COLD-WEATHER APPLICATION OF GAS MIXTURE (SF_6/N_2, SF_6/CF_4) CIRCUIT BREAKERS: A UTILITY USER'S PERSPECTIVE

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SUMMARY

Very low temperatures stress a circuit breaker in a complex manner. Mixed-gas circuit breakers were developed for use at temperatures as low as -50^{o}C. These breakers utilize a gas mixture of SF_6 and CF_4 or SF_6 and N_2 to prevent condensation of the SF_6 gas and have been type tested at -50^{o}C to ensure travel characteristics, operating times, and gas tightness are acceptably affected. Today's mixed-gas circuit breakers offer excellent cold-weather performance and provide the reliability needed for most utility users' systems.

1. INTRODUCTION

Manitoba Hydro is a Canadian electric utility located in the province of Manitoba. It is the fourth-largest electric utility in Canada, with a generating capacity of 5100 MW. The bulk of this energy is produced by hydro-electric generating stations located on the Nelson River in northern Manitoba. The power is moved from the north on a high-voltage direct current (HDVC) transmission line. Converter stations at either end convert electricity from alternating current to direct current and send the power to the southern part of the province at 500 kV. From here, power is distributed all over the province. Nominal voltage levels on the Manitoba Hydro interconnected transmission system are 115, 138, 230 and 500 kV. The northern collector system consists of isolated 138 kV and 230 kV systems connected to the northern high-voltage direct current facilities. Sub-transmission and distribution voltage levels are 66, 33, 24.94, and 12.47 kV.

Manitoba Hydro uses mixed-gas circuit breakers primarily at the transmission and sub-transmission voltage levels. The table below shows the quantity of mixed-gas circuit breakers presently on our system.

SYSTEM VOLTAGE	**SF_6/N_2**	**SF_6/CF_4**
500 kV	-	2
230 kV	5	62
138 kV	-	7
115 kV	2	46
66 kV	19	16
Totals	26	133

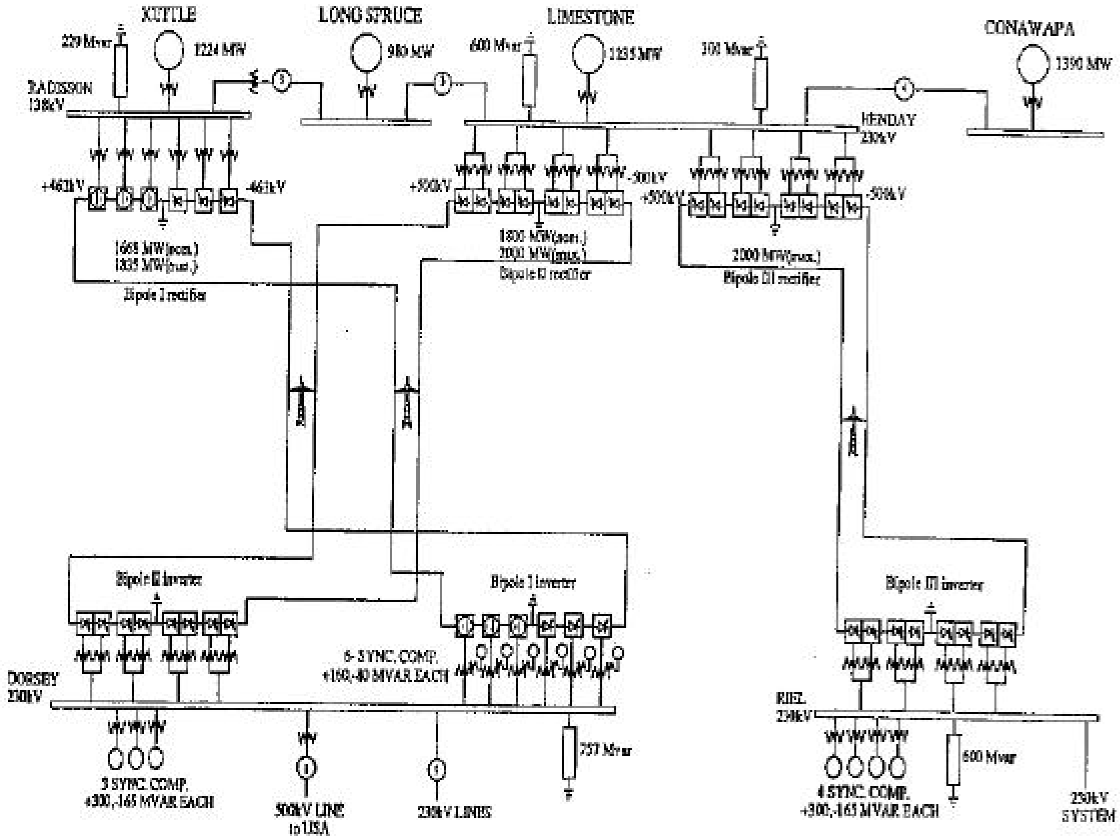


Figure 1: Single Line Diagram

We have been purchasing mixed-gas circuit breakers since 1988. These initial circuit breakers were purchased with a 0.5 MPa mixture ($0.31SF_6 + 0.2N_2$) at 20ºC. In 1990, a new gas mixture of SF_6 and CF_4 became available. This new mixture offered some very important advantages over the SF_6 and N_2 mixture. A circuit breaker filled with the SF_6/CF_4 mixture is, in most cases, able to retain its full interrupting capability at -50ºC with only very small values of grading capacitance. In some cases, depending on the interrupter chamber design, manufacturers have been able to eliminate the grading capacitors all together. Manitoba Hydro made the decision to standardize on this new gas mixture. The SF_6/CF_4 breaker operates with a slightly higher pressure of 0.7 MPa ($0.37SF_6 + 0.34CF_4$) at 20ºC. To date, these circuit breakers have performed flawlessly with no reported cold-weather-related problems (i.e., low-pressure alarms, gas leaks).

2. TECHNICAL CONSIDERATIONS

2.1 General

The role of the high-voltage circuit breaker is to perform routine and emergency connection and disconnection (i.e., switching) of network elements such as transmission lines and transformers. The disconnection process (i.e., opening or “tripping”) generally involves complex phenomena, not only in the case of emergency tripping following short circuits in which interruption of high currents is required, but also during routine switching. Consequently, circuit breaker technology is relatively sophisticated and is still undergoing changes.

Picture 1: 500 kV SF_6/CF_4 Live Tank Circuit Breaker at Manitoba Hydro's Dorsey Substation

Over the years, the performance of high-voltage outdoor circuit breakers during cold-weather conditions has been a matter of concern to Manitoba Hydro. As different types and designs were developed, new low temperature problems surfaced. To improve performance and reliability during adverse weather conditions, Manitoba Hydro specifies that circuit breakers must be able to operate down to ambient temperatures of -50^{o}C without the use of heaters. To meet this requirement, manufacturers must:

a) Provide a gas mixture to avoid the temporary condensation of the SF_6 gas at low temperatures.

b) Test the mechanical operation of the circuit breaker at -50^{o}C according to the low-temperature cycle test defined in IEC 56 (this test requires all heaters to be switched off for 2 hours at -50^{o}C and the circuit breaker operated).

2.2 Mixed Gas

At low ambient temperatures, below -30^{o}C or -40^{o}C (depending on filling pressure), there is a risk of SF_6 condensation, which can cause some reduction of breaking capacity. To avoid this, circuit breakers can be filled with a gas mixture of SF_6 and N_2 or SF_6 and CF_4.

Mixed gas filling with SF_6 and N_2 deteriorates the thermal and dielectric breaking capacity. The deteriorated dielectric characteristics can be compensated for with a slightly higher operating pressure.

High thermal stresses are imposed on the circuit breaker if it has to interrupt a short-line fault. The short-line fault is a fault that occurs on the line several hundred metres from the station and causes a rapidly rising voltage to develop across the circuit breaker contacts directly after current zero. Because of the reduced thermal performance of the SF_6/N_2 mixture, the circuit breaker must be de-rated one step (i.e., 40 kA to 31.5 kA) to protect against thermal failure of the circuit breaker. If de-rating is unacceptable, then grading capacitors must be connected across the circuit breaker contacts to limit the rate-of-rise of the recovery voltage. In some applications, however, the large values of grading capacitance that are required to avoid de-rating are unacceptable because they can lead to other problems (ferro-resonance) not directly associated with the circuit breaker.

Mixed gas filling with SF_6 and CF_4 results in practically unchanged thermal and dielectric breaking characteristics. This is because the thermal interrupting capability and flow velocity of CF_4 are similar to SF_6. An SF_6/CF_4-filled circuit breaker often retains its breaking capacity down to the lowest ambient temperatures.

It is usually not necessary to repeat all the type tests for the mixed-gas version if the circuit breaker has already been tested as a pure SF_6 version. The following type tests are typically repeated to confirm the switching capability of the circuit breaker with the gas mixture:

1) Cold performance test for capacitive and small inductive current switching cases
2) Terminal fault tests
3) Short line fault test

Tests performed at 20ºC are also valid for -50ºC. Theoretically, there is no difference in switching capability at very low temperatures as long as the liquefaction point of the gas is not reached.

2.3 Low-Temperature Cycle Test

Very low temperatures stress a circuit breaker in a complex manner. To qualify a circuit breaker for use at temperatures as low as -50ºC, it is essential that a circuit breaker be mechanically tested at the lowest operating temperature to ensure travel characteristics, operating times, and gas tightness are not unacceptably affected or compromised. Manitoba Hydro requires the low-temperature cycle type test be performed successfully in accordance with IEC 56, Clause 6.101.3.3 (see Figure 2).

2.4 Gas Leakage Rate

Today's gas-filled circuit breakers have very small leakage rates (<0.5% per year at 20ºC). Sealing at low temperatures must be very carefully and precisely engineered; proper materials must be used for gaskets to ensure seals reseal effectively following deformation associated with operation of the circuit breaker.

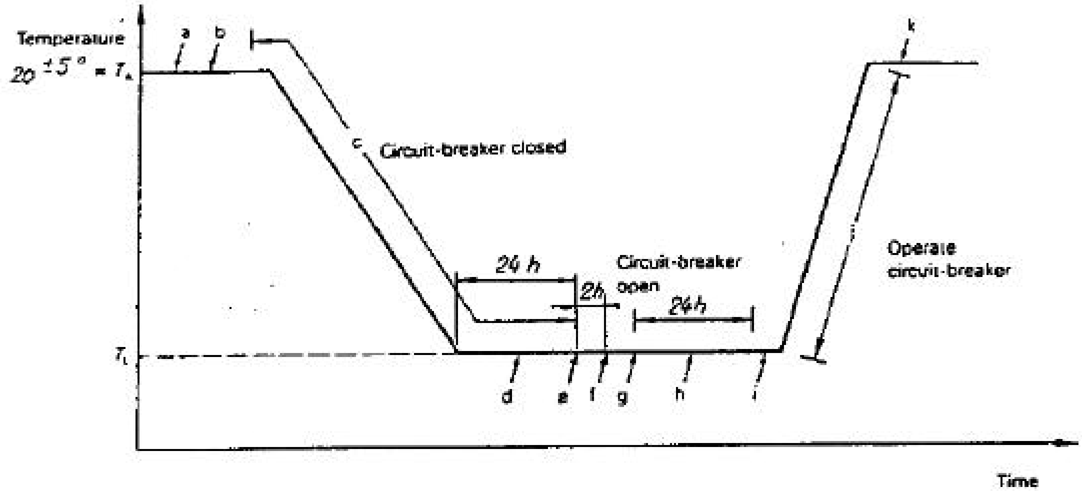
The IEC standard allows a low temperature leakage rate three times the rate at normal temperatures. This rate takes into account that -50ºC will occur only during very limited times over the year.

2.5 Circuit Breaker Types

There are two main categories of circuit breakers: one in which the enclosure for the extinguishing medium (SF_6) and the contacts is metallic and grounded, and the other in which the chamber containing the extinguishing medium and contacts is insulated from the ground. The former is commonly referred to as a dead tank design and the latter as a live tank design (see Figure 3).

In the past, only live tank designs were supplied with a gas mixture. Dead tank designs relied on the use of tank heaters to keep the SF_6 gas above its liquefaction temperature and to prevent seals from leaking. Today some manufacturers can offer a mixed-gas dead tank design up to a rating of 145 kV, 40 kA.

As evidenced from bids received during recent years, few suppliers are prepared to bid on a specification that prohibits the use of heaters at low temperatures. Developing a low temperature circuit breaker requires a very significant investment; manufacturers of high-voltage circuit breakers have been unwilling to make this investment because of the very small market share that low-temperature circuit breakers represent worldwide. Competition on recent Manitoba Hydro bids has, therefore, been confined to three suppliers. To increase the level of competition, some utilities will relax their low-temperature requirements at the lower voltage levels, specify less stringent low temperature specifications depending on location, or accept the use of tank heaters at low ambient temperatures.



a Erection and adjustments

b Characteristic measurements
Leakage tests in "closed" and "open" states

c Circuit breaker cools down in the "closed" state

d Leakage test whereby leakage < 3 x F_p (F_p = guaranteed leakage rate at 20 °C)

e Circuit breaker 1 x "O", 1 x "C" at U_n; characteristic measurements

f Mechanism heating switched off for 2 hours followed by 1 x "O"

g Circuit breaker in open state for 24 hours

h Leakage test whereby leakage < 3 F_p

i Characteristic measurements at 1 x "C" and 1 x "O"
3 x "CO" with minimum reversing time
50 x (- "C" - t_a - "O" - t_a -) t_a = 1.5 min.

j Heating up at approx. 10°/hour and withthe following simultaneous operations:
- "C" - t_a - "O" - t_a - "C" - 30 min. - "O" - t_a - "C" - t_a - "O" - 30 min. -

Figure 2: IEC 56 Low-Temperature Cycle Test

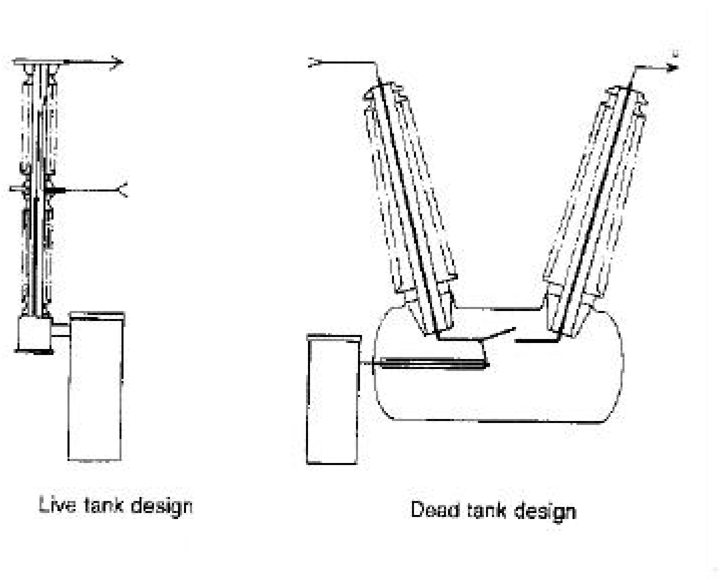


Figure 3: Circuit Breaker Tank Designs

Manitoba Hydro chose not to go this route. Cold weather is a reality in Western Canada and Manitoba, in particular. Low temperatures have frequently approached -50ºC. The Manitoba Hydro system serves many remote or isolated locations. Consequently, it is very important that circuit breakers operate when needed. Today's low-temperature tested mixed-gas circuit breakers offer improved cold-weather performance, especially over the older air blast designs, and provide the reliability needed for our system.

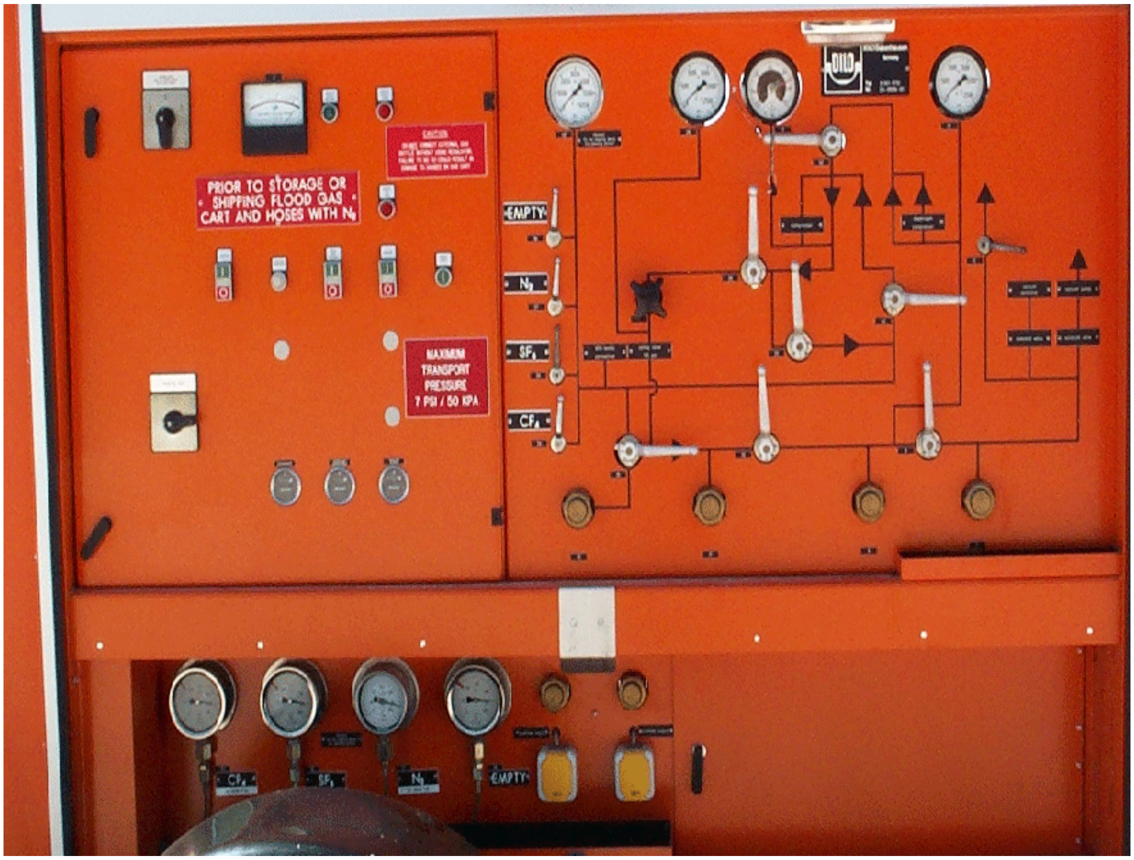
3. $SF_6/CF_4/N_2$ GAS HANDLING

Manitoba Hydro presently owns and utilizes three gas handling carts. These carts are manufactured by DILO Company, Inc., and are capable of handling SF_6, CF_4 and N_2 in either the gaseous or liquid form.

A diaphragm compressor allows a storage vessel or gas containment compartment to be evacuated to an absolute pressure of 50 mbar. All gas scavenged through use of the diaphragm compressor is accumulated in an "empty" gas bottle, located on the cart. A vacuum pump, which expels to the atmosphere, is capable of evacuating a gas compartment to an absolute pressure of 2 mbar. The vacuum pump would be activated after the diaphragm compressor has reduced the gas volume to a pressure of 50 mbar. This minimizes the amount of SF_6 exhausted to the atmosphere. Usually, the only time the vacuum pump is utilized is for the "drying" of the cart or the gas compartment of equipment that is to be refilled with SF_6.

Picture 2: DILO Gas Cart

Picture 3: Gas Collection Bottles



Picture 3: Gas Cart Instrumentation

The gas carts we utilize incorporate an in-line filtering unit. One component of the unit is a dry filter cartridge that is capable of absorbing moisture from the gas passed through it. The moisture (H_20) content of gas passed through the filter does not exceed 10 ppm mass. The filter unit incorporates a dust filter to cleanse unwanted gaseous particles from the gas such as SF_4, $S0_2F_2$, HF, $S0_2$, and WF_6. The filter also collects solid particles, created as the SF_6 gas decomposes after exposure to an electric arc. These particles include $W0_3$ and CuF_2.

To date, the filter element has not needed to be changed. When it is necessary to change the filter element and all similarly contaminated handling materials, they will be neutralized with soda ash and water, as detailed in a written procedure, prior to disposal.

We encourage all our field service personnel to utilize these carts when handling all SF_6 gas to ensure the quality of the gas is maintained and the environment is protected from unnecessary gas release. We do not knowingly release or encourage the release of SF_6 gas into the atmosphere. Whenever gas is extracted from a particular piece of equipment, the reclaimed gas is stored in an “empty” bottle, which is standard equipment on the gas cart. Normally, all gas stored in this empty bottle is returned to the equipment it was removed from. If it is not, the “empty” bottle is purged when the gas cart is returned to its storage location. The purged gas is collected and stored until a sufficient quantity is accumulated. The reclaimed gas is then sent to an outside agency for proper disposal.

We presently utilize more than 170 circuit breakers, 35 circuit switchers, and 1 station bus system that contain SF_6 gas. Most of our “stock” gas storage is done at the Waverley Service Centre, although some work centers maintain their own stock. This local storage is discouraged, but the issue has not been “pushed.” There are records kept with regard to the quantities of the various gases stored at Waverley, but no official records are kept on gas stored in the individual work centers. Also, there are no records kept regarding the quantity of SF_6 gas found in the various pieces of equipment presently in-service. No records are kept that would track the quantity of gas that is either leaking or has leaked from equipment nor the amount that is added to a given piece of equipment over the equipment's life cycle. The setup of a recording system to address these issues is one of our priorities. We feel that we should be monitoring and tracking this information both as "due diligence" and in preparation for the (probable) upcoming legislation.

4. CONCLUSIONS

Manitoba Hydro pioneered the use of mixed-gas circuit breakers in North America and was the first utility to install them on their system.

The population of mixed-gas circuit breakers on the Manitoba Hydro system continues to grow. These circuit breakers have performed flawlessly and have provided the cold-weather performance and reliability needed by Manitoba Hydro.

5. REFERENCES

(1) Middleton, R., Koschik, V., Hogg, P., Kulkarni, P., and Heiermeier, H. "Development work for the application of 245 kV circuit breakers using a SF_6/CF_4 gas mixture on the Manitoba Hydro System." Paper presented at Canadian Electrical Association Spring Conference. Toronto, Canada., March 1996.

(2) Dale, S.J., and Niemeyer, L. "Current Design of Gas Insulated Equipment." Paper presented at the U.S. Environmental Protection Agency's Conference on Electrical and Transmission Systems, Sulfur
Hexafluoride and Atmospheric Effects of Greenhouse Gas Emission. Washington, D.C., August 9-10, 1995.

(3) Landry, M., and Jeanjean, R. "Dielectric Withstand and Breaking Capacity of SF_6 Circuit Breakers at Low Temperatures." IEEE WM 121-7, 1987.

(4) International Electrotechnical Commission. "High Voltage Alternating Current Circuit Breakers." IEC 56, Fourth Edition, 1987.

6. BIOGRAPHY

Bob Middleton received his B.S. in electrical engineering from the University of Manitoba and is a registered professional engineer in the province of Manitoba. He joined Manitoba Hydro in 1972 and has held various positions in generation and transmission engineering. Between the years 1979 and 1986, he worked as a consultant in Vancouver and Winnipeg. Upon his return to Manitoba Hydro in 1986, he re-joined the Apparatus Engineering Group, where he currently holds the title of Apparatus and Quality Control Engineer.

Bob Middleton is a member of CSA Technical Committees 123 and 128, Canadian subcommittees on IEC TC 33 and IEC TC 38/WG 26 and the Canadian Electrical Association (CEA).