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Electric Field and Current Density Performance Analysis of Sf_6, C_4f_8 And Co_2 Gases As An Insulation

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Abstract. SF_6 gases are not only widely used as an insulating component in electric power industry but also as an arc extinguishing performance in high voltage (HV) gas-insulated circuit breaker (GCB). SF_6 gases is generally used in the production of semiconductor materials and devices. Though these gasses is widely used in many application, the presences of temperature hotspot in the insulations may affect the insulation characteristics particularly electric field and current density. Therefore, it is important to determine the relationship between electric field and current density of gasses used in the insulator in the presence of hotspot. In this paper, three types of gases in particular Sulphur Hexafluoride (SF_6), Octafluorocylobutane (C_4F_8), and Carbon Dioxide (CO_2) was used in the insulator for gas insulation with the presence of two hotspots. These two hotspost were detected by referring the rising temperature in the insulator which are 1000 and 2000 Kelvin temperature for hotspot 1 and hotspot 2, respectively. From the simulation results, it can be concluded that Sulphur Hexafluoride (SF_6) is the best choice for gas insulation since it had the lowest current density and electric field compared to Octafluorocylobutane (C_4F_8), and Carbon Dioxide (CO_2). It is observed that the maximum current density and electric field for SF_6 during normal condition are 358.94 x 10^3 V/m and 0.643 x 10^9 A/m^2, respectively. Meanwhile, during temperature rising at hotspot 1 and hotspot 2, SF_6 also had lowest current density and electric field compared to the other gasses where the results for E_{max} and J_{max} at hotspot 1 are 322.34 x 10^3 V/m and 1.934 x 10^9 A/m^2, respectively; While, E_{max} and J_{max} at hotspot 2 are 259.77 x 10^3 V/m and 2.824 x 10^9 A/m^2. The results of this analysis can be used to find the best choices of gas that can be used in the insulator.

1. Introduction

Dielectric gasses are utilized as electrical covers as a part of high voltage applications, such as transformer, circuit breakers, switchgear and etc. The gas that most commonly used are Sulphur Hexafluoride (SF_6), Octafluorocylobutane (C_4F_8), Carbon Dioxide (CO_2) and etc. SF_6 is widely use during the extinction phase for arc quenching and also gas insulating in high voltage (HV) gas circuit breaker (GCB). Furthermore, C_4F_8 is an organofluorine compound which enjoys several niche applications. It is related to cyclobutane by replacement of all C-H bonds with C-F bonds. Application that usually use with the gases is a production of semiconductor materials and devices. Octafluorocyclobutane (C_4F_8) serves as a deposition gas and etchant [1]. CO_2 is an odorless and colorless vital in earth. It present in the atmosphere and formed during respiration.

Electric field is a component of the electromagnetic field. It is a vector field and is generated by electric charges or time-varying magnetic fields, as described by Maxwell's equations [2]. To design an electrical equipment, current density is most important which is need to be emphasized. The circuit performance is fully depends on the designed current level. Current density also an important parameter in Ampere's Circuital Law which is relates current density to magnetic field [3].

Therefore this paper presents the electric field and current density performance of three gasses in particular Sulphur Hexafluoride (SF_6), Octafluorocylobutane (C_4F_8), and Carbon Dioxide (CO_2).

2. Methodology

This paper simulates the dielectric gasses configuration effect on electric field and current density according to electrical conductivity and temperature. Quickfield Software Version 6.1 was used to simulate the electric field and current density between different characteristic of dielectric gasses which is Sulphur Hexafluoride (SF_6), Octafluorocylobutane (C_4F_8), and Carbon Dioxide (CO_2).

It is important highlighting that the nformation and properties about dielectric gasses need to be studied and thoroughly investigate the advantages, disadvantages, physical properties of gasses, conductivity of gasses, and temperature of gasses in order to keep developing and design the insulator modeling without error.

Figure 1 shows the flowchart of Quickfield analysis of HVDC configuration for the overall process. The flowchart shows all the steps involving during the simulation process from creating, simulating, analyzing and solving a problem in Quickfield software.

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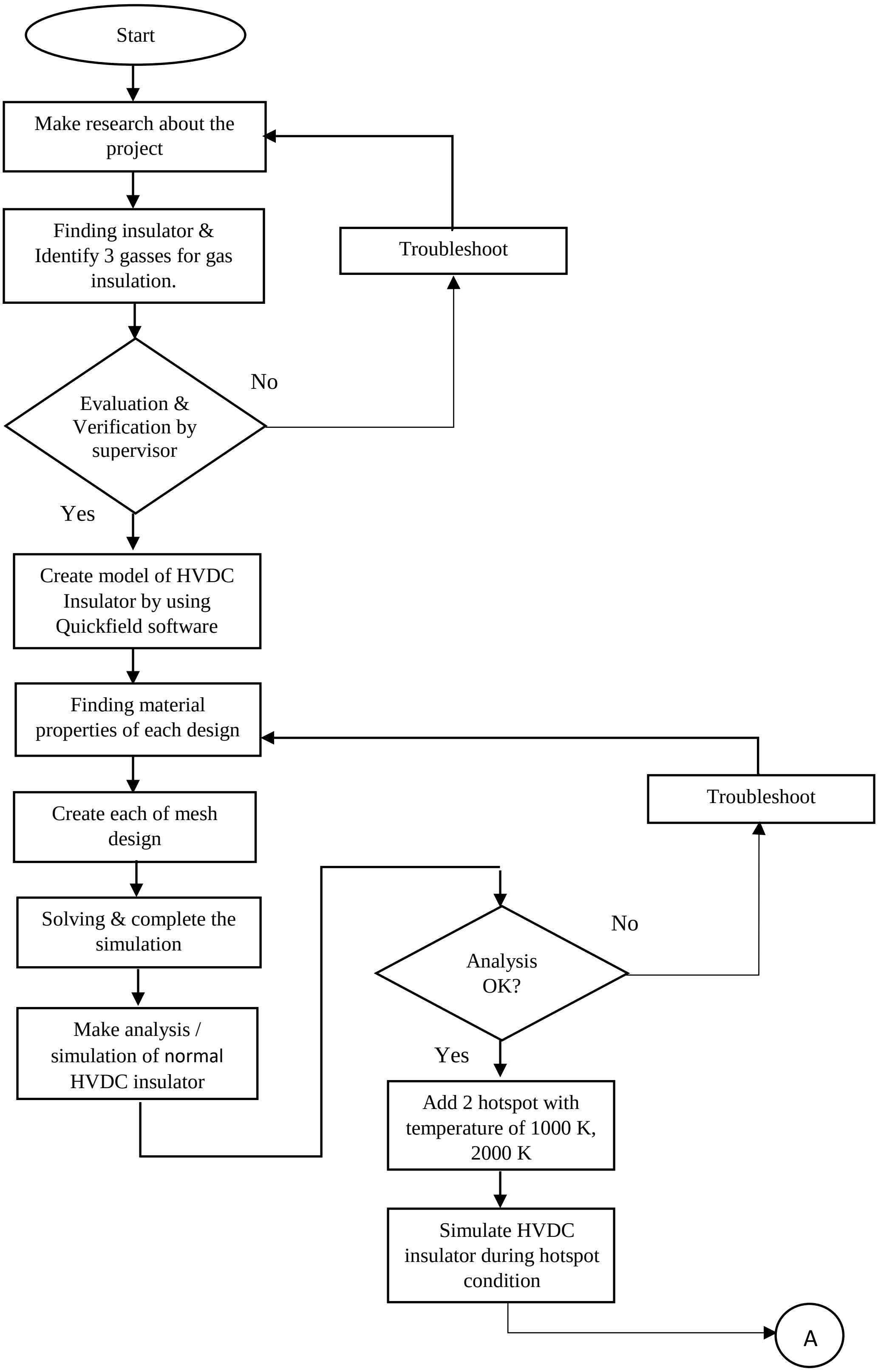

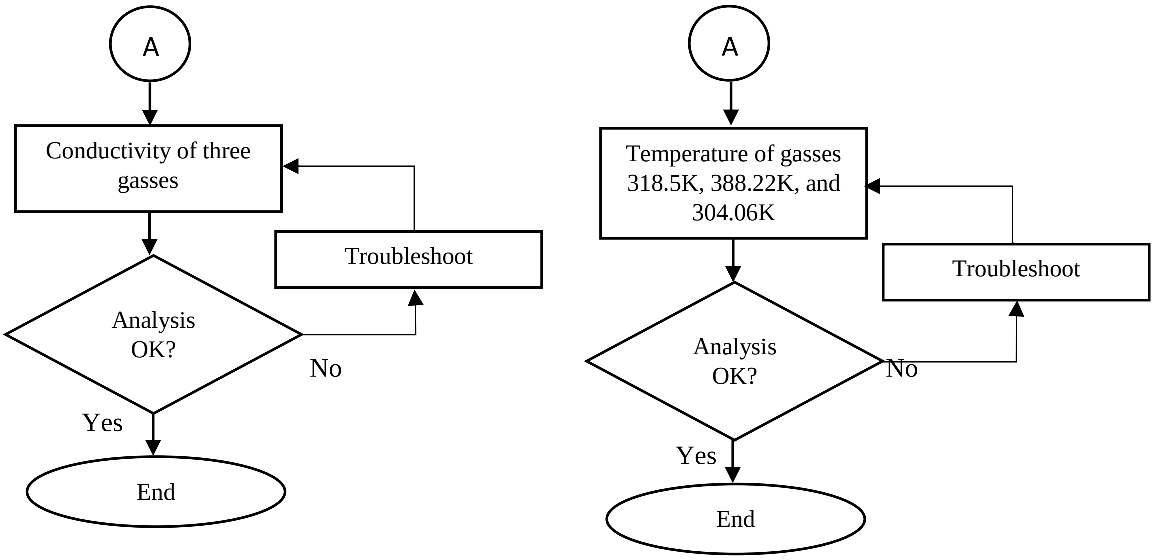

Figure 1: Flowchart of Quickfield analysis of HVDC configuration for the overall process

3. Results & Discussion

Properties of the problem that has been used for simulation on the 3 gasses are electrical conductivity, temperature, and injected voltage. Table 3.1 shows properties for the aforementioned gasses. It is worth highlighting that the insulator was injected with 33 kV with the area of hotspot 1 and hotspot 2 is same but with different temperature value.

Table 1. Properties of problem for 3 Gasses

Properties	**Type of Gasses**		
	Sulphur Hexafluoride (SF_6)	**Octaflurocyclobutane (C_4F_8)**	**Carbon Dioxide (CO_2)**
Electrical Conductivity	1.79 x 10^3 S/m	2.98 x 10^3 S/m	3.5 x 10^3 S/m
Temperature	318.5 Kelvin	388.2 Kelvin	304. 6 Kelvin
High Voltage	33 kV	33 kV	33 kV
Ground	0 V	0 V	0 V
Hotspot 1 : (a) **Temperature** (b) **Area**	1000 Kelvin 0.0050265 m^2	1000 Kelvin 0.0050265 m^2	1000 Kelvin 0.0050265 m^2

Hotspot 2 : **(a) Temperature** **(b) Area**	2000 Kelvin 0.0050265 m^2	2000 Kelvin 0.0050265 m^2	2000 Kelvin 0.0050265 m^2

3.1. HVDC Insulator during Normal Condition

3.1.1. Electrical Field and Current Density of Sulphur Hexafluoride (SF_6).

Figure 2 shows electrical field of Sulphur Hexafluoride (SF_6) in normal condition. Those arrow explained direction of electric field in the insulator. Electrical field in the middle area between two electrodes had highest value in units Volt/meter. Minimum and maximum value was 192.17 x 10^3 V/m and 358.94 x 10^3 V/m.

Figure 3 shows current density of Sulphur Hexafluoride (SF_6) in normal condition. Current density was focused in the middle of two electrodes. Units for current density are Ampere/meter^2. Minimum and maximum value was 0.344 x 10^9 A/m^2 and 0.643 x 10^9 A/m^2.

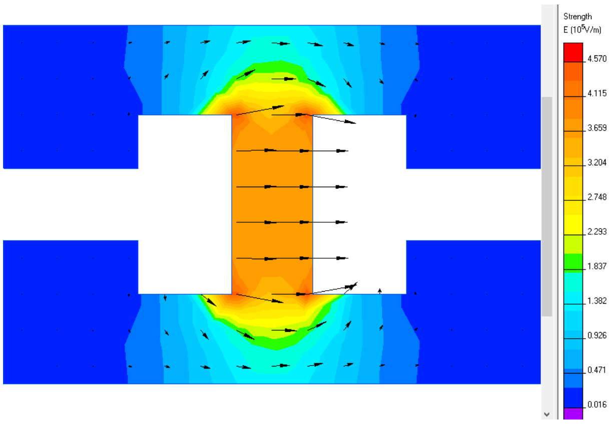

Figure 2: Electrical Field of SF_6 in normal condition

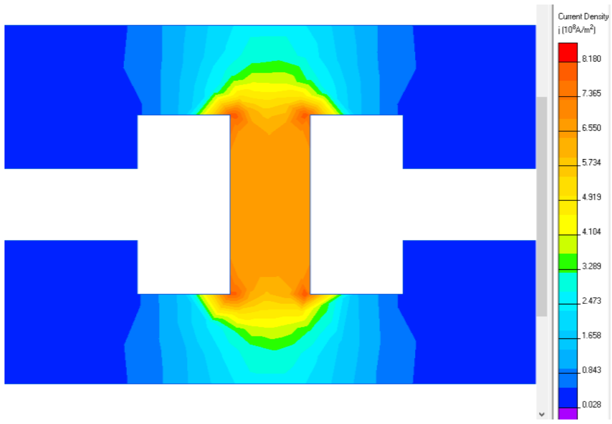

Figure 3: Current Density of SF_6 in normal condition

3.1.2 Electrical Field and Current Density of Octaflurocyclobutane

Figure 4 shows electrical field of Octaflurocyclobutane (C_4F_8) in normal condition. Those arrow explained direction of electric field in the insulator. Electrical field in the middle area between two electrodes had highest value in units Volt/meter. Minimum and maximum value was 191.82 x 10^3 V/m and 366.66 x 10^3 V/m.

Figure 5 shows current density of Octaflurocyclobutane (C_4F_8) in normal condition. Current density was focused in the middle of two electrodes. Units for current density are Ampere/meter^2. Minimum and maximum value was 0.492 x 10^9 A/m^2 and 1.025 x 10^9 A/m^2.

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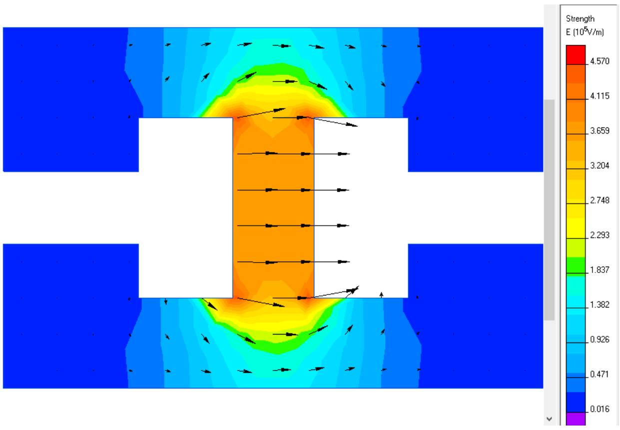

Figure 4: Electrical Field of C_4F_8 in normal condition

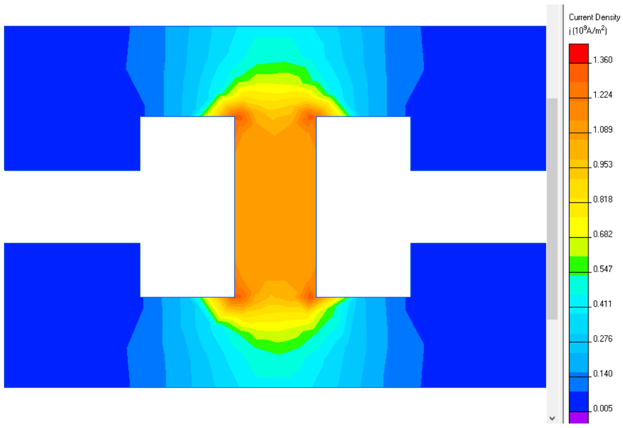

Figure 5: Current Density of C_4F_8 in normal condition

3.1.3 Electrical Field and Current Density of Carbon Dioxide

Figure 6 shows electrical field of carbon dioxide (CO_2) in normal condition. Those arrow explained direction of electric field in the insulator. Electrical field in the middle area between two electrodes had highest value in units Volt/meter. Minimum and maximum value was 182.05 x 10^3 V/m and 433.10 x 10^3 V/m.

Figure 7 shows current density of carbon dioxide (CO_2) in normal condition. Current density was focused in the middle of two electrodes. Units for current density are Ampere/meter^2. Minimum and maximum value was 0.669 x 10^9 A/m^2 and 1.478 x 10^9 A/m^2.

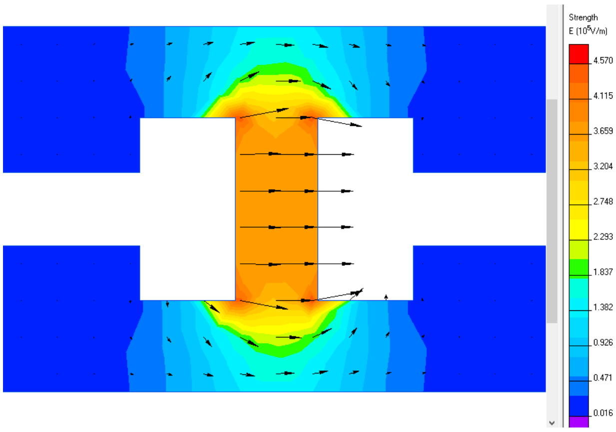

Figure 6: Electrical Field of CO_2 in normal condition

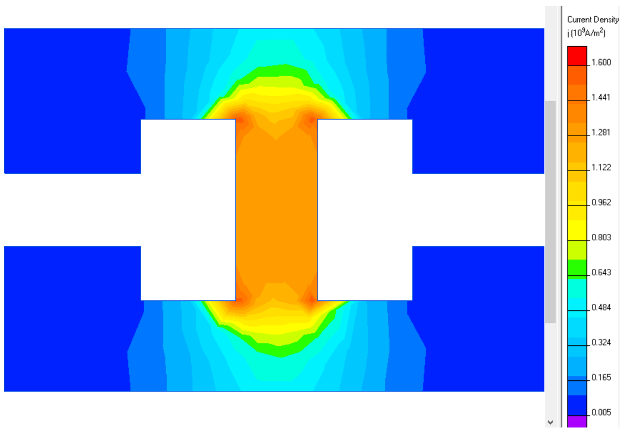

Figure 7: Current Density of CO_2 in normal condition

3.2 HVDC Insulator on Presence of Hotspot

Hotspot is an area which had high temperature occur during gas insulation. The temperature will be rising at certain temperature. For this simulation, had two hotspot with 1000 Kelvin and 2000 Kelvin. Both hotspot had same area. Three type of gasses was simulated was made by using Quickfield with this two hotspot. Figure 8 shows two hotspot in the insulator. Hotspot 1 was on top side while hotspot 2 occur on bottom side, both were place at the middle area between two electrodes.

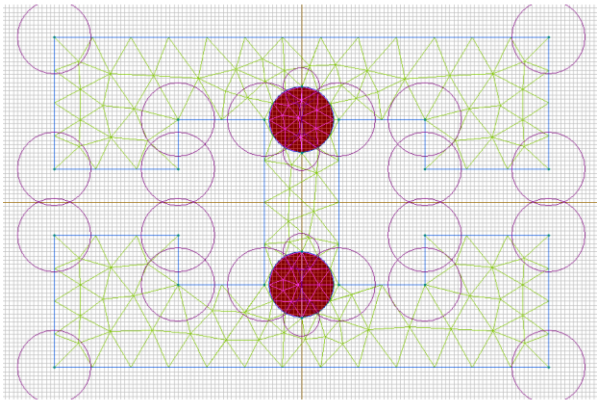

Figure 8: Two hotspot in the insulator

Figure 9 (a) and (b) shows properties of hotspot 1 and hotspot 2. The figure explained that temperature is rising until maximum temperature which is 1000 Kelvin for hotspot 1. Hotspot 2 showed maximum temperature is 2000 Kelvin.

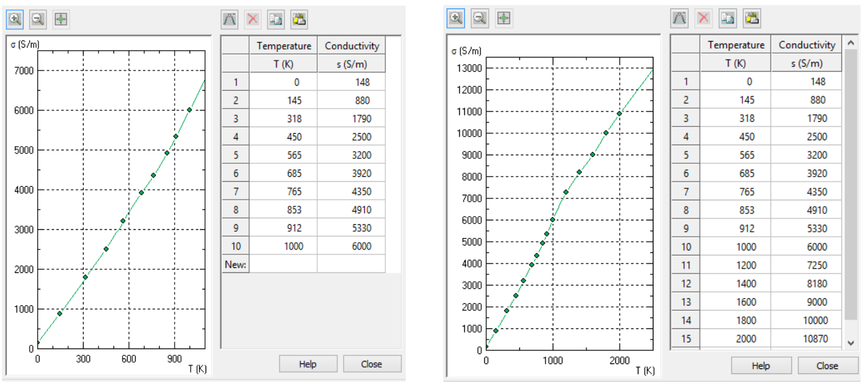

Figure 9: Properties of hotspot (a) Hotspot 1, (b) Hotspot 2

3.2.1 Electrical Field and Current Density of Sulphur Hexafluoride

Figure 10 shows electrical field of Sulphur Hexafluoride (SF_6) in hotspot condition. Those arrow explained direction of electric field in the insulator which is from 33kV side to grounding. Those hotspot give an effect to electrical field at in the middle of two electrodes. Minimum and maximum value of electrical field for hotspot 1 were 157.82 x 10^3 V/m and 322.34 x 10^3 V/m and for hotspot 2 were 121.81 x 10^3 V/m and 259.77 x 10^3 V/m.

Figure 11 shows current density of Sulphur Hexafluoride (SF_6) in hotspot condition. Current density was highest at the hotspot 1 side. Minimum and maximum value of current density for hotspot 1 were 0.947 x 10^9 A/m^2 and 1.934 x 10^9 A/m^2 and for hotspot 2 were 1.326 x 10^9 A/m^2 and 2.824 x 10^9 A/m^2.

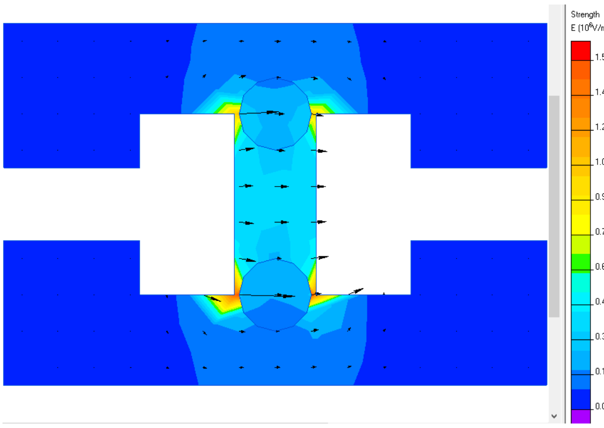

Figure 10: Electrical Field of SF_6 in hotspot condition

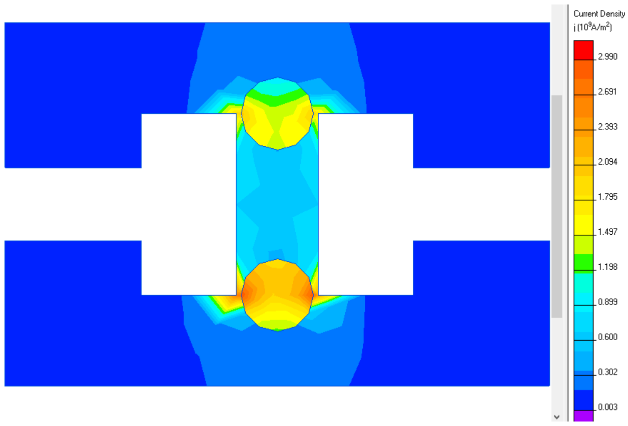

Figure 11: Current Density of SF_6 in hotspot condition

3.2.2 Electrical Field and Current Density of Octaflurocyclobutane

Figure 12 shows electrical field of Octaflurocyclobutane (C_4F_8) in hotspot condition. Those arrow explained direction of electric field in the insulator which is from 33kV side to grounding. Those hotspot give an effect to electrical field at in the middle of two electrodes. Minimum and maximum value of electrical field for hotspot 1 were 177.86 x 10^3 V/m and 355.43 x 10^3 V/m and for hotspot 2 were 143.75 x 10^3 V/m and 299.61 x 10^3 V/m.

Figure 13 shows current density of Octaflurocyclobutane (C_4F_8) in hotspot condition. Current density was highest at the hotspot 1 side. Minimum and maximum value of current density for hotspot 1 were 1.245 x 10^9 A/m^2 and 2.488 x 10^9 A/m^2 and for hotspot 2 were 1.850 x 10^9 A/m^2 and 3.856 x 10^9 A/m^2.

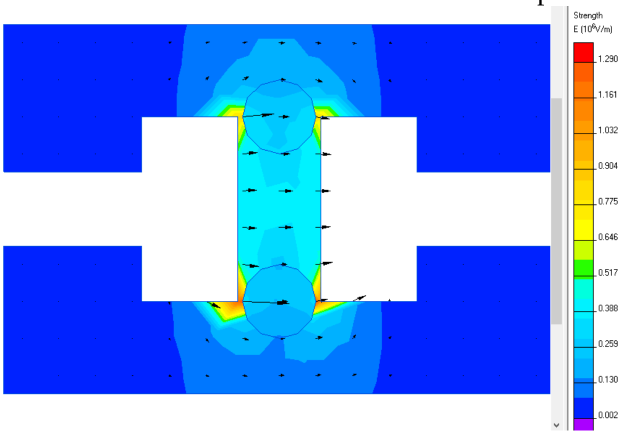

Figure 12: Electrical Field of C_4F_8 in hotspot condition

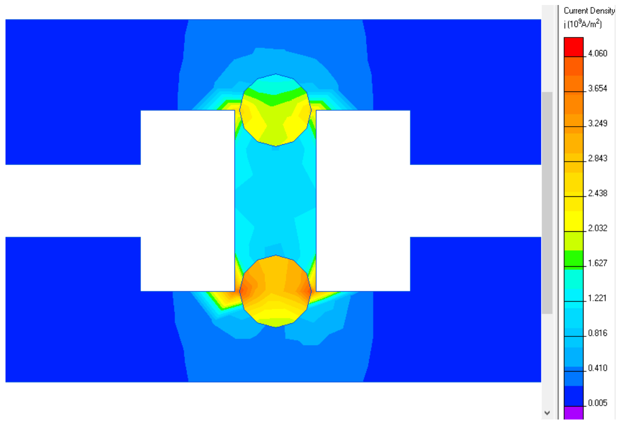

Figure 13: Current Density of C_4F_8 in hotspot condition

3.2.3 Electrical Field and Current Density of Carbon Dioxide

Figure 14 shows electrical field of Carbon Dioxide (CO_2) in hotspot condition. Those arrow explained direction of electric field in the insulator which is from 33kV side to grounding. Those hotspot give an effect to electrical field at in the middle of two electrodes. Minimum and maximum value of electrical field for hotspot 1 were 181.10 x 10^3 V/m and 359.54 x 10^3 V/m and for hotspot 2 were 151.70 x 10^3 V/m and 311.10 x 10^3 V/m.

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Figure 15 shows current density of Carbon Dioxide (CO_2) in hotspot condition. Current density was highest at the hotspot 1 side. Minimum and maximum value of current density for hotspot 1 were 1.399 x 10^9 A/m^2 and 2.772 x 10^9 A/m^2 and for hotspot 2 were 2.039 x 10^9 A/m^2 and 4.263 x 10^9 A/m^2.

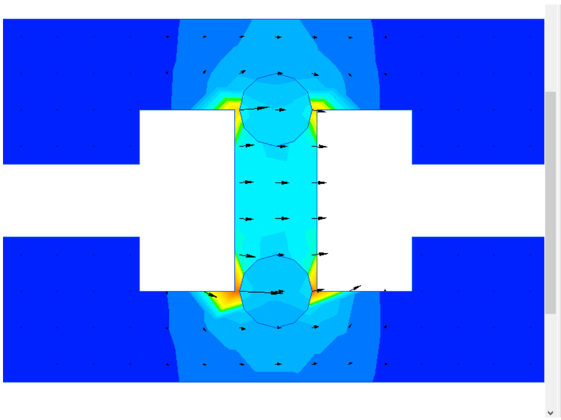


Figure 14: Electrical Field of CO_2 in hotspot condition

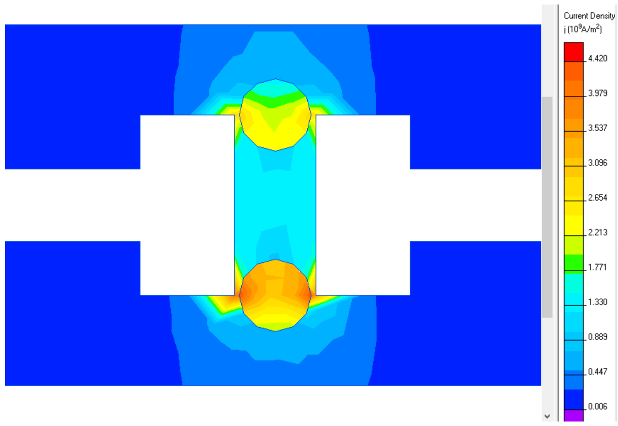


Figure 15: Current Density of CO_2 in hotspot condition

3.3 Comparison Electrical Field and Current Density of Gasses during Normal and Hotspot Condition
Based from the results, SF_6 obtain lowest current density in all condition. While, CO_2 obtain highest value of current density in all condition. Besides, Table 2 shows that when temperature is increasing in the hotspot area, current density on the hotspot area was decreasing

Table 2. Comparison between electric field and current density at normal, hotspot 1 and hotspot 2 of HVDC gas insulation

Gasses Condition	**Electric Field, E (V/m)**		**Current Densities, J(A/m^2)**	
	Minimum (E_{min})	**Maximum (E_{max})**	**Minimum (J_{min})**	**Maximum (J_{max})**
Sulphur Hexafluoride SF_6				
Normal	192.17 x10^3	358.94 x10^3	0.344 x10^9	0.643 x10^9
Hotspot 1	157.82 x10^3	322.34 x10^3	0.947 x10^9	1.934 x10^9
Hotspot 2	121.81 x10^3	259.77 x10^3	1.326 x10^9	2.824 x10^9
Octaflurocyclobutane (C_4F_8)				
Normal	181.92 x10^3	366.66 x10^3	0.492 x10^9	1.025 x10^9
Hotspot 1	177.86 x10^3	355.43 x10^3	1.245 x10^9	2.488 x10^9

Hotspot 2	143.75 x10^3	299.61 x10^3	1.850 x10^9	3.856 x10^9
Carbon Dioxide (CO_2)				
Normal	182.05 x10^3	433.10 x10^3	0.669 x10^9	1.478 x10^9
Hotspot 1	181.10 x10^3	359.94 x10^3	1.399 x10^9	2.772 x10^9
Hotspot 2	151.70 x10^3	311.10 x10^3	2.039 x10^9	4.263 x10^9

Figure 16 shows current density against electrical field graph during normal condition. Based on the graph, carbon dioxide (CO_2) had highest value of current density and electrical field, while Sulphur Hexafluoride (SF_6) was lowest value of current density and electrical field. The data on the graph was collected from Table 4.2. The gasses can carry a current when the current density is lower. Therefore, higher electrical field in the insulator were produced high current density.

Value of current density in the hotspot 2 was smaller than in hotspot 1. Figure 17 (a) and (b) shows current density against electrical field graph during hotspot 1 and hotspot 2. Comparison from both graph was value of current density in the hotspot 2 was smaller than in hotspot 1. All the gasses in hotspot 1 had slight different value of current density. Carbon dioxide had the highest maximum current density in hotspot 1 and hotspot 2 compared to SF_6 and C_4F_8. When temperature is rising during gas insulation was affect the current density and electrical field of the gasses.

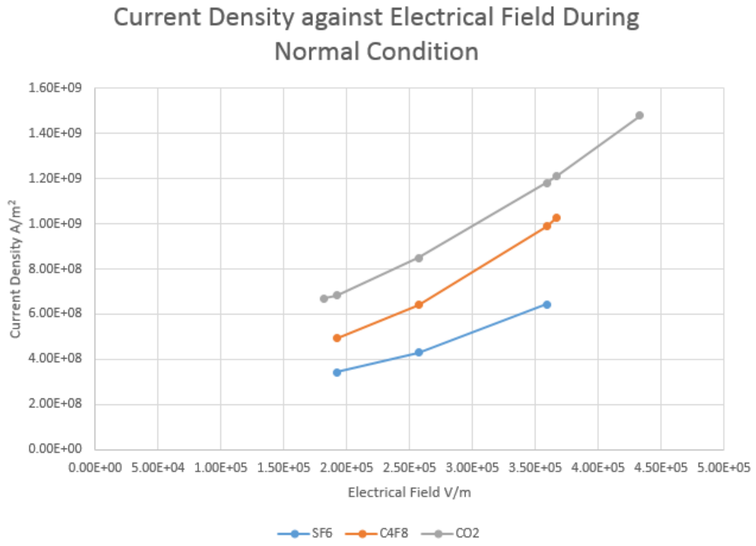
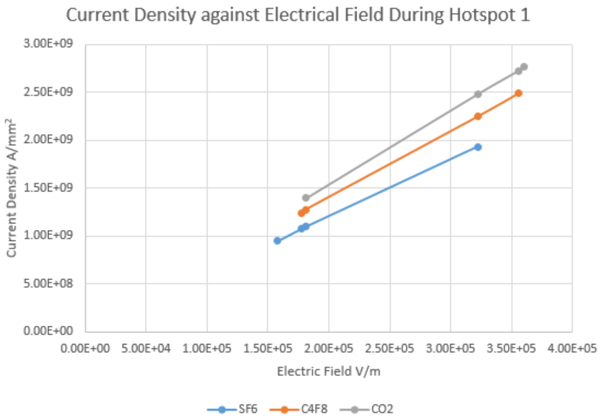


Figure 16: Current Density against Electrical Field in Normal Condition



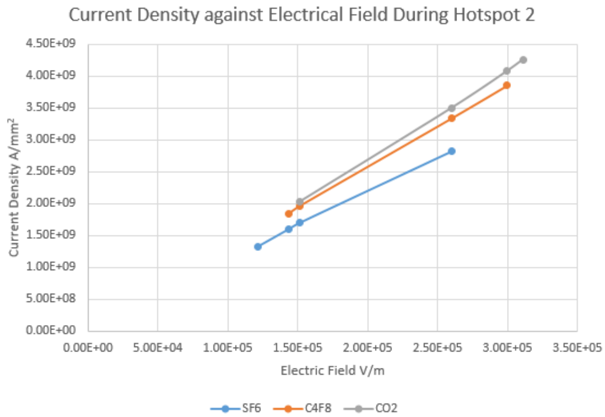


Figure 17(a): Current Density against Electrical Field in Hotspot 1
Figure 17(b): Current Density against Electrical Field in Hotspot 2

4.0 Conclusions

The main goal of the current study was to design HVDC gas insulator and evaluate the electric field and current density in normal insulator and defect insulator. The defect insulator was analyzed by varying temperature of hotspot during insulation. Three gasses were used and compared the electrical field and current density of gas insulator. Those gasses were Sulphur Hexafluoride (SF_6), Octafluorocylobutane (C_4F_8), and Carbon Dioxide (CO_2). Applied voltage was fixed at 33kV. Electrical field and current density of HVDC insulator were simulated using Quickfield Software.

From this research, several theories can be related to existing work. Theory part of the configurations described HVDC gas insulator configurations, the electric field, current density and effect of electric field and current density when insulator has been broken. The simulation of the HVDC gas insulator configuration is very important to evaluate the electric field and current density produced on the model. The methodology and process to get the simulation work already described in the project.

By using Quickfield software, the results has been analyzed the relationship between temperature of the hotspot occur in the insulator, maximum value of electrical field, maximum value of current density, electric field and current density pattern depends on hotspot temperature and type of gasses used in the insulator. Thus conclusion of this simulation can be identified.

Sulphur Hexafluoride (SF_6) is the best choice for gas insulation because of it had lowest current density and electric field compared to Octafluorocylobutane (C_4F_8), and Carbon Dioxide (CO_2). E_{max} and J_{max} for SF6 during normal condition are 358.94 x 10^3 V/m and 0.643 x 10^9 A/m^2. Furthermore, during temperature rising at hotspot 1 and hotspot 2 also had lowest current density and electric field compared to the other gasses. Results for E_{max} and J_{max} at hotspot 1 are 322.34 x 10^3 V/m and 1.934 x 10^9 A/m^2. While, E_{max} and J_{max} at hotspot 2 are 259.77 x 10^3 V/m and 2.824 x 10^9 A/m^2.

Simulation results shows that when temperature rising in certain part in the insulator, it produced lower E_{max} and higher J_{max} compare to normal condition. This happens because conductivity of gas in the insulator is increasing at the area of hotspot. Therefore electric field is decreasing at the area of hotspot.

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Acknowledgments
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