Advances in Leak Detection in the Manufacturing Process

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Agenda

1. Introduction

2. SF₆ Leak Detection Methods

3. Implementation

4. Benefits

5. Conclusions
Introduction

• Reduction of leak rates in high-voltage SF$_6$ insulated circuit breakers (1.0% to less than 0.5% per year).

• Implementation of leak detection method into production environment.

• Challenge to keep cycle time within constraints while being capable to verify low leak rates.

• Test on fully assembled circuit breakers.

• Impact on detection rates, process feedback, product reliability, field incidents.
## Comparison of detection methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Sensitivity (kg/year)</th>
<th>Ratio vs. bubble test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum increase</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Infrared camera</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Bubble test</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Density monitor</td>
<td>0.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Infrared absorption spectroscopy</td>
<td>0.06</td>
<td>16.7</td>
</tr>
<tr>
<td>Negative ion detector</td>
<td>0.02</td>
<td>50.0</td>
</tr>
<tr>
<td>Electron capture detector</td>
<td>0.002</td>
<td>500.0</td>
</tr>
<tr>
<td>Helium mass spectrometer</td>
<td>0.002</td>
<td>500.0</td>
</tr>
<tr>
<td><strong>Photo-acoustic infrared spectroscopy</strong></td>
<td><strong>0.0002</strong></td>
<td><strong>5000.0</strong></td>
</tr>
</tbody>
</table>

- **Greatest Sensitivity and Accuracy**
  - Method used by ALSTOM Grid for Type Tests and Production
Photo-Acoustic Infrared Spectroscopy

Light passed through a filter impacts SF6 molecules in a sample volume.

Pressure increase translates to an acoustic signal.
Photo-Acoustic Infrared Spectroscopy

• Highest sensitivity method for leak detection
  - 5000x sensitivity of bubble test or infrared camera.
  - 10x sensitivity of helium mass spectrometer method
    ➢ 2g/year vs. 0.2 g/year.

• Allows to accurately measure and verify <0.5% per year leakage rate in a production environment.
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Implementation

Concept and Prototype Test Chamber
Implementation

• Testing Criteria:
  - Pass/Fail Leak Rate: Acceptable SF6 gas loss rate is any rate less than 0.5% of the initial breaker SF6 gas content per year.
    • A new 72kV breaker contains 29 lbs. of SF6 @ 67 psi pressure.
      - 0.5% of 29 lbs. = 0.145 lbs. per year (10,730 cm$^3$ per year).
      - Adjusted Rate for Testing = .0204 cm$^3$ per minute.
    • Chamber Volume = Approximately 2.5x10$^6$ cm$^3$
    • The equivalent SF6 concentration change in the chamber is equal to 36 Parts Per Billion (PPB) over a 45 minute test period.
      - Concentration adjusted for reduced chamber volume with breaker present.

• Production testing
  - Initiated December 2010.
  - Has greatly reduced reported field leaks.
  - High first pass yield for breaker tested.
Optimizing the Testing Procedure

Faster, less accurate sampling performed to verify gas monitoring equipment.
Implementation

Optimizing the Testing Procedure

- Slower, more accurate sampling performed to verify gas monitoring equipment.
Case Study

- Details:
  - This breaker passed the current standard tightness test procedure.
    - An SF6 hand ‘Sniffer’ tool (comparative gas) was used to examine the joints and potential leak points on the breaker.
    - No leaks were detected.
  - The breaker exhibited a leak 4x greater than the acceptable rate after less than 15 minutes in the Volumetric Test Chamber.
    - The breaker was pulled from the chamber and re-checked with the hand sniffer much more rigorously than the standard procedure.
    - The leak was found only after the tip of the hand sniffer tool was placed this close to a test fitting on the breaker.
  - Graphs of the test are shown on the following pages.
Case Study

Graph of Leak Indication

Breaker removed after high leak rate was observed.
Graph after Leak Repair

The breaker tested exceptionally well after the leak was addressed.
Implementation

Example: Typical Production Test Graph
Test Chamber Integrity Validation

• Pressurized Smoke Test
  - Chamber filled with smoke and pressurized.
    • Utilized smoke cartridges and supply air blower only, exhaust vent sealed.
    - Leaks detectable by smell and sight.
    - Minimal Leaks found and addressed.
    - Also used to verify chamber gas evacuation times.

• Extended Chamber Monitoring
  - Performed with and without a pre-charge of SF6 gas.
    • Performed with a 50 cm³ pre-charge of SF6 to detect SF6 concentration loss to the lower background SF6 gas levels outside of the test chamber.
    • Performed without a pre-charge of SF6 to detect SF6 concentration increase from the higher background SF6 gas levels outside of the test chamber.
Test Chamber Integrity Validation

Extended Chamber Monitoring – With SF6 Charge

Approximately 3 Hours with no detectable SF6 concentration loss.
Today

Dual Test Chambers in High Volume Production Test Line
Implementation

SAFETY | QUALITY | COST | DELIVERY
Production Test Lab with Dedicated Mechanical Bays and SF6 Volumetric Tightness Chambers

we are shaping the future   ALSTOM
Benefits

• First installation of Accumulation Chamber (AC) ~ Jan 2011

• Fully assembled breaker tested

• Products tested in original AC
  ➢ DTI – 38 FK
  ➢ DTI – 72.5 FK

• Additional AC installation for all product lines
  ➢ 2 new chambers currently to test 38 kV – 170 kV dead tank products
  ➢ Future chambers to test all other products

• Internal and External Improvements
Benefits

Percent Site SF6 Leakage Rate Reported

Implementation of Accumulation Leak Detection Chamber

Year

Percent Site SF6 Leaksages

Percent Leak Rate

2006 2007 2008 2009 2010 2011 2012 2013
**Benefits**

- **Historical Mean time to reported site SF6 leakage:**
  - Date leakage reported – Manufacture Date
  - 15.2 months (DTI-72.5 FK Product)

- **Reliable Data:**
  - ~ Today – 15.2 months
  - January 2013 (any data prior to this date considered reliable)

- **Δ Mean % Leak Rate:**
  - Mean prior to AC installation = 19.5(X) %
  - Mean after AC installation = X %
Benefits

Percent Site SF6 Leakage Rate Reported

Implementation of Accumulation Leak Detection Chamber

Year

2006 2007 2008 2009 2010

Percent Site SF6 Leaks

- Mean Before Chamber
- Mean After Chamber

Reduction

Reliable Data

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Benefits

• Δ Mean % Leak Rate:

  = Mean prior to AC installation = 19.5(X) %
  = Mean after AC installation = X %

• Reduction:

  ➢ Overall % reduction = 19.5(X) % - X % = R %
  ➢ % reduction of existing leakage rate = R% / 19.5(X)% = 94.87%
Conclusions

- ALSTOM has successfully implemented a high accuracy SF6 leak detection test system for use in a production assembly facility.
- The system supports fully-loaded production flow requirements.
- Reliability data indicates this method is immediately effective.
- The volumetric tightness testing system ensures product quality and reliability.
- This testing system reduces product leak emissions...
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