Limiting SF6 Gas Emissions by Optimization of Design and Handling over the Life Cycle of HV Switchgear

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Introduction
Introduction

- Technologies advances makes that emissions was averaged 4.5% per year of volume installed, now is reduced to 1% per year for older circuit breakers.
- Today emission objective is less than 0.5% per year.
- Need maintaining of all life cycle phases in particular during
  - Maintenance
  - End of life.
- Disposal of used SF$_6$ at the end of life: now recycled (99%) or disposed by burning it (1%).

SF$_6$ gas is now never released to the atmosphere.
SF₆ Management During Development of Products and Manufacture
Management of SF$_6$ gas

- SF$_6$ storage and Distribution in R&D and Manufacturing workshops
  - Example of Medium voltage switchgear.
  - Example of HV and EHV switchgear.
  - Shipment of additional gas in bottles or containers.

CAPIEL is recommending proper management of SF6 Gas
Manufacturing

- GL31x series manufacturing (HV & EHV)

Semi-Automatic tightness test facility for High-Voltage circuit breaker
$SF_6$ Gas Tightness
SF₆ Tight Design

- Aging effect is due to:
  - Hardening of the gaskets
  - Chemical attack
  - Corrosion

- Decrease in the mechanical, chemical and physical characteristics of the gasket material.

Historical development
The one-O-ring seal and the two-O-ring.
**SF₆ Tight Design**

The Three-O-ring seal
1. **Electro-Chemical corrosion:** Study of various compounds and it was noted the importance of a low electrochemical couple between the seal material, the aluminum alloy flanges and outdoor rain water.

2. The selection of gasket was also crucial in decreasing the difference of potential. A compound of EPDM was selected that comply with all the above requirements.

3. Many tests were performed in the 1980’s and 1990’s.
SF₆ Tight Design

The Tests

- Oven: -60 / +150°C
- Leakage rate viewing and storage of data.
- Pneumatic rotating device
- Seal of a FXT circuit breaker
- Connecting hoses test set - B&K analyser
- Gas Analyser type B&K 1302
The Tests

The inside ring R28 shows a lot of wear, low pressure side. Some shavings can be seen in the grooves.

Numerous shavings can be seen on the shaft.
SF₆ Tight Design

Application to dead tank circuit breakers

Typical 245 kV dead tank circuit breaker
SF₆ Tight Design

Low temperature leakage test
Maintenance
1. **Work on circuit breaker**: temporary store and re-use the \( \text{SF}_6 \) gas during service and maintenance.

2. **Ensure that there is adequate ventilation** (natural or mechanical).

3. **Do not agitate \( \text{SF}_6 \) decomposition by-products unnecessarily.**

4. **Remove \( \text{SF}_6 \) decomposition by-products immediately after opening the circuit breaker to prevent moisture combination with by-products.**

5. **Neutralize \( \text{SF}_6 \) by-products (arc products) with desiccant and used cloths, soak them in 3% soda solution for 24 hours (effervescence).**

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**Safety comes first**
Minimizing the maintenance needs to avoid unnecessary $\text{SF}_6$ handling.

Hydro One – Belleville substation
Minimizing the maintenance needs to avoid unnecessary SF$_6$ handling.

Grand County Public District Typical Monitoring
Minimizing the maintenance needs to avoid unnecessary SF\textsubscript{6} handling.

Why an electronic monitoring system for the SF\textsubscript{6} gas?

- The conventional densimter can be the origin of wrong alarms when a spread of temperature variation within a day is large.

- The use of an electronic allows the analysis of a rate of leakage and the generation of advanced alarms in addition to the computation of the density of the gas.

- The rate of Return On Investment (ROI) can be assured with only one false alarm (as liquefaction) in the life of the circuit breaker.
Minimizing the maintenance needs to avoid unnecessary SF₆ handling.

- Example: Breaker at James Bay (Northern Quebec)
- When, exceptionally, temperature falls below the liquefaction point:
- A conventional densimeter will activate the P2 threshold (refilling required),
- CBWatch will send the message: Temperature too low. Do not refill.
Minimizing the maintenance needs to avoid unnecessary SF$_6$ handling.

Alarms are set within a range of 20 to 200 days before a topping up is required (20 mn to 20 hours before the locking pressure).
Minimizing the maintenance needs to avoid unnecessary SF₆ handling.

- System based on the state equation of the SF₆ gas developed by Beattie & Bridgeman.
- Internal range -40°C to + 60°C equivalent to -55°C to + 60°C ambient with heaters on the dead tank circuit breakers.
- Sensor send the information to the control board.
- Inhibits false alarms in the event of gas liquefaction, and indicates liquefaction.
- Calculates SF₆ leakage rates to:
  - Give advance warning
  - Lockout threshold levels
Minimizing the maintenance needs to avoid unnecessary SF$_6$ handling.

Circuit Breaker 145 kV Dead Tank with CBWatch1 (Hydro Québec-”Les Cèdres”)

More than 400 units installed since 1998
Strategy for Applying Digital Monitoring in mixed gases
Minimizing the maintenance needs to avoid unnecessary SF$_6$ handling

Typical density monitor for SF$_6$/N$_2$ mix circuit breakers.

Ref: “Non Intrusive Method for the Assessment of SF$_6$/N$_2$ Gas Mixture Ratio”

Dallas, 2003
Minimizing the maintenance needs to avoid unnecessary $\text{SF}_6$ handling.

$\text{SF}_6$ monitoring: the CBWatch
Minimizing the maintenance needs to avoid unnecessary SF$_6$ handling. Sensors.

SF$_6$ monitoring the CBWatch: typical pressure sensor and temperature probe.
Minimizing the maintenance needs to avoid unnecessary SF₆ handling. Communicate!!!

“Mobile Pad” on Pocket PC

- No more need of drawings to find faulty sensor #FHG34, thanks to WiFi connection to the monitoring system, its location is displayed in your hand!

SF₆ monitoring the CBWatch.
End of life
End of Life

Typical old SF6 circuit breakers
End of Life

Gas Phase Chromatography (GPC) (Agilent P200) with software “Ezchrom 200”.

Typical old SF6 circuit breakers

Recovery container
### Table 2. Different Waste Management subcontractors according to the material. The SF₆ gas is the last item.

<table>
<thead>
<tr>
<th>Channels</th>
<th>Collection</th>
<th>Treatment</th>
<th>Sub-Contractor</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>EPUR</td>
<td>23/11/2001</td>
<td>EPUR</td>
<td>22/03/1982</td>
</tr>
<tr>
<td>Copper</td>
<td>SOBRAL</td>
<td>23/06/1998</td>
<td>SOBRAL</td>
<td>27/05/1994</td>
</tr>
<tr>
<td>Steel</td>
<td>CFF Recycling</td>
<td>Not available</td>
<td>CFF Recycling</td>
<td>02/09/1975</td>
</tr>
<tr>
<td>Bulky</td>
<td>SITA MOS</td>
<td>21/11/2003</td>
<td>SITA MOS</td>
<td>09/06/1982</td>
</tr>
<tr>
<td>Oils</td>
<td>SRRHU</td>
<td>Special agreement</td>
<td>SRRHU</td>
<td>16/10/1990</td>
</tr>
<tr>
<td>SF₆ gas</td>
<td>STML</td>
<td>16/02/2004</td>
<td>AVANTEC</td>
<td>14/06/2004</td>
</tr>
</tbody>
</table>
### Table 3. Recycling rates and qualitative considerations for end of life.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Recyclability rate (grinding)</th>
<th>Recyclability rate (dismantling)</th>
<th>Energetic valorization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>80%</td>
<td>~100%</td>
<td>-</td>
</tr>
<tr>
<td>Aluminum</td>
<td>80%</td>
<td>~100%</td>
<td>-</td>
</tr>
<tr>
<td>Copper</td>
<td>95%</td>
<td>~100%</td>
<td>-</td>
</tr>
<tr>
<td>PTFE</td>
<td>0%</td>
<td>15%</td>
<td>Good</td>
</tr>
<tr>
<td>Oils</td>
<td>-</td>
<td>-</td>
<td>Very good</td>
</tr>
<tr>
<td>SF₆</td>
<td>-</td>
<td>99%</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

**Consideration for End of Life**

**End of Life**
Conclusion
Conclusions (1)

1. **Improve management of the gas in the electrical industry.**
2. **Many efforts were done in the design, manufacturing, testing, to reduce and master to the lowest possible level emissions of gas.**
3. **Objective is the life cycle of the equipment, mainly during maintenance and at the end of life of the equipment.**
4. **One of the problem is leakage and we described at length the tests, material selection, various gaskets to prevent leakage due to corrosion.**
5. **Maintenance is usually where some gas escape to atmosphere. Ways to improve leak detection, sensing and handling of SF₆ gas during operations and maintenance were described.**

Drastic reduction of emission of SF₆ gas in the atmosphere.
6. Solutions are available for extremely low $\text{SF}_6$ emissions for conventional and low temperature countries.

7. Recycling rate is very high.

8. We recommend continuous monitoring of $\text{SF}_6$ gas.

9. Management of the End of Life of a circuit breaker is discussed in particular the recycling of the gas from “cradle to cradle” (99%) and if the pollution is too high from “cradle to grave” (1%).

Drastic reduction of emission of $\text{SF}_6$ gas in the atmosphere.