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Development of mixed gas GCB applied to low-temperature environment

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SUMMARY

An SF6 and CF4 gas mixture has a lower condensation temperature than pure SF6 and thus allows gas circuit breakers (GCBs) to operate at extremely low ambient temperatures (less than -40°C) without tank heaters. The disadvantage of an SF6 and CF4 gas mixture is that it has lower dielectric and interrupting properties compared to pure SF6 gas. This paper focuses on the development and key features of several types of mixed gas GCBs for low temperature applications.

An 800 kV dead tank mixed gas GCB has been developed using a two-break interrupter and a single operating mechanism. Type tests were performed using pure SF6 gas in accordance with ANSI standards followed by another set of type tests using mixed gas in accordance with IEC standards to meet the requirements of customers at various locations.

Two types of 245 kV dead tank mixed gas GCBs were developed based on an existing 245kV SF6 GCB design. One is a GCB with independent pole operation (IPO), and the other is a GCB with three phase gang operation (GO). The spring operating mechanisms that are applied to both types of 245kV GCBs are widely used on other ratings since they allow utilities to reduce life time costs including maintenance cost of the GCB because of their high reliability. Investigation results of CIGRE WG A3.06 shows that fewer failures are expected in spring operating mechanisms than in hydraulic mechanisms.

Maintenance work can be reduced by applying a spring operating mechanism to GCBs because of the reduced replacement parts and maintenance items. The number of replacement parts for a spring operated GCB is only 40% of that for a hydraulic operated GCB. Maintenance items including test items can also be reduced to 40% of a hydraulic operating mechanism.

Wide use of spring operating mechanisms at higher ratings is required because of their key benefits of less maintenance work and high reliability. The torsion bar spring operating mechanism applied to the 245kV gang operated mixed gas GCB is applicable to GCBs up to 550kV rating because a higher operating force can be obtained with a torsion bar spring than with a helical coil spring.

KEYWORDS

Mixed gas - GCB - Spring operated - Spring operating mechanism - Pneumatic operating mechanism - Low temperature environment - Maintenance work - High reliability

1. Introduction

A gas mixture of SF6 and CF4 enables the application of GCBs to extremely low ambient temperatures (less than -40 °C) because the condensation temperature is lower than pure SF6 gas with minimal reduction in dielectric and interrupting capability. This paper introduces two ratings of dead tank mixed gas GCBs developed for applications in extreme low temperature environments and their key features. Spring operating mechanisms that are applied to the 245kV GCBs are widely used in other ratings since they help utilities reduce maintenance costs because of their high reliability.

2. Development of 800 kV GCB

An 800 kV dead tank mixed gas GCB has been developed using a two-break interrupter and single pneumatic operating mechanism. Figure 1 shows the layout of the 800kV pneumatic operating mechanism. The pneumatic operating mechanism has a simple construction and is common in North America. Figure 2 shows the layout and construction of the two-break interrupter. Two interrupters from a 550kV one-break GCB design are paired with closing resistors to reduce closing surges. The 800kV interrupters and closing resistors are arranged in such a way as to allow one operating mechanism to drive both interrupters simultaneously by the force of the mechanism through an insulating rod. The linkage connection is supported by linkage guides to minimize differences in operation timing between the two interrupters, and ensure the high operating reliability. Additionally this single mechanism arrangement will have reduced maintenance compared to other 800kV GCBs with multiple mechanisms. This interrupter arrangement also allows for the nozzle and the arcing contacts to be removed and exchanged without removing the entire interrupter from the tank of the GCB. In addition, this 800kV GCB attains lighter weight and higher seismic performance by applying composite insulators that are lighter than porcelain insulators. The closing resistors are sized to allow four closing operations into the maximum short circuit current rating or one closing operation out-of-phase. The closing resistor contact has a gas damper that shown high reliability through use in conventional 550kV GCBs.

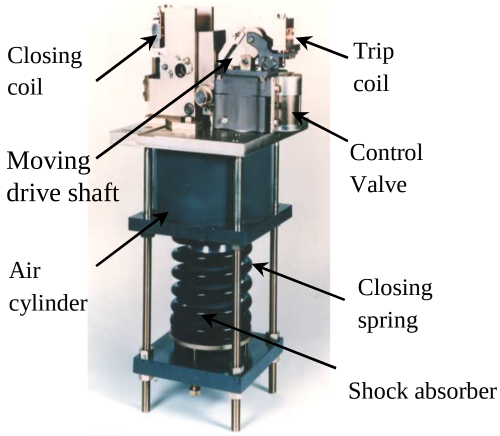


Fig. 1. Layout of pneumatic operating mechanism

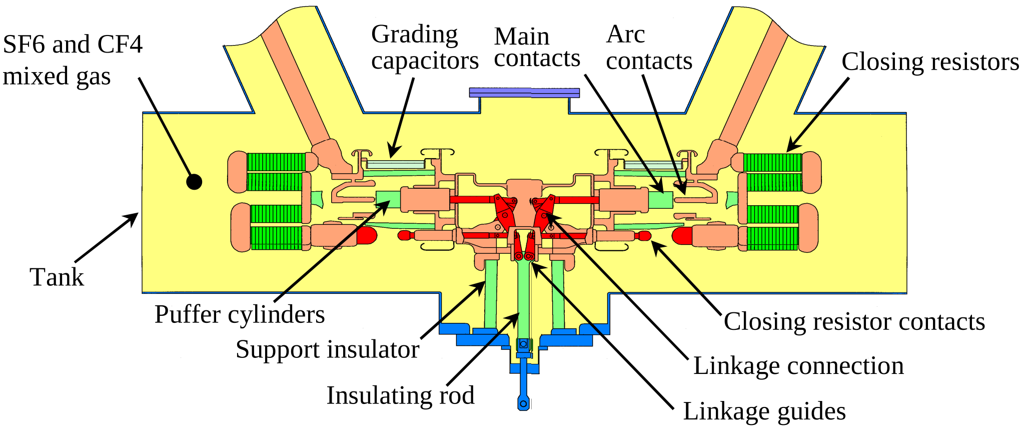


Fig. 2. Layout and construction of interrupter with closing resistor of 800 kV 2-break GCB

Table 1 shows the ratings for the 800kV GCB with pure SF6 gas compared to a gas mixture of SF6 and CF4. The maximum rated breaking current for the mixed gas 800kV GCB is only 40kA due to the lower interrupting capability of the gas mixture. The mixed gas 800kV GCB has a lower ambient temperature rating of -50°C and does not require tank heaters or other outside sources of heat to operate at -50°C as required by some Canadian utilities.

Table 1. Ratings for 800 kV GCB

	Pure SF6 gas	SF6 and CF4 mixed gas
Rated voltage	800 kV	
Rated lightning impulse withstand voltage (phase to earth)	2100 kV	2100 kV
2 μs chopped wave (ANSI standard)	2640 kV	-
Rated normal current	4000 A	
Rated breaking current	63 kA	40 kA
Rated interruption time	2 cycles	
Operation sequence	O-0.3sec.-CO-1min.-CO	
Operation mechanism	Pneumatic (Open), Spring (Close)	
Rated gas pressure (20℃)	0.59 MPa-g	
Ambient air temperature	-30 to +50℃	-50 to +50℃

Type tests were performed with pure SF6 gas in accordance with ANSI standards followed by type testing with mixed gas in accordance with IEC standards to meet the requirement of customers at various locations. Special test arrangements were required for testing at such high voltage and extremely low ambient temperature. For example, opposite voltage was applied to the tank of the test breaker to verify the internal insulation capability, so the tank was isolated during the interruption tests. Additionally, special short bushings were used for verifying the gas leak of bushing connections in testing room during high and low temperature test in compliance with IEC standards. Figures 3 and 4 show the pictures of type testing.

Fig. 3. 800 kV GCB during interruption test

Fig. 4. 800 kV GCB during high and low temperature test

3 Development of 245 kV GCB

Two types of 245 kV dead tank mixed gas GCB were developed based on a 245kV SF6 gas one-break GCB. Figure 5 shows the layout and construction of interrupter. One is a GCB that has independent phase operation (IPO), and the other GCB has three-phase gang operation (GO). Figure 6 shows the 245 kV mixed gas IPO GCB during interruption testing. The rated breaking current shown in Table 2 is 50 kA in case of using pure SF6 gas but rated breaking current is 40 kA without capacitor in the case of SF6 and CF4 mixed gas because of the mixed gas's lower dielectric capability and interrupting capability.

A spring operating mechanism stores mechanical energy in the solid spring. Since the operating characteristics of a spring operating mechanism are less affected by the change of ambient temperature and loss of mechanical pressure, which often occurs in hydraulic mechanisms due to hydraulic leakage, spring mechanisms are inherently superior in long-term reliability when compared to a pneumatic or hydraulic operating mechanism. Spring operating mechanisms are used on both types of 245kV GCBs. The helical spring operating mechanism in Figure 7 is used on the IPO GCB and the torsion bar spring operating mechanism in Figure 8 is used on the GO GCB. Due to the spring mechanism's low lifetime maintenance cost and high reliability, spring mechanisms are common in other GCB designs. CIGRE WG A3.06 investigations show that fewer failures are expected in spring operating mechanisms than in hydraulic mechanisms. Additionally, failure records show hydraulic mechanisms and their components fail more often than spring operated mechanisms. A 245kV pure SF6 GCB with a design similar to that shown in Figure 5 has been in continuous service for more than 16,000 operations without replacing any of the main components. This long service life verifies the reliability, integrity, and performance of the spring operating mechanism.

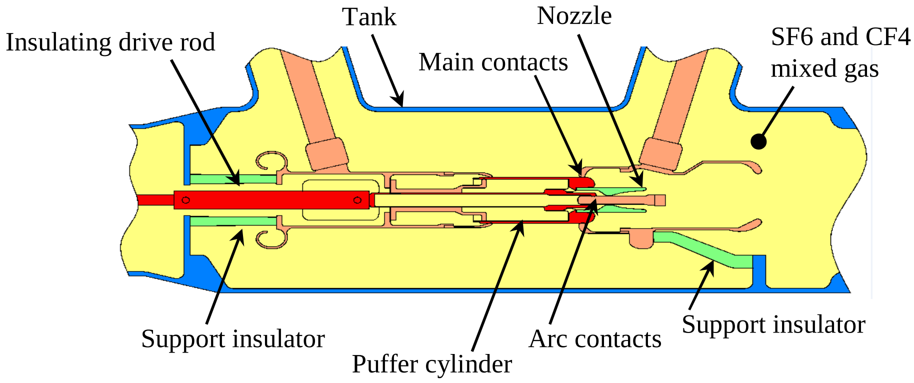


Fig. 5. Layout and construction of interrupter of 245 kV mixed gas GCB

Fig. 6. 245 kV mixed gas GCB
during interruption test

Table 2. Ratings for 245 kV GCB

	Pure SF6 gas	SF6 and CF4 mixed gas
Rated voltage	245 kV	
Rated lightning impulse withstand voltage (phase to earth)	900 kV	950 kV
2 μs chopped wave (ANSI standard)	1160 kV	-
Rated normal current	4000 A	
Rated breaking current	50 kA	50 kA with TRVcapacitor 40 kA without TRV capacitor
Rated interruption time	2 cycles	
Operation sequence	O-0.3sec.-CO-1min.-CO	
Operation mechanism	Spring (Open, Close)	
Rated gas pressure (20℃)	0.59 MPa-g	
Ambient air temperature	-30 to +50℃	-50 to +50℃

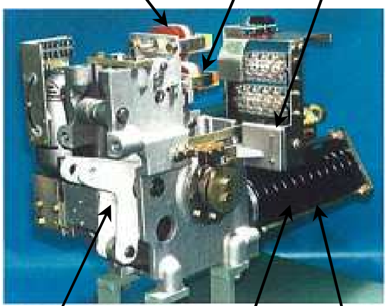


Fig. 7. Layout of helical spring operating mechanism for 245 kV IPO GCB

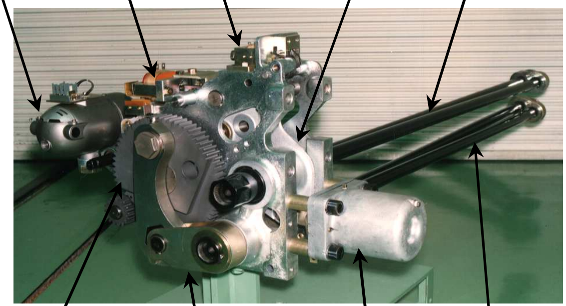


Fig. 8. Layout of torsion bar spring operating mechanism for 245 kV GO GCB

4. Advantage of spring operating mechanism

Low maintenance cost and high reliability are key advantages of a spring operated GCB. Maintenance work can be reduced when a spring operating mechanism is applied to GCB because of the reduced maintenance items and replacement parts. The number of replacement parts for a spring operated GCB is also reduced to 40% of that for hydraulic operated GCB. Maintenance items including test items can also be reduced to 40% of hydraulic operating mechanism.

Wide use of spring operating mechanism at higher ratings is required because of its key benefits of less maintenance work and high reliability. The torsion bar spring operating mechanism applied to 245kV mixed gas GO GCBs are applicable to circuit breakers up to 550kV rating because higher operating force can be obtained with a torsion bar spring than with a helical coil spring.

4.1 Advantage in maintenance work of spring GCB

Spring mechanisms can reduce the maintenance work on a circuit breaker by reducing the number of parts that need to be inspected and replaced. Table 3 shows the typical maintenance items for a spring operated GCB and a hydraulic operated GCB.

The number of parts in a spring operated GCB is 60% of that for a hydraulic operated GCB because the spring operated GCB does not need separate components such as a hydraulic pump, accumulator, and the hydraulic piping that connects the hydraulic components. The number of replacement parts for a spring operated GCB is also only 40% of that for a hydraulic operated GCB because of the reduced number of electric control parts including hydraulic parts such as pressure switches and oil level switches. Table 3 also shows that maintenance items and test items can be reduced to approximately 60% and 40% of a hydraulic operating mechanism respectively.

Figure 9 shows an example of the maintenance cost estimated on condition that internal inspection is carried out every 12 years. Total maintenance cost is estimated considering the life time of the GCB. The total maintenance cost for a spring operated GCB can be reduced to 40% of that for a hydraulic operated GCB [1].

Table 3. Number of parts and maintenance

Item		Spring GCB	Hydraulic GCB
Number of Parts		60%	100%
Number of parts for replacement		40%	100%
Number of oil seal location		>1%	100%
Maintenance	inspection item	60%	100%
	test item	40%	100%

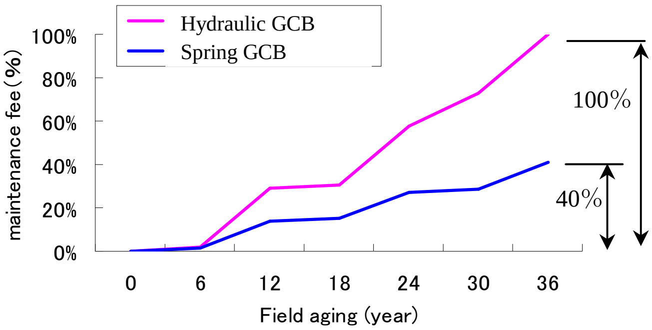


Fig.9. Example of the maintenance cost for hydraulic GCB and spring GCB

4.2 High reliability of spring mechanism

Comparison of failure rate between spring operated GCBs and hydraulic operated GCBs is shown in Figure 10 While major failures are comparable, minor failures of hydraulic operated GCBs are 7 times higher than that of spring operated GCBs. Figure 11 shows failure rates of components in operating mechanism in GCBs. Many of the failures are observed in the hydraulic components such as pipes, valves, hydraulic pumps, position indicators and accumulators, which are not equipped in spring operated GCBs. Failure rates of controls are also higher for hydraulic operated GCBs because of the higher number of control parts. Hydraulic pumps operate many times a day to maintain pressure for operation because rated hydraulic pressure is so high that small hydraulic leaks are inevitable. On the other hand, a spring operating mechanism can store stable mechanical driving energy for GCB operation for a long period without the need for additional charging.

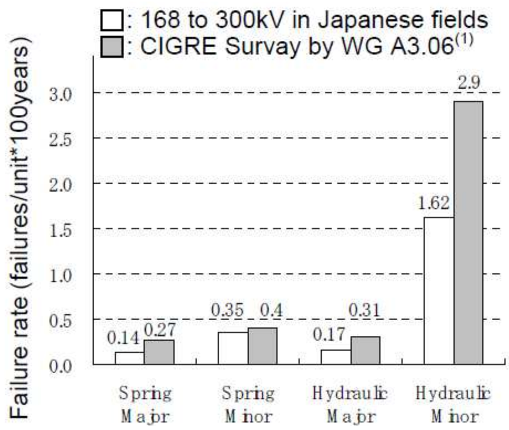


Fig.10. Failure rate of spring and hydraulic operated GCBs

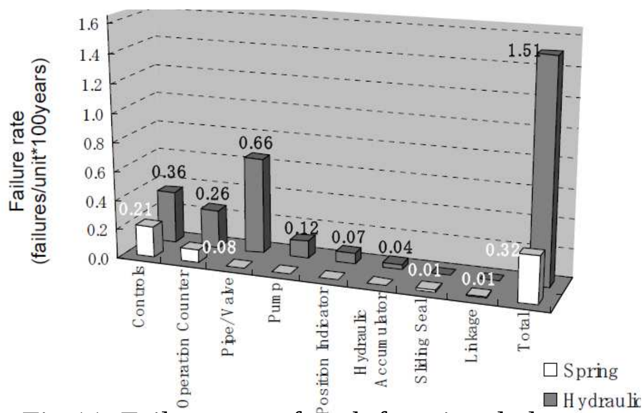


Fig.11. Failure rate of each functional element in spring and hydraulic operated GCB

4.3 Feature of torsion bar spring operating mechanism

A torsion bar spring gives higher spring energy for operation because the kinetic energy loss is insignificant, and can enhance the maximum operating energy where spring operating mechanism is applicable to a GCB.

Table 4. Comparison of torsion bar spring and helical spring

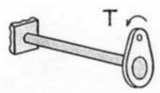
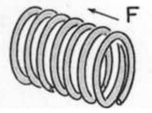
	Torsion spring	Helical spring
Shape		
Volume	10%	100%
Mass per Energy	65%	100%
Equivalent spring mass	1%	100%
Kinetic energy consumption	0%	25%
Driving energy for interrupter	100%	75%

Table 4 shows a comparison between the torsion bar spring and the helical spring, their equivalent mass considering the motion of the spring, kinetic energy consumed for the motion of the spring during operation, and final operating energy that can be used to drive the interrupter. Kinetic energy consumed for the torsion bar spring during operation is almost zero because the spring is just twisted and no motion of the spring position is required. On the other hand, kinetic energy of the helical spring is 25% of total changed energy because the motion of mass of the helical spring is required during operation. As a result, a torsion spring can utilize almost all the charged energy for driving the interrupter, while a helical spring can use only 75% of the total charged energy for operation. This enables the design of a torsion bar spring operating mechanism with higher stored operating energy and a practical size for manufacturing.

Due to the torsion bar spring's highly efficient operating force, it can be applied to GCB designs up to a 550kV rating. A torsion bar spring operating mechanism and a two-break interrupter have been applied to a 550kV GCB. Figure 12 shows a photograph of this GCB.

Operating speed that can achieve capacitive current switching capability is a key item to design spring operated GCB for higher rated voltage such as 550kV because charged spring energy is limited compared to the stored energy in a hydraulic system. A torsion bar spring operating mechanism contains higher spring energy for operation with a sufficient opening speed for capacitive current switching at rated voltage of 550kV as well as an application of a lightweight two-break interrupter [2].

Fig.12. 550kV Torsion bar spring operated GCB

5. Conclusion

A gas mixture of SF6 and CF4 enables the application of GCBs to extremely low ambient temperatures (less than -40 °C) because the condensation temperature is lower than pure SF6 gas with minimal reduction in dielectric and interrupting capability.

Spring operating mechanisms applied to 245kV mixed gas GCBs are widely used to other ratings since they enable utilities to reduce life time costs including maintenance cost of the GCB because of their high reliability. Torsion bar spring operating mechanisms are applicable to GCBs up to 550kV rating because higher operating force can be obtained with a torsion bar spring than with a helical coil spring.

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