

Comparison breakdown voltage Dichlorotrifluoroethane using N₂/CO₂ mixtures for new gas insulation material

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Abstract. SF₆ gas is gas as a filler material for insulating material in Gas Insulated Switchgear. The Kyoto Protocol issued amendments to limit and reduce the use of SF₆ gas in various applications, especially as gas isolation applications in substations because SF₆ is gas that contributes to the greenhouse effect, the occurrence of global warming and the cause of the ozone layer depletion. This study investigated the use of CF₃CHCl₂ gas as a new gas to replace SF₆ gas as insulation gas. The use of mixture N₂/CO₂ gas aimed to reduce the main gas concentrate if it leaked into the air and to reduce the cost of procuring the main gas material. The high voltage test showed that CF₃CHCl₂ gas mixed with N₂/CO₂ gas was able to withstand a breakdown voltage of 752-837 kV. The ability to withstand the breakdown voltage of the N₂ gas mixture is 9 kV-26.7 kV lower than the CO₂ gas mixture. The techno-economic value of the use of CF₃CHCl₂ gas mixed with N₂/CO₂ gas gives a cost of 5.18 times cheaper than the cost of procurement SF₆ gas. The use of CF₃CHCl₂ gas mixed with N₂ gas gives a cost of 1.01 times more expensive than a cost of the use of CF₃CHCl₂ gas mixed with CO₂. In the future, the priority gas is CF₃CHCl₂ gas as a new gas material that needs to be considered as a potential alternative gas to replace SF₆ gas.

1. Introduction

The Kyoto Protocol is a weather and climate convention agreement held in Kyoto Japan. The Convention produces an agreement that limits the use of sulfur hexafluoride (SF₆) gas [1], [2]. Restrictions on the use of SF₆ gas because the gas causes the effects of global warming and the greenhouse effect [3]–[5]. In addition, SF₆ gas also has global warming potential and potential for ozone depletion. Sulfur hexafluoride is a gas that belongs to the chlorofluorocarbon (CFC) family. Sulfur hexafluoride gas is used as a gas isolation medium because it has a capability that can be relied upon as a gas isolation medium, such as having a bond energy value of 1962 kJ / mol that can withstand a breakdown voltage of 665 kV, has chemical electronegativity in a bond of 3.98 and can extinguish an electric arc with fast [6]–[8]. Sulfur hexafluoride has a weakness, it has a global warming potential (GWP) value of 23,900 times compared to CO₂ gas and has 0.08 times the ozone-depleting potential (ODP) value of CO₂ gas [9], [10]. The Kyoto Convention recommended the use of gas belonging to the hydrochlorofluorocarbon (HCFC) family as an alternative to the use of gas which was included in the hydrofluorocarbon (HFC) family and the chlorofluorocarbon (CFC) family gas because they could damage the environment and atmosphere [11]–[13].



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Dichlorotrifluoroethane (CF_3CHCl_2) is one of the HCFC family gases that have the chemical name HCFC₁₂₃. CF_3CHCl_2 gas is recommended as an alternative substitute for SF_6 gas because it has the ability as a filler medium in substation equipment, namely as gas insulation and has the ability as an electric fire extinguisher.

This research paper discusses the capable of CF_3CHCl_2 gas as a potential gas to replace SF_6 gas as a gas isolation medium in high voltage equipment such as circuit breakers at high voltage substations. Another research objective is the use of calculations using binding energy as a basis for predicting the value of breakdown stresses in insulation materials, especially gas materials. The use of binding energy in insulating materials to make predictions about the ability of the material to breakdown stress has not been exploited. By using the binding energy method, prediction of the breakdown value of gas material can be made. State of the art or Positive responses and researchers who act proactively with the Kyoto Protocol are seen in [14]–[17]:

S. Meijer et al in 2006 with a research entitled "Comparison of the Breakdown Strength of N_2 , CO_2 and SF_6 using the Extended Up-and-Down Method".

Lin Xin et al in 2015 with a research entitled "Experiment on Breakdown Characteristics of SF_6/N_2 Mixtures in Short Gap".

Nechmi et al in 2016 with a research entitled "Fluoronitriles/ CO_2 Gas Mixture as Promising Substitute to SF_6 for Insulation in High Voltage Applications".

Widger et al in 2016 with a research entitled "Breakdown Performance of Vacuum Circuit Breakers Using Alternative $\text{CF}_3\text{I}-\text{CO}_2$ Insulation Gas Mixture".

The above research still relies on SF_6 gas as the main medium or other gas which is still a family gas group of CFCs and HFCs that are banned from the Kyoto protocol. This research discusses the use of CF_3CHCl_2 gas mixed with CO_2/N_2 gas as a gas isolation application. This research also discusses CF_3CHCl_2 gas mixed with CO_2/N_2 gas to obtain breakdown voltage and economic value for the procurement of goods. The test was carried out using CF_3CHCl_2 gas mixed with CO_2/N_2 gas. The amount of gas mixture used was 10-30% of space capacity. The purpose of mixing with CO_2/N_2 gas was to reduce the gas concentration of CF_3CHCl_2 if it leaked into the air and to reduce the cost of procuring gas for CF_3CHCl_2 .

The selection of CF_3CHCl_2 gas as a gas substitute for SF_6 cannot be separated from the nature and characteristics of the gas. SF_6 and CF_3CHCl_2 gas have elements of group VII-A (halogen) in compounds that form their chemical compounds. The constituent elements of SF_6 and CF_3CHCl_2 are elements F (Flor) and Cl (Chlor). The halogen group has the largest electronegativity value of the chemical structure currently available. Electronegativity values of halogen gas are Flor 3.98, Chlor 3.16, Brom 2.96, Iod 2.66, Astatine 2.2. Electronegativity of chemical molecules shows the ability of a gas to extinguish an electric arc. The greater the electronegativity value of a compound, the faster the gas material to extinguish an electric arc when the process of manoeuvring in the substation or the switching process.

N_2 and CO_2 gas are very abundant gas in the atmosphere. 78% of the gas in the atmosphere is N_2 . CO_2 gas also has a large amount in nature. CO_2 gas arises from processes carried out by humans and natural processes that occur in the air. The abundance of N_2 gas and CO_2 in the air can be used as the low-cost main gas mixture. The purpose of adding mixed gas was to anticipate if the gas leaked in the GIS and in the air. This anticipation is to hold the principle that no gas has a zero effect on atmospheric damage. In addition to the above objectives, it is also to reduce procurement costs so that the use of new gas materials has a techno-economic value that is beneficial to the user.

The focus of this research is the use of CF_3CHCl_2 gas as an alternative potential material to replace SF_6 gas and to test the ability of the gas when withstand breakdown voltage by mixing the potential gas CF_3CHCl_2 with N_2 or CO_2 gas. The purpose of mixing gas is to reduce procurement costs and CF_3CHCl_2 gas concentrates. Another focus of this research is the use of binding energy calculations as a method for predicting breakdown voltage values.

2. Methodology Research

2.1. Bond Energy method

The purpose of calculating the bond energy was to determine the ability of gas in withstanding breakdown voltage based on the bond energy of the test gas compound [18]–[20]. Bond energy shows the amount of energy required to release chemical bonds, can be used formula [21], [22]:

$$E_{\text{Bond}} = \Delta E_{\text{elstat}} + \Delta E_{\text{Pauli}} + \Delta E_{\text{oi}} \quad (1)$$

where E_{elstat} is the electrostatic interaction calculated using the unperturbed densities of the fragments, E_{Pauli} is the energy change caused by orthogonalization of fragment wave functions and E_{oi} arises from the recombination of the orthogonalized fragment orbitals to form the supermolecular wave function.

All compounds in the form of solid, liquid, or gas have binding energy. Bonding energy indicates the minimum energy needed to release chemical compounds in the material. The greater the binding energy, the greater the energy needed to penetrate or release the bonds in their chemical compounds. Calculation of binding energy also refers to the standard of bonding between molecules according to table 1.

Table 1. Bond Energy

| Bond | Energy (kjoule/mol) | Bond | Energy (kjoule/mol) |
|--------|------------------------|---------|------------------------|
| C--C | 348 | H--I | 299 |
| C--H | 413 | H--C | 413 |
| C--N | 293 | H--N | 391 |
| C--O | 358 | H--O | 366 |
| C--F | 485 | H--H | 436 |
| C—Cl | 328 | O—O | 145 |
| C—Br | 276 | O—H | 463 |
| C—I | 240 | O—F | 190 |
| C—S | 259 | O—Cl | 203 |
| Si—H | 323 | O—I | 234 |
| Si—Si | 226 | S—H | 339 |
| Si—C | 301 | S—F | 327 |
| Si—O | 368 | S—Cl | 253 |
| N—H | 391 | S—Br | 218 |
| N—N | 170 | S—S | 266 |
| N—O | 201 | F—F | 158 |
| N—F | 272 | Cl-Cl | 243 |
| N—Cl | 200 | Cl—F | 253 |
| N—Br | 243 | Br-Br | 193 |
| I---Cl | 208 | Br---F | 237 |
| I--Br | 175 | Br---Cl | 218 |
| I----I | 151 | Br---P | 65 |

2.2. High Voltage Tests

The aim of high voltage testing was to get the ability or value of breakdown voltage that can be retained by the test gas. Breakdown voltage is an event when the magnetic field is raised (continuous voltage is increased), the atom will be ionized and the extent of the ability to isolate to the voltage

when the isolator will turn into a conductor. Breakdown Voltage in a gas according to Townsend's Law using the equation (2)-(4) [23], [24]:

$$V_B = f(pd), \quad (2)$$

$$V_B = f\left(\frac{E}{p}\right)pd, \quad (3)$$

$$V_B = \frac{Bpd}{\ln\left(\frac{Apd}{\ln\left(1+\frac{1}{\gamma}\right)}\right)}, \quad (4)$$

where V_B is the breakdown voltage (V), P is the pressure gas (bar), d is the gap distance electrode (mm), and γ is the secondary electron emission coefficient (the number of secondary electrons produced per incident positive ion). A is the saturation ionization at the particular in the gas, and B is related to the excitation and ionization energies. $A = 112.50 \text{ (kPa cm)}^{-1}$ and $B = 2737.50 \text{ V/kPa cm}$ [25].

V_B is breakdown voltage the material gas (kV), P is the gas pressure in the chamber (bar), d is the electrode gap distance at the test (mm), a is the ionization in the gas at a particular level and b is related to the excitation and ionization energies gas at particular.

The bond energy equation is related to eV in volts calculation with the elementary charge. Electron-volt (symbol eV) is a unit of energy which is the amount of kinetic energy obtained by a single electron which is not bound when the electron passes through a single volt electrostatic potential difference in a vacuum. The voltage V in volts (V) is equal to the energy E in electron-volts (eV), divided by the electric charge or elementary charge or proton/electron charge (e), the equation:

$$V = \frac{E}{Q} \quad (5)$$

Energy is measured in units of joules, and the amount of material is calculated in units of moles. 1 kJ/ mol is equal to 0.239 kcal/mol- or 1.04×10^{-2} eV for each ingredient. The value of energy conversion can be seen in table 2.

Table 2. conversion energy

| | Joule | Calorie | eV |
|---------|-----------------------|-----------------------|------------------------|
| Joule | 1 | 0.2389 | 6.242×10^{18} |
| Calorie | 4.186 | 1 | 2.613×10^{19} |
| eV | 1.6×10^{-19} | 3.8×10^{-20} | 1 |

The amount of bond energy for mixed gases is obtained by equation (6) [26].

$$P_{\text{Gas mixture}} = P_{\text{CF}_3\text{CHCl}_2} + P_{\text{CO}_2} \quad (6)$$

where $P_{\text{gas mixture}}$ is total pressure of the gas mixture, $P_{\text{CF}_3\text{CHCl}_2}$ is the partial pressure of CF_3CHCl_2 gas and P_{CO_2} is partial pressure of CO_2 gas.

Based on equation (6), a formula can be made that connects all of them to obtain a breakdown voltage based on bond energy. The breakdown voltage formula based on bond energy can be seen in the description below.

Percentage of bond energy gas (E_{Total}) is (equation 7):

$$E_{\text{Total}} = E_1 + E_2 + \dots + E_n \quad (7)$$

where, E_{Total} is the percentage of total bond energy, E_1 percentage of gas to 1 time the gas bond energy to 1, E_2 the percentage of gas to 2 times the gas bond energy to 2 and E_n is the percentage of gas to n multiplied by the gas bond energy to n . While the magnitude of the breakdown voltage is in accordance with equation (8) - (11).

$$V = f(V) \quad (8)$$

$$V_B = f\left(\frac{E}{Q}\right) \quad (9)$$

$$V_B = \left(\frac{E_1 + E_2 + \dots + E_n}{Q}\right) \quad (10)$$

$$V_B = \left(\frac{E_1 + E_2 + \dots + E_n}{226.72 \times 10^{-6}}\right) \times 1.04 \times 10^{-2} \quad (11)$$

If the charge (Q) has a value of 226.72×10^{-6} electrons, then the formula above can be reduced to equations (12).

$$V_B = 45.87(E_1 + E_2 + \dots + E_n) \quad (12)$$

where V_B showing breakdown voltage with volt (V), E_1 the amount of bond energy multiplied by percentage in gas material to 1 in eV, E_2 the amount of bond energy multiplied by percentage in gas material to 2 in units of eV, and large E_n the bond energy is multiplied by the percentage in the gas material to n in eV units. Based on the description of the formula (12) above. The breakdown voltage can be made a prediction based on bond energy.

3. Experimental Setup

Prepare a test gas chamber. The chamber was made of an iron plate with a thickness of 3mm tube with a diameter of 40 cm by using electrodes made of brass with a diameter of 5cm as shown in figure 1, and Teflon as an isolator retaining electrode had the ability to withstand breakdown voltage of 75 kV.



Figure 1. Chamber Gas Test progress

Vacuum Pump with type VE180N was used to make the vacuum chamber before filled with test gas and ensure the chamber tube in vacuum condition of air, as shown in figure 2.



Figure 2. Vacuum chamber process

Prepare HV tests that use step-up transformer type JEC-120 equipment, 5 kVA capacities, 100-200 VAC Primary Voltage, 50000 VAC Secondary Voltage. High voltage test equipment as shown in figures 3 - 5.

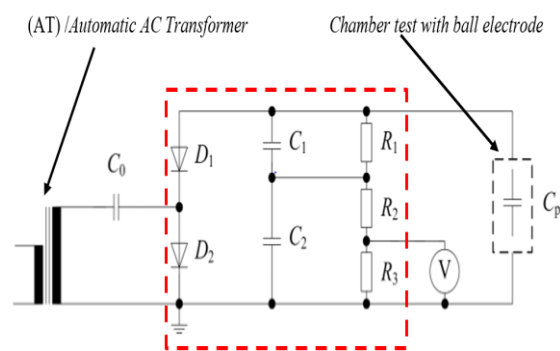


Figure 3. HV Tests circuit

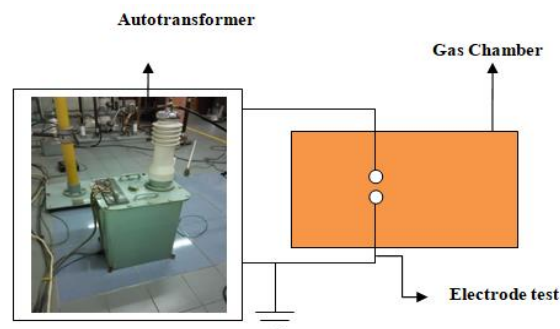


Figure 4. Layout visual HV tests circuit



Figure 5. Visual layout HV Tests

Preparation of testing equipment, setting the test with room pressure (P) 0.1 bar, electrode distance /gap (d) 1mm and 2mm. Testing by giving a gas voltage in the chamber with an electrode gap

according to the arrangement that started with giving the lowest voltage and was gradually increased until the breakdown voltage of the gas test was obtained. Testing was carried out using CF_3CHCl_2 gas mixed with CO_2 and N_2 gas with a gas ratio of 10% - 30%. Techno-economics is an established process. Prices on the market can be reached when developed with technology, usually being part of the process in the management of company product development and related research [27], [28].

4. Result and Discussions

The values of bond energy by using calculations according to equation (1) and table 1 were obtained as shown in table 3. Obtained the binding value of the main gas CF_3CHCl_2 mixed with N_2 gas and CO_2 with a percentage of a gas mixture of 10-30%.

Using the equation and calculation as above, the breakdown voltage values were obtained on the base of bond energy as shown in table 3. Calculation of binding energy converted to breakdown voltage needs to be explained in stages so that a brief overview is obtained to calculate the value of the binding energy converted to a breakdown voltage values in the gas material.

Bond energy by mixing CF_3CHCl_2 gas using equation (1) and standard of value bond energy Calculation of bond energy can be described as follows [29]:

- Bond Energy CF_3CHCl_2 :
 $3 (\text{C---F}) = 3 (485 \text{ kJ/mol}) = 1455 \text{ kJ/mol}$
 $2 (\text{C---Cl}) = 2 (328 \text{ kJ/mol}) = 656 \text{ kJ/mol}$
 $\text{C---H} = 1 (413 \text{ kJ/mol}) = 413 \text{ kJ/mol}$
 Bond energy CF_3CHCl_2
 $(1455 + 656 + 413) \text{ kJ/mol} = 2524 \text{ kJ/mol}$.

In the same way, it can be obtained that the value of bond energy in other mixed gases can be seen in table 3.

Table 3. Bond Energy $\text{CF}_3\text{CHCl}_2 + \text{N}_2/\text{CO}_2$

| Gas | Bond Energy (kJ/mol) |
|---|----------------------|
| N_2 | 170 |
| CO_2 | 716 |
| SF_6 | 1962 |
| CF_3CHCl_2 | 2524 |
| 90% $\text{CF}_3\text{CHCl}_2 + 10\% \text{N}_2$ | 2288.6 |
| 80% $\text{CF}_3\text{CHCl}_2 + 20\% \text{N}_2$ | 2053.2 |
| 70% $\text{CF}_3\text{CHCl}_2 + 30\% \text{N}_2$ | 1868.8 |
| 90% $\text{CF}_3\text{CHCl}_2 + 10\% \text{CO}_2$ | 2343.2 |
| 80% $\text{CF}_3\text{CHCl}_2 + 20\% \text{CO}_2$ | 2162.4 |
| 70% $\text{CF}_3\text{CHCl}_2 + 30\% \text{CO}_2$ | 1981.6 |

SF_6 gas binding energy is 1962 kJ / mol which is able to withstand a 90 kV breakdown voltage [30]. Table 5 shows the predicted breakdown voltage that can be held by CF_3CHCl_2 gas mixed with N_2 and CO_2 gas as shown in table 3 using equation 5. The value of 1 kJ / mol is equal to 1.04×10^{-2} eV for each material. The Voltage Breakdown value is searched by equation (5):

$$1 \text{ kJoule/mol} = 1.04 \times 10^{-2} \text{ eV}$$

$$E_{\text{SF}_6} = 1962 \text{ kJoule/mol} = 1962 \times 1.04 \times 10^{-2} \text{ eV} = 20.4 \text{ eV}$$

$$\text{VB}_{\text{SF}_6} = 90 \text{ kV}$$

$$\text{VB}_{\text{SF}_6} = E_{(\text{eV})} / Q_{(\text{e})}$$

$$90000 = 1962 \times 1.04 \times 10^{-2} / Q$$

$$Q = 1962 \times 1.04 \times 10^{-2} / (90000) = 226,72 \times 10^{-6}$$

If the bond energy of the CF_3CHCl_2 gas is 2524 kJoule / mol

Then the value of $V_B \text{ CF}_3\text{CHCl}_2$

$$V_B \text{ CF}_3\text{CHCl}_2 = E / Q = (2524 \times 1.04 \times 10^{-2}) / (226.72 \times 10^{-6}) = 115779 \text{ Volt} = 115.8 \text{ kV}$$

Breakdown voltage using equations (13) and data bond energy in the table 3 obtained results:

- Breakdown voltage 100% CF_3CHCl_2
 $45.87 \times (2524) = 115775.88 \text{ volt}$
- Breakdown voltage 90% CF_3CHCl_2 + 10% CO_2
 $45.87 \times ([0.9 \times 2524] + [0.1 \times 716]) = 107482.58 \text{ volt}$

In the same way, it can be obtained that the value of bond energy in other mixed gases can be seen in table 5.

Table 4. Breakdown voltage using Bond Energy base

| Gas | Bond Energy (kJ/mol) | Breakdown Voltage (kV) |
|--|-------------------------|---------------------------|
| SF_6 | 1962 | 90 |
| CF_3CHCl_2 | 2524 | 115.8 |
| 90% CF_3CHCl_2 + 10% N_2 | 2288.6 | 112 |
| 80% CF_3CHCl_2 + 20% N_2 | 2053.2 | 94.2 |
| 70% CF_3CHCl_2 + 30% N_2 | 1868.8 | 83.4 |
| 90% CF_3CHCl_2 + 10% CO_2 | 2343.2 | 107.5 |
| 80% CF_3CHCl_2 + 20% CO_2 | 2162.4 | 99.2 |
| 70% CF_3CHCl_2 + 30% CO_2 | 1981.6 | 90.9 |

The results of CF_3CHCl_2 gas mixed testing with N_2 gas and CO_2 gas with the percentage of mixed gas using HV tests was obtained the results as showed in table 5 and table 6.

Table 5. HV tests CF_3CHCl_2 + N_2

| P (Bar) | d (mm) | Breakdown Voltage using mix N_2 (kV) | | | |
|------------|-----------|---|------------------|------------------|------------------|
| | | 0% N_2 | 10% N_2 | 20% N_2 | 30% N_2 |
| 1 | 1 | 119.6 | 107.4 | 95.2 | 83.7 |
| 1 | 2 | 225.8 | 205 | 172 | 156 |
| 2 | 1 | 220.8 | 195 | 177 | 146 |
| 2 | 2 | - | 423 | 375.6 | 329 |

Table 6. HV tests CF_3CHCl_2 + CO_2

| P (Bar) | d (mm) | Breakdown Voltage using mix CO_2 (kV) | | | |
|------------|-----------|--|------------------|------------------|------------------|
| | | 0% N_2 | 10% N_2 | 20% N_2 | 30% N_2 |
| 1 | 1 | 119.6 | 116.4 | 114.2 | 110.4 |
| 1 | 2 | 239.6 | 233.4 | 217.4 | 195.4 |
| 2 | 1 | 250.8 | 242.2 | 230.2 | 212.2 |
| 2 | 2 | - | 464.8 | 415.6 | 314.2 |

Table 4 shows that the binding energy of SF_6 gas (1962 kJoule / mol) is lower than that of CF_3CHCl_2 gas (2524 kJoule / mol). The smaller the binding energy between compounds that material possesses, the less energy is needed to release the bonds between the chemical compounds it forms. Table 4 also shows the breakdown voltage that can be held by SF_6 gas (90 kV) is lower than CF_3CHCl_2 gas (115.8 kV). The breakdown voltage value of CF_3CHCl_2 gas is greater than that of SF_6 gas. Evidence of binding energy calculations and the results of high voltage tests show the ability of

CF₃CHCl₂ gas to withstand breakdown stress is better than SF₆ gas. Based on the comparison of specifications and characteristics between SF₆ gas and CF₃CHCl₂ gas can be seen in table 7 [29].

Tabel 7. Gas specifications and characteristics SF₆ and CF₃CHCl₂ [31]

| No | Spesification and Charateristics | SF ₆ | CF ₃ CHCl ₂ |
|----|----------------------------------|-----------------------------|-----------------------------------|
| 1 | <i>Chemical name</i> | <i>Sulphur Hexafluoride</i> | <i>Dichlorotrifluoroethane</i> |
| 2 | <i>Molecul Weight</i> | 146,065 | 152,93 |
| 3 | <i>Thermal Conductivity</i> | 101,3 kJ/m.hr.K | 34,38 kJ/m.hr.K |
| 4 | <i>Freezing Point</i> | -63,72°C | -107°C |
| 5 | <i>Critical Temperature</i> | 45,5°C | 183,79°C |
| 6 | <i>Critical Pressure</i> | 37,59 Bar | 37,44 Bar |
| 7 | <i>Vapour Pressure</i> | 320 kgf/cm ² | 0,940 kgf/cm ² |
| 8 | <i>Electronegativitas</i> | 3,98 | 7,14 |
| 9 | <i>Dielectric Strength</i> | 1 | 1,29 |
| 10 | <i>Global Warming Potential</i> | 23900 | 77 |
| 11 | <i>Ozone Depleting Potential</i> | 0,08 | 0,02 |
| 12 | <i>Atmosphere live-time</i> | 3200 Year | 1,3 Year |

Comparison of CF₃CHCl₂ Gas with SF₆ Gas as an Alternative Substitute for Gas Insulated Switchgear Equipment The results of using the HV test showed the experimental results that the ability to withstand the breakdown voltage CF₃CHCl₂ mixed with N₂ gas had a lower breakdown voltage than if the CF₃CHCl₂ gas was mixed with CO₂ gas. The ability to withstand the breakdown voltage of CO₂ mixed gas reached 9 kV-26.7 kV higher than mixed gas N₂. In table 4 and table 5 also show that the greater the percentage of mixed gas, the lower the ability to withstand the breakdown voltage.

At the substation, the pressure of the SF₆ gas used reaches 7 bars. With the ability to withstand a breakdown voltage of 90 kV / bars, the SF₆ gas can withstand a breakdown voltage of 90 kV x 7 bar = 630 kV. SF₆ gas can be operated at a working voltage of 500 kV. If it is assumed that the gas pressure in the chamber at the substation is the same, then the capability of the CF₃CHCl₂ gas is in a pure condition and when mixed with N₂ and CO₂ gas with a certain percentage, it can withstand the breakdown stress as shown in table 8.

Table 8. Breakdown voltage CF₃CHCl₂ + N₂/CO₂

| Gas | Breakdown Voltage (kV) |
|--|------------------------|
| CF ₃ CHCl ₂ | 837.2 |
| 90% CF ₃ CHCl ₂ + 10%N ₂ | 751.8 |
| 80% CF ₃ CHCl ₂ + 20%N ₂ | 666.4 |
| 70% CF ₃ CHCl ₂ + 30%N ₂ | 585.9 |
| 90% CF ₃ CHCl ₂ + 10%CO ₂ | 814.8 |
| 80% CF ₃ CHCl ₂ + 20%CO ₂ | 799.4 |
| 70% CF ₃ CHCl ₂ + 30%CO ₂ | 772.8 |

Table 5 shows that by mixing CF₃CHCl₂ + N₂ gas with a maximum percentage of 20% of nitrogen gas, the mixed gas can be used as a filler for gas switching equipment and operating voltage of 500

kV. Whereas if mixed with CO₂ gas, the use of GIS equipment can be used as an operational voltage of 500 kV with a CO₂ gas mixture reaching 30%.

Comparison of breakdown stresses with predictions using bond energy and HV tests shows the breakdown voltage deviation values as shown in table 9. Table 6 shows the breakdown voltage deviation values by comparing the predictions using the bond energy base for the experiments of HV tests. Deviation of the breakdown voltage between bond energy prediction and HV tests shows a deviation number of 0.4% -21%. The results of breakdown voltage deviation are <25%. With a deviation value below 25%, the predicted breakdown voltage of material against breakable stress that can be retained by the material on the basis of bond energy can be used to predict the breakdown stress value in an insulating material based on the bond energy of an insulating material compound.

New materials cannot be separated from the value of the material's ability and reliability to the material it replaces. New materials can be accepted by the market if they have the ability that is equal or even more than the material to be replaced.

Table 9. Deviation of Breakdown Voltage Bond energy/HV Test

| Gas | Bond Energy (kV) | HV tests (kV) | Deviation (%) |
|--|---------------------|------------------|------------------|
| CF ₃ CHCl ₂ 100% | 810.6 | 837.2 | 3.3 |
| 90% CF ₃ CHCl ₂ + 10%N ₂ | 784 | 751.8 | 4.1 |
| 80% CF ₃ CHCl ₂ + 20%N ₂ | 659.4 | 666.4 | 1 |
| 70% CF ₃ CHCl ₂ + 30%N ₂ | 583.8 | 585.9 | 0.4 |
| 90% CF ₃ CHCl ₂ + 10%CO ₂ | 752.5 | 814.8 | 8.3 |
| 80% CF ₃ CHCl ₂ + 20%CO ₂ | 694.4 | 799.4 | 15 |
| 70% CF ₃ CHCl ₂ + 30%CO ₂ | 636.3 | 772.8 | 21 |

Based on the experimental results and the analysis above, it can be seen that the use of CF₃CHCl₂ gas as a potential gas substitute for SF₆ gas is very appropriate because of the ability of CF₃CHCl₂ gas as gas insulation and the ability to withstand breakdown voltage is better than SF₆ gas. The benefit value of SF₆ gas will be more complete if market availability is easily available and prices are more competitive than SF₆ gas. Techno-economy here discusses the procurement price of CF₃CHCl₂ gas mixed with N₂ and CO₂ gas as new potential material as a substitute for SF₆ gas. The list of gas prices in the Indonesian market is shown in table 10. Based on prices shown in table 10, an estimate of the costs needed for gas procurement costs can be made.

Table 10. Pricelist gas in the Indonesian market

| Gas | Pricelist/kg (IDR) |
|-----------------------------------|--------------------|
| N ₂ | 70,000 |
| CO ₂ | 2,240 |
| SF ₆ | 1,554,800 |
| CF ₃ CHCl ₂ | 300,000 |

The gas requirement for experimental equipment is 30 kg/bar so for a gas pressure of 7 Bar, as is needed at 210kg. Gas Insulated Switchgear (GIS), which works at a working voltage of 500 kV optimally, pure gas or mixed gas is required for a maximum of 20% of total gas. For SF₆ gas with a price list in table 10, the value of procurement costs is IDR 1,554,800 x 210kg, valued at IDR 326,508,000. The cost of procuring CF₃CHCl₂ gas is cheaper than the cost of procuring SF₆ gas. The cost of procuring CF₃CHCl₂ gas mixed with CO₂ gas is cheaper than the cost of procuring CF₃CHCl₂ gas mixed with N₂ gas.

5. Conclusions

The results of testing, calculation and analysis of the use of CF_3CHCl_2 gas can be concluded: The CF_3CHCl_2 gas is very potential to be used as a substitute for SF_6 gas at the substation because it is capable of working at an operating voltage of 500 kV and has gas insulating properties and electric arc extinguisher.

Calculation of breakdown voltage can use the base of bond energy as a base for the predictive breakdown of insulating material with an accuracy rate below 25% of the experimental HV tests. The cost of procuring CF_3CHCl_2 gas as a substitute for SF_6 gas has a price that is much cheaper than SF_6 gas (5.18 times cheaper than SF_6 gas). The use of CF_3CHCl_2 mixed with N_2/CO_2 gas to reduce gas procurement costs is very optimal as a percentage of 10-30% because it is still able to withstand the breakdown voltage at a working voltage of 500 kV. The use of CF_3CHCl_2 gas mixed with N_2 gas gives a cost of 1.01 times more expensive than a cost of the use of CF_3CHCl_2 gas mixed with CO_2 .

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