–0% CO_2 is 281.09–332.18 kV/cm, 70% air–30% CO_2 is 325.43–354.86 kV/cm and 50% air-50% CO_2 is 374.67–375.61 kV/cm. The graph also shows the value of E_{max} of 50% air-50% CO_2 and 70% air–30% CO_2 decrease at first fourth gap distance but on 2.5cm the value increase while for 100% air–0% CO_2 linearly increase without dropped at any gap distance.



a)

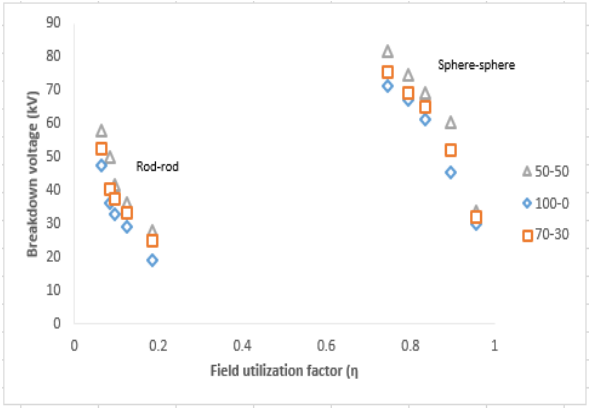


b)

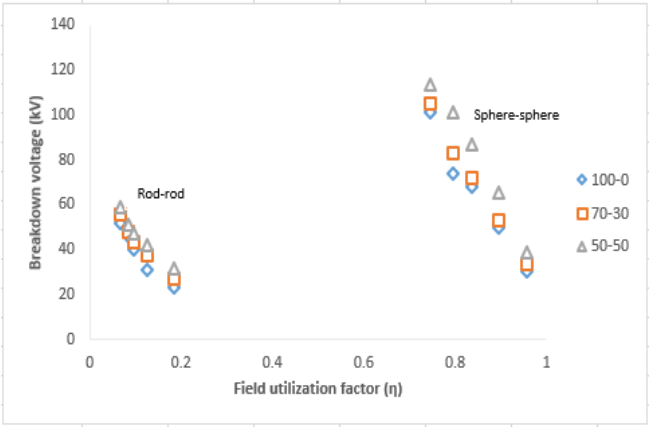
Fig 7: Maximum electric field against gap distance. a) AC, b) DC

3.3. Field utilization factor under AC and DC

Figure 8 illustrates the field utilization factor of AC and DC for sphere-sphere and the rod-rod configuration. It shows that the non-uniform field contributes to higher E_{max} which provided lower breakdown voltages for all mixtures. In theory, the higher of field utilization factor will be providing the higher of U_{50}. In this experiment, for a certain electrode pairs, the U_{50} decreases with increment of field utilization factor. This is due to the fact that when the gap distance between the electrodes gets higher, the field uniformity will become lesser, and hence lower field utilization factor. As the result, since gap distance increases, U_{50} will also increase. The figure also shows that sphere-sphere electrode configuration provide higher field utilization factor, which is more uniform as compared to rod-rod electrode configuration. This is the reason why IEC has adopted sphere gaps as a calibration device since it has given more uniform field and linearity is maintained even the gap distance is increasing [16]. Plus, the rod-rod configuration are not allowed to be used as measuring devices because of the large scatter of distructive discharge voltage and also strong influence of the humidity [21].



a)



b)

Fig 8: Breakdown voltage against field utilization factor of sphere-sphere and rod-rod a) AC, b) DC

4. Conclusion

The goal of this work is to investigate the breakdown voltage (U_{50}) and the electric field of air-CO_2 with three types of mixtures ratio under AC and DC voltage. The gas pressure is fixed at 2 bar (abs). Two different electrode configurations with 5 level of gap distances were used to provide a different uniformities field. The electric field acquired from U_{50} and simulated using finite element methods. It appears that the U_{50} of the DC voltage is higher than the AC voltage. In addition, the breakdown voltage of the sphere-sphere electrode is higher than the rod-rod electrode in all gap distance and mixing ratio. In other words, U_{50} is affected by variation in gap length and mixing ratio which is when the gap distances and mixing ratio increase, the breakdown voltage will be increasing. By comparing these mixing ratios, the highest U_{50} was discovered by 50% air-50% CO_2, second is 70% air–30% CO_2 and followed by 100% air-0% CO_2. The pure air was the lowest U_{50} for all the time. The distributions of the E_{max} are strongly affected by the gap distance and mixing ratio. The E_{max} of the sphere-sphere electrode is a lower than the rod-rod electrode with a very high field utilization factor value. From the result, the sphere-sphere electrode is more uniform field than the rod-rod electrode. Moreover, the sphere-sphere electrodes have shown the highest withstand capacity of breakdown since they provided less stress to the field gaps.

Acknowledgement

The authors wish to thank Universiti Tun Hussein Onn Malaysia (UTHM) for the approved Postgraduate Research Grant (GPPS) number U960, as well as Centre for Graduate Studies (CGS) and Research Management Centre (RMC), UTHM for providing the financial support for this publication.

References

[1] Beroual A & Coulibaly ML (2016), Experimental investigation of breakdown voltage of CO2, N2 and SF6 gases, and CO2-SF6 and N2–SF6 mixtures under different voltage waveforms. IEEE Int. Power Modul. High Volt. Conf., pp. 292–295.

[2] Guo C, Zhang Q, You H, Ma J, Li Y, Wen T & Qin Y (2017), Influence of electric field non-uniformity on breakdown characteristics in SF6/N2 gas mixtures under lightning impulse. IEEE Journals Mag., vol. 24, no. 4, pp. 2248–2258.

[3] Meijer S, Smitt JJ & Girodet A (2006), Comparison of the breakdown strength of N2, CO2 and SF6 using the extended up-and-down method. IEEE 8th Int. Conf. Prop. Appl. Dielectr. Mater., pp. 653–656.

[4] Ambo NF, Zainuddin H, Kamarudin MS, WJM & Zahari A (2018), Finite element analysis of maximum electric field for air break-

down under various electrode configurations. Indones. J. Electr. Eng. Comput. Sci., vol. 10, no. 2, pp. 416–425.
[5] Kamarudin MS, Haddad A, Kok BC & Jamail NAM (2017), Pressurized CF3I-CO2 Gas Mixture under Lightning Impulse and its Solid By-Products, vol. 7, no. 6, pp. 3088–3094.
[6] Hu Zhoa HL & Yunkun Deng (2017), Study of the synergistic effect in dielectric breakdown property of CO2–O2 mixtures. Am. Inst. Phys., vol. 7.
[7] Howard Cohen E (1956), The electric strength of highly compressed gases. Proc. IEE - Part A Power Eng., vol. 103, no. 7, pp. 57–68.
[8] Seeger M, Stoller P & Garyfallos A (2017), Breakdown fields in synthetic air, CO2, a CO2 / O2 mixture, and CF4 in the pressure range 0.5-10 MPa. IEEE Trans. Dielectr. Electr. Insul., vol. 24, no. 3, pp. 1582–1591.
[9] Chen Z, Niu C, Zhang H, Sun H, Wu Y, Yang F, Rong M & Xu Z (2015), Investigation on the reduced critical breakdown field of hot CO2 gas and CO2-based mixtures. 3rd Int. Conf. Electr. Power Equip. – Switch. Technol., pp. 36–39.
[10] Mashidori H, Ogawa T, Izawa Y & Nishijima K (2012), Sparkover characteristics of air–CO2 mixed gas in nonuniform field gap. IEEE Int. Symp. Electr. Insul., pp. 38–42.
[11] Kamarudin MS, Albano M, Coventry P, Harid N & Haddad A (2010), A survey on the potential of CF3I gas as an alternative for SF6 in high voltage application. Proccedings Univ. Power Eng. Conf.
[12] Chen L, Widger P, Kamarudin M, Griffiths H & Haddad A (2016), CF3I Gas Mixtures: Breakdown Characteristics and Potential for Electrical Insulation. IEEE Trans. Power Deliv., vol. PP, no. 99, p. 1.
[13] Chen L, Griffiths H, Haddad A and Kamarudin MS (2016), Breakdown of CF3I Gas and its Mixtures under Lightning Impulse in Coaxial-GIL Geometry. IEEE Trans. Dielectr. Electr. Insul., vol. 23.
[14] Sharif MHM, Jamail NAM, Othman NA & Kamarudin MS (2017), Analysis of Electric Field and Current Density on XLPE Insulator. Int. J. Electr. Comput. Eng., vol. 7, no. 6, p. 3095.
[15] Luqman HM, Baharom MNR, Ahmad H & Ullah I (2017), Planning and Conducting Magnetic Field Level Measurement from Overhead Transmission Line. Int. J. Electr. Comput. Eng., vol. 7, no. 6, pp. 3124–3132.
[16] European Commitee for Electrotechnical Standardization, BS EN 60060-1:2010 High-voltage test techniques, Part 1: General definition and test requirements. BSI Standards Publication, 2010.
[17] Abd-Rahman R, Haddad A, Kamarudin MS, Yousof MFM & Jamail NAM (2017), Dynamic modelling of polluted outdoor insulator under wet weather conditions. PECON 2016 - 2016 IEEE 6th Int. Conf. Power Energy, Conf. Proceeding, pp. 610–614.
[18] Kamarudin MS, Radzi NH, Zulkifli SA & Abd-Rahman R (2014), Experimental Investigation on Air Breakdown under Lightning Impulses with Various Electrode Configurations. 3rd IET International Conference on Clean Energy and Technology (CEAT) 2014, pp. 1–5.
[19] Sadaoui F & Beroual A (2013), Surface discharges over insulators of various materials in presence of SF6, CO2, N2 and SF6-CO2 and SF6-N2 mixtures under DC voltage. Annu. Rep. Conf. Electr. Insul. Dielectr. Phenom., pp. 472–475.
[20] Ravindra A & Wolkgang M, High Voltage and Electrical Insulation Engineering. John Wiley & Sons. Inc, Hoboken, New Jersey, (2011).
[21] Dieter K and Feser K, High Voltage Test Technique, 2nd ed. Reed Educational and Professional Publishing (2001).