Cold Weather Applications of Gas Mixture (SF₆/N₂, SF₆/CF₄) Circuit Breakers: A User Utility’s Perspective

By
Bob Middleton, Manitoba Hydro

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Mixed Gas Circuit Breakers

Presentation Outline

• Overview of Manitoba Hydro system
• Technical considerations for -50°C operation:
  • Gas mixtures and dielectric testing
  • Low temperature cycle test
  • Leakage rate
  • Circuit breaker tank designs
• Handling of gas mixtures
Where Are We?

Manitoba Hydro is a Canadian electric utility located in the province of Manitoba.
Manitoba Hydro

- 100% owned by the Province of Manitoba
- 4th largest electric utility in Canada
- 99% of our energy is generated from hydro

Capacity:
- 4900 MW (hydro)
- 237 MW (thermal)

- Peak demand: 3500 MW
Manitoba Hydro

- Revenue - $1081.6 million
- Assets - $7865.9 million
- Customers – 398,863
- Number of employees – 3,277 (plus 836 construction)
- 30% of our revenue from exports
- 80% of our energy is produced by the five generating stations on the Nelson River
Power is moved from the north on a high voltage direct current (HVDC) transmission line.
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• The transmission of power on HVDC power lines requires converter stations at either end
• These stations convert electricity from alternating current to direct current, and send the power at 500 kV
• From here, power is distributed all over the province or sold to neighbours, including the United States
Manitoba Hydro has approximately 160 mixed gas circuit breakers on its system at various transmission and sub-transmission voltage levels.

<table>
<thead>
<tr>
<th>SYSTEM VOLTAGE</th>
<th>SF$_6$/N$_2$</th>
<th>SF$_6$/CF$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 kV</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>230 kV</td>
<td>5</td>
<td>62</td>
</tr>
<tr>
<td>138 kV</td>
<td>--</td>
<td>7</td>
</tr>
<tr>
<td>115 kV</td>
<td>2</td>
<td>46</td>
</tr>
<tr>
<td>66 kV</td>
<td>19</td>
<td>16</td>
</tr>
</tbody>
</table>
MIXED GAS CIRCUIT BREAKERS

- SF$_6$/N$_2$ mixture:
- First breakers purchased (1988 – 1990) were supplied with SF$_6$/N$_2$ mixture
- 60/40 mixture
- Filling pressure (at 20ºC):
  - 0.31 Mpa SF$_6$
  - +
  - 0.2 Mpa N$_2$
- Alarm pressure (20ºC):
  - 0.45 Mpa
- Blocking pressure (20ºC):
  - 0.43 Mpa
MIXED GAS CIRCUIT BREAKERS

- SF$_6$/CF$_4$ mixture:
  - This mixture first became available in 1991; since then Manitoba Hydro has standardized on this mixture for all new breakers
  - 50/50 mixture
  - Filling pressure (at 20°C):
    \[
    0.36 \text{ MPa SF}_6 + 0.34 \text{ MPa CF}_4
    \]
  - Alarm pressure (20°C):
    0.62 Mpa
  - Blocking pressure (20°C):
    0.60 MPa
MIXED GAS CIRCUIT BREAKERS

- ABB Type ELF SP7-4
- 550 kV, 4000A, 40 kA, SF$_6$/CF$_4$ circuit breaker at our Dorsey Converter Station
- Line to ground insulation 1800 kV BIL
- Grading capacitors 1500 pF
- Closing resistor:
  - 450 ohm
  - Energy rating 13000 kJ
  - Pre insertion time 8 +/- 2 ms
• We specify that circuit breakers must be able to operate down to ambient temperatures of -50°C without the use of heaters.

• To meet this requirement manufacturers must:
  • Provide a gas mixture to avoid liquefaction of the SF$_6$ gas at low temperatures
  • Test the mechanical operation of the circuit breaker at 50°C according to the low-temperature cycle test defined in IEC 56
TECHNICAL CONSIDERATIONS

- Mixed gas:
  - Gas mixture of SF$_6$ and N$_2$ or SF$_6$ and CF$_4$ required to avoid liquefaction of the SF$_6$ gas at low temperatures
  - Filling with SF$_6$ and N$_2$ deteriorates the dielectric and thermal capacity
  - Manufacturers compensate for this reduced performance by:
    - A slightly higher operating pressure (dielectric)
    - De-rating the breaker under SLF conditions (thermal)
• If de-rating of the circuit breaker is unacceptable then grading capacitors have to be connected across the circuit breaker contacts to limit the rate-of-rise of the recovery voltage.

• Disadvantages of grading capacitors:
  i) Makes the breaker more expensive
  ii) Can lead to other problems not directly associated with the circuit breaker (e.g. Ferro-resonance)
TECHNICAL CONSIDERATIONS

- Mixed gas filling with SF$_6$ and CF$_4$ results in practically unchanged thermal and dielectric breaking characteristics

- Circuit breakers filled with an SF$_6$/CF$_4$ mixture often retain their breaking capacity down to the lowest ambient temperatures
TECHNICAL CONSIDERATIONS

- It is not necessary to repeat all the type tests for the mixed gas version if the circuit breaker has been fully type tested as a pure SF$_6$ version.

- Tests typically repeated to confirm the switching capability of the mixed gas circuit breakers:
  i) Cold performance test (for capacitive and small inductive current switching cases)
  ii) Terminal fault tests
  iii) Short line fault test

- Tests performed at 20°C are valid for -50°C.
TECHNICAL CONSIDERATIONS

- **Low-temperature cycle test:**
  - Based on IEC 56, Clause 6.101.3.3
  - This test is done to confirm that travel characteristics, operating times, and gas tightness are not compromised by low temperatures

![Diagram showing low-temperature cycle test](image)

- Erection and adjustments
- Characteristic measurements, leakage test in ‘closed’ and ‘open’ states
- Circuit breaker cools down in the ‘closed’ state
- Leakage test whereby leakage <3*F_p (F_p = guaranteed leakage rate at 20 deg C)
- Circuit breaker 1 * ‘O’, 1 * ‘C’ at U_n; characteristic measurements
- Mechanism heating switched off for 2 hours followed by 1 * ‘O’
- Circuit breaker in open state for 24 hours
- Leakage test whereby leakage < 3 F_p
- Characteristic measurements at 1 * ‘C’ and 1 * ‘O’, 3 * ‘CO’ with minimum reversing time, 50*(‘C’-ta-‘O’-ta)-ta=1.5 min.
- Heating up at approx. 10 deg/hour and with the following simultaneous operation:
  - ‘C’-ta-‘O’-ta-‘C’-30 min. ‘O’-ta-‘C’-ta-‘O’-30 min.
MIXED GAS CIRCUIT BREAKERS
TECHNICAL CONSIDERATIONS

- Gas leakage rate:
  - < 0.5% per year at 20°C
  - At -50°C the IEC standard allows a leakage rate of 3 x the rate at normal temperatures
TECHNICAL CONSIDERATIONS

- Until recently only the live tank design was supplied with a gas mixture.
- It is only recently that some manufacturers can offer mixed gas dead tank designs up to 145 kV, 40 kA; previously, dead tank designs relied on the use of tank heaters to keep the SF₆ gas above its liquefaction temperature.
MONTANA HYDRO owns and utilizes three gas handling carts

- The carts are manufactured by DILO Company Inc.
- Capable of handling $\text{SF}_6$, $\text{CF}_4$, and $\text{N}_2$ in either the gaseous or liquid form
GAS HANDLING CONSIDERATIONS

- A diaphragm compressor evacuates the gas containment compartment to an absolute pressure of 50 MBAR
- The scavenged gas is accumulated in an “empty” gas bottle, located on the cart
- A vacuum pump is then used to evacuate to an absolute pressure of 2 MBAR
GAS HANDLING CONSIDERATIONS

• In-line filtering is used to:
  • Absorb moisture from the gas
  • Cleanse unwanted gaseous particles from the gas \((\text{SF}_4, \text{SO}_2\text{F}_2, \text{HF}, \text{SO}_2, \text{and} \ \text{WF}_6)\)
  • Collect solid particles which are created as the \text{SF}_6 decomposes after exposure to an electric arc \((\text{WO}_3, \text{CuF}_2)\)
CONCLUSIONS

- Manitoba Hydro was the first North American utility to install mixed gas circuit breakers on its system.
- Our mixed gas circuit breaker population continues to grow with over 170 presently in-service.
- These circuit breakers have performed flawlessly and have provided the cold weather performance and reliability demanded by our company.
Manitoba Hydro

Bob Middleton
Apparatus Quality Control Engineer

820 Taylor Avenue
Winnipeg, Manitoba
Canada   R3M 3T1
(204) 474-3828
bmiddleton@hydro.mb.ca