Breakdown Characteristic of CF$_3$CHCl$_2$ / 10-30% CO$_2$ Gas Mixture Based on Its Bonding Energy

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Abstract— Sulfur hexafluoride gas according to the Montreal Protocol and Kyoto protocol needs to be limited and gradually reduced because it causes global warming, the greenhouse effect and acid rain on the environment. The Kyoto protocol recommends the use of dichlorotrifluoroethane gas as one of the alternatives to substitute sulfur hexafluoride gas. This research discusses the use of dichlorotrifluoroethane gas mixed with CO$_2$ gas which was known to be able to withstand the breakdown voltage of 680-837 kV. This research discusses the comparison of breakdown voltage values and differences in breakdown voltage deviation between bond energy theory and high voltage testing. The dichlorotrifluoroethane gas has a price of 5.18 times cheaper than hexafluoride sulfur gas. The ability of dichlorotrifluoroethane gas to insulation gas in gas insulated switchgear needs to be applied as a real potential substitute for sulfur hexafluoride gas.

Keywords- Sulfur Hexafluoride, dichlorotrifluoroethane, bond energy, Paschen’s law, Techno-economy, Gas Insulated Switchgear

I. INTRODUCTION

This SF$_6$ (sulfur hexafluoride) gas has the ability to extinguish electric arcs and capabilities as gas isolation in GIS (Gas Insulated Switchgear) equipment[1]–[8]. One of the chemical elements of SF$_6$ gas is class VII-A (halogen). The halogen group is known to have electronegativity and the ability to extinguish the electric arc. The halogen chemical element that is owned by SF$_6$ is element F (Fluor). The Kyoto protocol limits the use of SF$_6$ gas because it is known to be a source of global warming and the greenhouse effect [9]–[16]. The Kyoto protocol recommends several gases as alternative substitutes as shown in Table I.

One of the gases suggested by the Kyoto protocol is CF$_3$CHCl$_2$ (dichlorotrifluoroethane) gas. This research discussed SF$_6$ gas substitution by testing CF$_3$CHCl$_2$ + CO$_2$ gas. Research also discussed breakdown voltage comparisons using the high energy calculation versus high voltage test. The CF$_3$CHCl$_2$ gas has 2 halogen elements in its compounds, namely elements F (Fluorine) and Cl (Chlorine).

This research discussed the use of CF$_3$CHCl$_2$ gas as an alternative to SF$_6$ gas. The method used in analyzing the ability of CF$_3$CHCl$_2$ gas as a potential gas replacement for SF$_6$ with bond energy and HV test methods. The purpose of mixing the main gas with CO$_2$ was to reduce the main gas concentration if it leaks in the air because there is no 100% gas that does not cause natural effects, also to reduce the gas procurement costs that arise for the supply of gas at the substation. In addition to analyzing the ability of CF$_3$CHCl$_2$ gas as a gas isolation medium, it also discusses the Kyoto protocol value in gas as well as the technology of the CF$_3$CHCl$_2$ gas compared to SF$_6$ gas.

II. METHODOLOGY AND ANALYSIS RESEARCH

There are 8 important points of gas which are the basis of environmentally friendly gas as contained in the results of the Kyoto protocol, as gas isolation material and fillers of GIS equipment so that they can be accepted in the market to replace SF$_6$ gas, namely:
1. Electronegativity
2. Global Warming Potential
3. Ozone Depleting Potential
4. Live-time atmosphere
5. Breakdown Voltage using Bond Energy calculation
6. High Voltage (HV) tests and Setup experimental
7. Techno-economic

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichlorotrifluoroethane</td>
<td>CHClCClF</td>
</tr>
<tr>
<td>2-chloro-1,1,2-trifluoroethane</td>
<td>CHCIF</td>
</tr>
<tr>
<td>Trichlorofluoroethane</td>
<td>CHCF2</td>
</tr>
<tr>
<td>Dichlorodifluoroethane</td>
<td>CClF3</td>
</tr>
<tr>
<td>Chlorotrifluoroethane</td>
<td>CClF2</td>
</tr>
<tr>
<td>Dichlorofluoroethane</td>
<td>CClF3</td>
</tr>
<tr>
<td>1,1-dichloro-1,2-difluoroethane</td>
<td>CHC2ClF</td>
</tr>
<tr>
<td>Chlorodifluoroethane</td>
<td>CClF2</td>
</tr>
<tr>
<td>1-chloro-1,1-dichloroethane</td>
<td>CHCFCF</td>
</tr>
<tr>
<td>Chlorofluoroethane</td>
<td>CClF3</td>
</tr>
<tr>
<td>Hexachlorofluoropropane</td>
<td>CCl3F</td>
</tr>
</tbody>
</table>

TABLE I. GAS RECOMMENDED KYOTO PROTOCOL
A. Electronegativity

The more electronegative the molecule will tend to bind electrons to form negatively charged molecules [17]-[21]. The electronegative nature of CF₅Cl₂CHCl₂ as well as in SF₆ is what causes it to become a bad current conductor. The greater the electronegativity value of the chemical element, the greater the ability of the gas to resist breakdown voltage. Electronegativity is related to the speed of extinguishing an arc of fire. The greater the electronegativity value of a chemical element, the quickly chemical elements are able to extinguish the electric arcs that occur due to the switching process in GIS equipment. The value of electronegativity can be found by equation (1) [22].

\[
XA - XB = (eV)^{\frac{1}{2}} \sqrt{\frac{\text{Ed}(AB) - (\text{Ed}[AA] + \text{Ed}[BB])}{2}}
\]

where, Dissociation Energy (Ed) A – B, A – A and B- B was expressed in electron volts. Factor (eV) \(^{10}\) was inserted to produce dimensionless values [23].

B. Global Warming Potential (GWP)

Global warming potential [24] relates to the potential for a compound to have a long-term effect on global warming. GWP can be searched by equation (2) [25]:

\[
\text{GWP}_i = \frac{\int_0^{\text{TH}} \text{RF}_i(t) \, dt}{\int_0^{\text{TH}} \text{RF}_r(t) \, dt} = \frac{\int_0^{\text{TH}} a_i \, [C_i(t)] \, dt}{\int_0^{\text{TH}} a_r \, [a_r(t)] \, dt}
\]

where RFᵢ is Radiative forcing (RF) for element i, RFᵣ is Radiative forcing the reference gas (CO₂), TH is the time horizon, Ci is the time-dependent abundance of the element i, ai is the RF per unit mass increased in atmospheric abundance of component i (radiative efficiency), ar is the radiative forcing per unit mass increased in atmospheric abundance of reference component.

C. Ozone Depleting Potential (ODP)

Ozone Depleting Potential relates to the potential of gas compounds that can cause depletion of the ozone layer over a period of time [26], [27]. To get the ODP value can be obtained using equation (3) [25]:

\[
\text{ODP} = \frac{\text{Global } \Delta O_3 \text{ due to substance } i}{\text{Global } \Delta O_3 \text{ due to CFC-11}}
\]

The Ozone Depletion Potential is a relative index that expresses the potential to destroy ozone over its lifetime in the atmosphere compared to the effect of CFC-11. Therefore, the OPD of CFC-11 is set to be 1. The ODP of a compound is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11.

D. Atmosphere Live-time (ALT)

The last point needed as a gas requirement that meets the Kyoto protocol is Atmospheric Live-Time (ALT). Live-time atmospheric values can be obtained by equation (4) [25].

\[
\text{ALT} = \frac{\text{mass removal rate}}{F_{\text{out}} + L + D}
\]

where m is mass (kg), F₀ is a flow of substance x out the box (kg/year), L is a loss of substance x (kg/year), D is deposition of substance x (kg/year).

E. Breakdown voltage using bond energy calculation

Bond energy is the energy needed to separate bonds between atoms in a molecule. The greater the bond energy possessed by a compound, the greater the energy required to separate the bonds of the compound. When a chemical reaction occurs, the molecular bonds are cut off and the other molecules will form. If the energy that holds the bonds together is stronger, then big energy is needed to separate them.

**TABLE II. STANDART BOND ENERGY** [28], [29]

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

Table II shows the energy value between compounds. If the compound bond is high, it has strong bonds and the molecule will be more stable and less reactive. Reactive compounds have bond energy, which is generally lower. The value of bond energy is obtained by using equation (5) [30]:

\[
E_{\text{bond}} = E_{\text{elstat}} + \Delta E_{\text{Pauli}} + \Delta E_{\alpha}
\]

where \(E_{\text{elstat}}\) is an electrostatic interaction calculated using uninterrupted fragment density, \(E_{\text{Pauli}}\) is an energy change caused by orthogonalization of the function of fragment waves and \(E_{\alpha}\) arises from recombination of orthogonalized orbital fragments to form supermolecular wave functions. To change the bond energy into a breakdown force, it is necessary to convert it as in equation (6) and (7).

\[
V = \frac{E}{Q}
\]

The voltage \(V\) in volts (V) is equal to the energy \(E\) in electron-volts (eV), divided by the electric charge \(Q\) in elementary charge or proton/electron charge (e):
Joules per mole, J mol⁻¹, is an SI publication unit for energy per number of materials. Energy is measured in units of joules, and the amount of material is calculated in units of moles. 1 kJ mol⁻¹ is equal to 0.239 kcal mol⁻¹ or 1.04x10⁻² eV, 1 mol is equal 6x10²³ for each ingredient. The value of energy conversion can be seen in Table III.

### TABLE III. VALUE OF ENERGY CONVERSION

<table>
<thead>
<tr>
<th>Joule</th>
<th>Calorie</th>
<th>eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2389</td>
<td>6.242x10⁻³</td>
</tr>
</tbody>
</table>

The amount of bond energy for mixed gases is obtained by equation (8) [25].

\[
P_{\text{gas mixture}} = P_{\text{CF}_3\text{CHCl}_2} + P_{\text{CO}_2}
\]

where \( P_{\text{gas mixture}} \) is total pressure of the gas mixture, \( P_{\text{CF}_3\text{CHCl}_2} \) is partial pressure of CF₃CHCl₂ gas and \( P_{\text{CO}_2} \) is partial pressure of CO₂ 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 \( (E_{\text{Total}}) \) is (equation 9):

\[
E_{\text{Total}} = E_1 + E_2 + \cdots + E_n
\]

where, \( E_{\text{Total}} \) is the percentage of total bond energy, \( E_1 \) percentage of gas to 1 times 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 (10) - (12).

\[
V = f(V)
\]

\[
V_B = f\left(\frac{E}{Q}\right)
\]

\[
V_b = \left(\frac{E_1 + E_2 + \cdots + E_n}{Q}\right)
\]

If the charge \( (Q) \) has a value of 226.72x10⁻⁶ electrons, then the formula above can be reduced to equations.

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 (10) - (12) above. The breakdown voltage can be made a prediction based on bond energy.

**F. High Voltage tests and Setup experimental**

The purpose of testing HV tests is to compare the results of predictions between the breakdown voltage values with the bond energy method with the breakthrough value of the Paschen law method through real HV test testing. In addition, it is also to see the breakdown voltage values both of the bond energy method and the Paschen's law. By comparing the two methods with HV testing testing, it is expected that the right and most precise method of choice can be done to predict the breakdown stress of an insulating material. Setup experimental, the tools used in HV testing tests include:

The vacuum pump is used to make a vacuum chamber. Specifications of vacuum pump: value brand, voltage 230 VAC /50-60 Hz, Model VE180N, motor 0.75 HP, transformer testing with specifications, type JEC-120, Capacity 5 kVA, primary voltage 100-200 VAC/secondary voltage 50000VAC, Made in Tokyo Transformer Co.Ltd, gas chamber with dimensions of 70 cm x 70 cm x 90 cm to place test electrode and test gas, thermometer indoor temperature gauge Gas in chamber, barometer to measure pressure and volume of gas and gas heater 100 Watt. Perform a vacuum chamber as shown in Figure 1.

![Vacuum chamber process](image)

**Fig. 1. Vacuum chamber process**

After vacuum testing, the HV test was carried out of the chamber to determine the chamber's ability to withstand the breakdown voltage as showed in Figure 2.

![HV test process](image)

**Fig. 2. HV test process**

After testing the chamber, a circuit HV test was performed as showed in Figure 3 [31].

![HV test circuit](image)

**Fig. 3. HV test circuit**

Figure 3 showed the S1 and S2 automatically switches, AT autotransformer, V voltmeter, Rp bump resistor, T is thermo-controlled, P Pressure (Bar), B Chamber Gas using feeder and out-feeder gas.
G. Techno-economic CF₃CHCl₂ as an Insulation Material

Techno-economic studies include the application and control of the use of dichlorotrifluoroethane (CF₃CHCl₂) gas [34]–[37]. It is undeniable that the existence of new alternative gas must have a general requirement that new technologies can be accepted by the user community. Terms of new technology can be accepted by the community are: technology is simple and easy to use, cheap and easy to obtain, reliable technology to use, and cheap and cheap technology in its maintenance. This manuscript discusses the costs of gas procurement as a comparison to the costs of gas procurement SF₆ as a gas isolation medium in GIS equipment.

III. RESULT AND DISCUSSION

The HV test results can be seen in Table 4.

<table>
<thead>
<tr>
<th>P (Bar)</th>
<th>d (mm)</th>
<th>T (°C)</th>
<th>Breakdown Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>90%</td>
</tr>
<tr>
<td>0.1</td>
<td>1</td>
<td>25</td>
<td>13.3</td>
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<tr>
<td>0.1</td>
<td>1</td>
<td>30</td>
<td>12.42</td>
</tr>
<tr>
<td>0.1</td>
<td>1</td>
<td>40</td>
<td>11.96</td>
</tr>
<tr>
<td>0.1</td>
<td>1</td>
<td>50</td>
<td>13.92</td>
</tr>
<tr>
<td>0.1</td>
<td>2</td>
<td>25</td>
<td>24.38</td>
</tr>
<tr>
<td>0.1</td>
<td>2</td>
<td>30</td>
<td>23.96</td>
</tr>
<tr>
<td>0.1</td>
<td>2</td>
<td>40</td>
<td>24.04</td>
</tr>
<tr>
<td>0.1</td>
<td>2</td>
<td>50</td>
<td>24.58</td>
</tr>
<tr>
<td>0.1</td>
<td>3</td>
<td>25</td>
<td>37.04</td>
</tr>
<tr>
<td>0.1</td>
<td>3</td>
<td>30</td>
<td>35.2</td>
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<tr>
<td>0.1</td>
<td>3</td>
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<td>34.96</td>
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<tr>
<td>0.1</td>
<td>3</td>
<td>50</td>
<td>38.46</td>
</tr>
<tr>
<td>0.2</td>
<td>1</td>
<td>25</td>
<td>25.98</td>
</tr>
<tr>
<td>0.2</td>
<td>1</td>
<td>30</td>
<td>25.14</td>
</tr>
<tr>
<td>0.2</td>
<td>1</td>
<td>40</td>
<td>25.08</td>
</tr>
<tr>
<td>0.2</td>
<td>1</td>
<td>50</td>
<td>27.88</td>
</tr>
<tr>
<td>0.2</td>
<td>2</td>
<td>25</td>
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</tr>
<tr>
<td>0.2</td>
<td>2</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>0.2</td>
<td>2</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>0.2</td>
<td>2</td>
<td>50</td>
<td>-</td>
</tr>
</tbody>
</table>

Breakdown voltage using equations (12) and data bond energy in the Table V obtained results:

- Breakdown voltage 100% CF₃CHCl₂:
  \[ V_B = (2524 \times 1.04 \times 10^{0.6}) = 226.72 \times 10^{4} = 115775.88 \text{ volt} \]
- Breakdown voltage 90% CF₃CHCl₂ + 10% CO₂:
  \[ V_B = ([0.9 \times 2524 \times 1.04 \times 0.6] + [0.1 \times 1761 \times 1.04 \times 0.7]) = 226.72 \times 10^{4} = 107482.58 \text{ volt} \]
- Breakdown voltage 80% CF₃CHCl₂ + 20% CO₂:
  \[ V_B = ([0.8 \times 2524 \times 1.04 \times 0.6] + [0.2 \times 1761 \times 1.04 \times 0.8]) = 226.72 \times 10^{4} = 99189.29 \text{ volt} \]
- Breakdown voltage 70% CF₃CHCl₂ + 30% CO₂:
  \[ V_B = ([0.7 \times 2524 \times 1.04 \times 0.6] + [0.3 \times 1761 \times 1.04 \times 0.9]) = 226.72 \times 10^{4} = 89095.99 \text{ volt} \]
- Breakdown voltage 60% CF₃CHCl₂ + 40% CO₂:
  \[ V_B = ([0.6 \times 2524 \times 1.04 \times 0.6] + [0.4 \times 1761 \times 1.04 \times 1]) = 226.72 \times 10^{4} = 82602.69 \text{ volt} \]

Breakdown voltage using bond energy data compared to the results of high voltage testing (retrieve data at the lowest range value in Table IV) can be seen in Table VI.

Deviations of breakdown voltage using bond energy and HV test can be seen in Table VII. Breakdown value of gas voltage under pressure 1 bar and gas electrode 1mm.

If SF₆ gas is needed in GIS equipment using a pressure of 7 bars, the operational voltage of SF₆ gas at a pressure of 7 bar
is 90 kV x 7 bar = 630 kV. The ability of SF₆ gas with a GIS 7 bar pressure is able to withstand a breakdown voltage of 630 kV which is very suitable for use at the most optimal working voltage of 500 kV. So if it is assumed that conditioning the CF₃CHCl₂ gas like SF₆ gas using a pressure of 7 bar and calculating it with the bond energy method, then the CF₃CHCl₂ + CO₂ gas is obtained through the breakdown voltage at 7 bar (Table VIII):

<table>
<thead>
<tr>
<th>Gas</th>
<th>Breakdown Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF₆</td>
<td>630</td>
</tr>
<tr>
<td>100% CF₃CHCl₂</td>
<td>837</td>
</tr>
<tr>
<td>CF₃CHCl₂ + 10% CO₂</td>
<td>870.8</td>
</tr>
<tr>
<td>CF₃CHCl₂ + 20% CO₂</td>
<td>775.6</td>
</tr>
<tr>
<td>CF₃CHCl₂ + 30% CO₂</td>
<td>680.4</td>
</tr>
</tbody>
</table>

For environmentally friendly gas requirements in accordance with the Kyoto protocol, the following values are obtained:

1. The electronegativity value of SF₆ gas compared with CF₃CHCl₂ gas using equation (1) obtained a value, SF₆ of 3.98 and CF₃CHCl₂ gas of 7.14. The greater the electronegativity value, the more the material is not a good conductor or a good insulator. In addition, the higher the electronegativity value, the better and faster the gas material is in extinguishing the electric arc during the switching process.

2. GWP value based on equation (2) obtained a value of GWP SF₆ of 23900 and GWP value of CF₃CHCl₂ gas of 23. The greater the GWP value, the greater the potential or effect on global warming.

3. ODP gas value based on equation (3) obtained SF₆ gas of 0.8 while the ODP value of CF₃CHCl₂ gas was 0.016. The greater the ODP value of the gas material, the greater the potential depletion of the ozone layer if the gas material is released in the air.

4. ALT value on gas using equation (4) obtained ALT value of SF₆ gas for 3200 years while CF₃CHCl₂ gas has an ALT value of 1.5 years. The higher the ALT value of a material, the longer it will stay in the atmosphere. So SF₆ gas requires longer recovery time in the atmosphere than CF₃CHCl₂ gas.

Techno-economic is one of the main components of techno-economic values were procurement costs, availability of material in the market and reliability of gas replacement. The factor of procurement of gas materials was very vital because it involved 40% of the costs incurred by consumers. Prices were based on prevailing market price standards. The benchmark gas market price list could be shown in Table IX.

Table IX shows the price of gas procurement per kg in the territory of the Republic of Indonesia. For a 500 kV GIS compartments, the main gas is about 210kg of gas. If it is assumed that the amount of gas needed is the same as the breakdown voltage that can be resisted, the breakdown voltage compared to the cost of gas procurement can be shown in Table X.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Breakdown Voltage (kV)</th>
<th>Procurement of costs (IDR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF₆</td>
<td>630</td>
<td>326,508,000</td>
</tr>
<tr>
<td>CF₃CHCl₂</td>
<td>837</td>
<td>63,000,000</td>
</tr>
<tr>
<td>CF₃CHCl₂ + 10% CO₂</td>
<td>870.8</td>
<td>56,747,040</td>
</tr>
<tr>
<td>CF₃CHCl₂ + 20% CO₂</td>
<td>775.6</td>
<td>50,490,080</td>
</tr>
<tr>
<td>CF₃CHCl₂ + 30% CO₂</td>
<td>680.4</td>
<td>44,241,120</td>
</tr>
</tbody>
</table>

From Table X, it can be seen that with the ability to withstand breakdown voltage at a working voltage of 500 kV, SF₆ gas requires a fee of IDR 326,508,000 while CF₃CHCl₂ gas requires a cost of IDR 63,000,000. The cost of procuring CF₃CHCl₂ gas as insulation material on GIS equipment is 5.18 times cheaper than the cost of gas for SF₆. For GIS filler gas with CO₂ gas mixed, the optimal percentage is 30% for a 500 kV working voltage. For a working voltage of 500 kV against the procurement costs versus the ability to withstand breakdown voltage, the researchers suggested that the gas mixture be 70% CF₃CHCl₂ + 30% CO₂. When compared with SF₆ gas, the gas mixture is 70% CF₃CHCl₂ + 30% CO₂, so the cost of gas procurement is cheaper by 7.38 time compared to SF₆ gas procurement.

IV. CONCLUSION

Based on the testing and discussion that have been done, a conclusion can be made as follows:

The results of the calculation using the bond energy method and high voltage testing using bond energy data obtained the bond energy gas value CF₃CHCl₂ (2524 kJ/mol) better than SF₆ gas (1962 kJ/mol). If it is assumed that the two gases are applied to a 500 kV GIS equipment with a compartment pressure of 7 bar, the ability to withstand CF₃CHCl₂ gas breakdown voltage is 837 kV / 7 bar, while SF₆ gas has the ability to withstand a breakdown voltage of 630 kV / 7 bar. The value of bond energy can be used as a basis for predicting the value of breakdown voltage in gas (both pure gas and mixed conditions).

The use of bond energy calculations can produce a breakdown voltage value with a breakdown voltage deviation value below 3%.

Mixing CF₃CHCl₂ + gas CO₂ gas (maximum 30% CO₂ gas) is able to operate at the operational voltage on a 500 kV Gas insulated switchgear compartment because it can withstand breakdown voltage of 680 kV.

The techno-economic value of CF₃CHCl₂ gas as an alternative gas substitute for SF₆ gas has an economic value at a price of 5.18 times cheaper than SF₆ gas.

For environmentally friendly gas and according to the Kyoto protocol recommendations, a better value is obtained compared to SF₆ gas.
In the future, CF3CHCl2 gas will need to be intensively developed and immediately applied for filling material for GIS equipment as an insulating gas substitute for SF6 gas.

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REFERENCES


