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A3 TRANSMISSION AND DISTRIBUTION EQUIPMENT
PS2 - Decarbonisation of T&D Equipment

Experimental and Numerical Analysis of the Interruption Capability of SF_6-Free 245kV 63kA GCB

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SUMMARY

In this paper, the performance of gas circuit breaker(GCB) using the mixture of C_4F_7N and CO_2 is evaluated experimentally and numerically, focusing on the interruption capability gas circuit breakers. The rating of the GCB used in the experiment and analysis is 245 kV 63 kA self-blast type GCB and the work had been done for basic research of SF_6-free solution. The experiment was conducted using synthesis testing facility, and several tests for L90 duty of 63kA had been done. Interruption capability for SLF90 duty had been evaluated for each case. In addition, performance analysis through Computational Fluid Dynamics (CFD) had been done in parallel to evaluate the interruption capability by experiment. Modification of initial design such as the nozzle shape and thermal heating chamber had been done to increase the pressure and lower the temperature, and the interruption performance was evaluated using synthesis testing facility. As a result, the interruption performance was improved compared to the initial model. However, we found a problem that does not occur in the SF_6 GCB, such as the relatively large post-arc current, and an optimal design is needed to reduce the post-arc current. It is expected that this result can be usefully used for development of SF_6-free 245kV 63kA gas circuit breaker.

KEYWORDS

Gas Circuit Breaker(GCB), SF6-free, C_4F_7N, Computational Fluid Dynamics(CFD), SLF90, Post-arc current

1. INTRODUCTION

Nowadays, high voltage Gas circuit breakers (GCB) are widely used and considered as essential equipment in the power transmission and distribution field. For long years Sulfur hexafluoride (SF_6) has been widely used as an arc quenching medium since it has been commercially introduced because of its high dielectric strength and strong interruption performance. Due to the excellent interrupting performance, SF_6 gas was evaluated as the best medium because it is chemically stable, non-toxic, and has no ozone depletion potential (ODP). However, SF_6 gas is one of the most potent greenhouse gas with a global warming potential (GWP) about 23,000 times higher than that of CO_2. For this reason, a lot of research and development has been dedicated to finding an alternative gas to SF_6. Among the numerous SF_6-free alternative gases that have been studied, C_4F_7N and CO_2 gas mixture is widely used as an alternative gas due to its excellent insulating performance. In the case of a mixed gas of C_4F_7N and CO_2, Global Warming Potential is extremely lower than that of SF_6 and with the higher filling pressure, it is known that the insulation performance is similar to that of SF_6. However, it is known that the interruption performance based on CO_2 is much lower than that of SF_6. In addition, it is difficult to evaluate the interruption capability because it is related to the flow characteristics that vary depending on the shape of the circuit breaker. Therefore, in order to satisfy the interrupting capability of GCB using alternative gas, it is necessary to improve and change according to the flow characteristics of alternative gas rather than simply increasing the filling pressure or using a higher rating circuit breaker which is already developed for SF_6 gas. For this, it is necessary to understand the flow characteristics of alternative GCB and to accurately evaluate the interruption capability.

In this paper, the performance of GCB using the mixture of C4F7N and CO2 is evaluated experimentally and numerically, focusing on the SLF interruption capability of gas circuit breakers. The rating of the circuit breaker used in the experiment and analysis is 245 kV 63 kA self-blast type gas circuit breaker and the work had been done for fundamental research of SF6-free solution. The experiment was conducted using synthesis testing facility, and several tests for L90 duty of 63kA had been done. Interruption capability for SLF90 duty had been evaluated for each case. In addition, performance analysis through Computational Fluid Dynamics (CFD) had been done in parallel to evaluate the interruption capability of tested model. The analysis program was developed for in the design stage. A database was established by analyzing all experiment cases and numerous design proposals that were not actually tested, and the correlation between the CFD results and interruption capability was analyzed. The analyzed results were reflected in improving the design of circuit breakers. In this way, in parallel with the experimental and numerical analysis, the interruption capability of the 245kV 63 kA self-blast SF6-free gas circuit breaker was evaluated and an improved design was derived.

2. SYNTHETIC TEST MODEL FOR 245KV 63KA 50HZ GCB

The interruption capability test had been done at the synthetic testing facility. Test conditions are shown in Table 1.

Table 1. Test condition

Rated Voltage	245kV
Rated short-circuit current	63kA
Rated frequency	50Hz
Types of interruption	Self-blast
Medium gas	CO_2(95%) + C_4F_7N
Test duty	SLF 90
Rate of Rise of Recovery Voltage (RRRV) of 1st peak	12.5kV/us

The commercial SF_6 245kV 63kA GCB is used as a base model for the interruption test. First of all, the interruption performance to satisfy the SLF90 duty was the main objective of this work. Therefore, the interruption test was conducted with 1st peak value of Rate of Rise of Recovery Voltage (RRRV) as 12.5 kV/us.

3. INFLUENCE FACTORS FOR INTERRUPTION CAPABILITY

There are many factors that determine the interruption performance of all types of circuit breakers as well as eco-friendly gas circuit breakers. Basically, pressure rise, post-arc current and arc conductance are representative. Among them, the initial design was carried out using two influencing factors that are easy to handle with the help of CFD analysis. The first factor is pressure rise in the heating chamber and the second is gas temperature out from the heating chamber. In both cases, the effects of changes depending on the design can be easily analyzed through CFD analysis.

3.1. PRESSURE RISE

In the case of pressure rise, it is very important in determining the interruption performance of the gas circuit breaker. The pressure in the heating chamber of the gas circuit breaker can be the most important driving force for extinguishing the arc at the current zero. In general, it is known experimentally or theoretically that the pressure of CO_2-based eco-friendly gas rises higher than that of SF_6. The same trend was observed in the tests of this work as shown in figure 1. However, after the current peak time, the speed of outflow from heating chamber is also faster compared to SF_6, resulting in quick pressure drop.

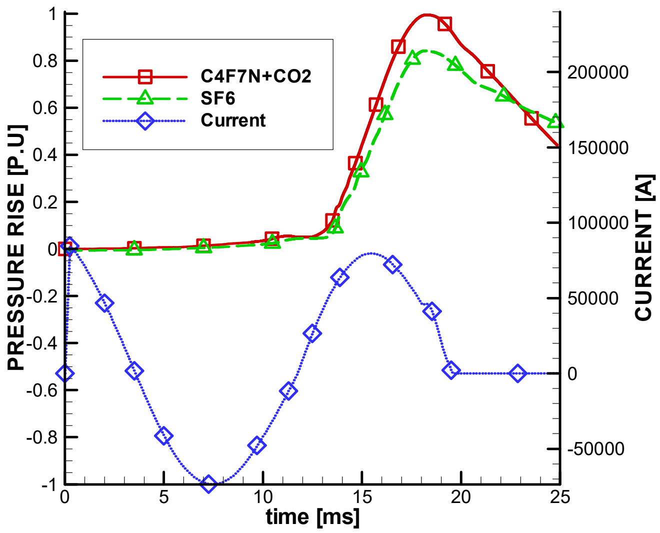


Fig 1. Comparison of pressure rise of SF_6 and CO_2 mixture

The rapid pressure drop can be overcome to some extent by the design modification of the circuit breaker. Therefore, major changes has been done to increase the maximum pressure and maintain the pressure rise.

3.2. GAS TEMPERATURE

The temperature of the arc and outflow gas at the current zero is also very important in determining the interruption performance of the gas circuit breaker. The temperature of the gas from the heating chamber and the arc temperature between the electrodes is directly related to the arc resistance at the current zero. In general, unlike the puffer type gas circuit breaker, the performance of the self-blast gas circuit breaker is particularly sensitive to the upstream gas temperature because the temperature heat chamber may be very high. Also, the temperature between the arcing contacts is related to the arc conductance of the gas circuit breaker and G(200ns), which is a widely-used index to evaluate the SLF interrupting performance of the gas circuit breaker. Although arc conductance was not directly analyzed in this study, design modification has been done to minimize the arc temperature and outflow gas temperature from the heat chamber.

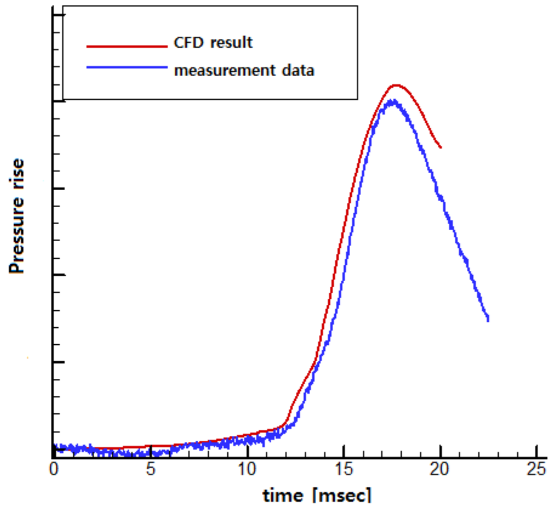
4. CFD ANALYSIS

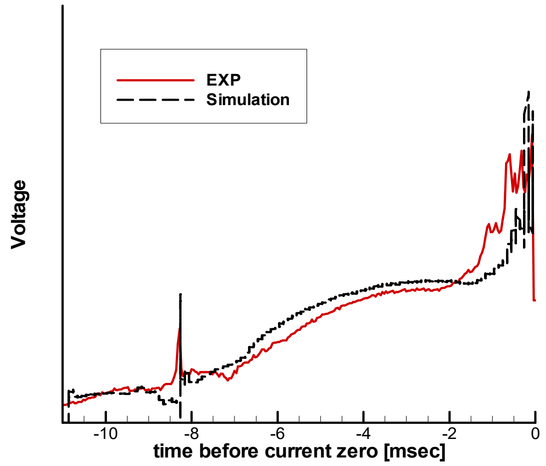
For the design modification to satisfy the factors discussed in section 3, CFD analysis was used. An in-house code based axisymmetric 2D program was developed and validated for the study. Numerical method used in the program is listed in table 2.

Table 2. Numerical schemes used in the paper

	scheme	References
Inviscid flux	AUSMPW+ (FVS)	[1]
Time integration	LU-SGS (implicit) Dual-time-stepping	[2]
Grid system	Structured grid Overset method	[3]
Radiation	DOM 11 bands with Planck averaging	[4]

First, the measurement value and the CFD result were compared as shown in figure 2. The pressure in the heat chamber and arc voltage between the electrode had been validated. As can be seen from the figure 2, the analyzed pressure as well as arc voltage were considerably matched with the measurement data.

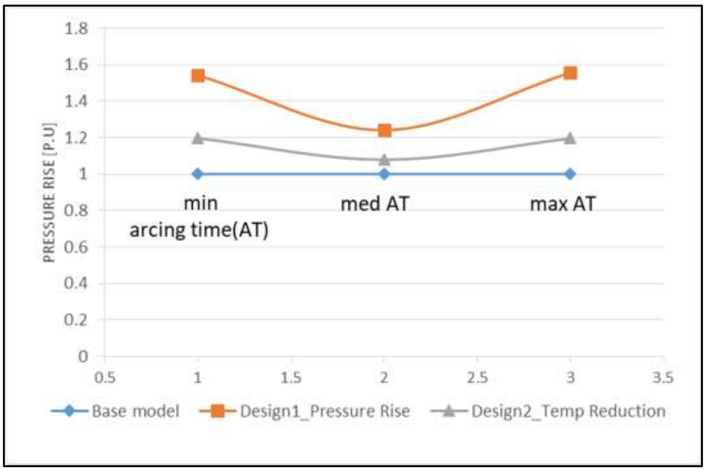




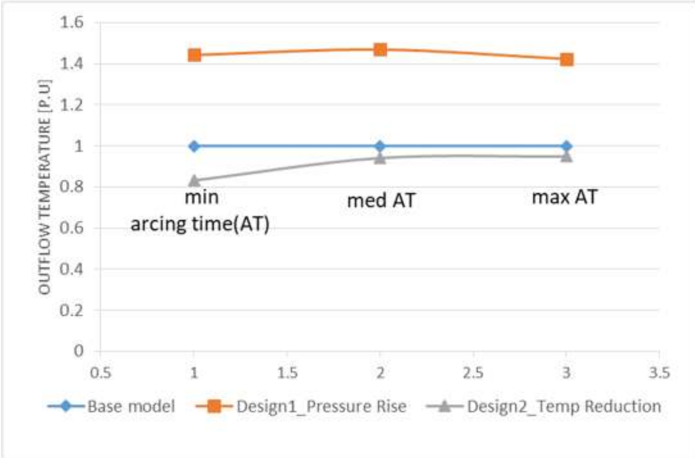
(a) Pressure rise (b) Arc voltage

Fig. 2 Validation result of SF_6-Free Gas Circuit Breaker (C_4F_7N and CO_2 mixture)

In this study, the design modification has been done to increase and maintain the pressure in the heat chamber and decrease the outflow and arc temperature at the current zero as discussed in section 3. First, in order to increase and maintain the upstream pressure, the shape of nozzle was mainly changed. Also, in order to lower the temperature, major changes were done in the shape of the nozzle as well as the shape of the heat chamber. Pressure and outflow temperature were analyzed for the modified design. The result is shown in figure 3.



(a) Pressure rise at current zero in heat chamber



(b) Outflow temperature in the heating channel
Fig 3. Pressure rise and Temperature at the channel of new design

In the case of pressure increase design, as shown in the figure 3, it was possible to significantly increase the pressure with mainly changing the shape of the nozzle. The nozzle length was increased by 30% and the nozzle diameter was decreased by 10%. The shape of nozzle, heat chamber and flow channel between the heat chamber and the nozzle were also changed. Through this design concept, the pressure at current zero was increased as well. As shown in the figure 3, when the pressure is raised in self-blast type circuit breaker, the temperature of the gas also rises, so it was necessary to find an appropriate optimal design in the final design stage.

In the case of the outflow gas temperature and arc temperature between the arc contacts, it was difficult to make a dramatic change as in the case the pressure, but it was possible to lower it through a design change of the heat chamber. As described above, when the outflow gas temperature is lowered, the pressure is generally lowered as well. Therefore, a design that can significantly lower the temperature while maintaining the pressure was selected and tested.

5. TEST RESULT AND DISCUSSION

The baseline model is a 245kV 63kA 60Hz circuit breaker with SF_6 gas that is commercially developed. In the first test, the SLF90 performance evaluation was done under the same conditions by changing the medium gas of the base circuit breaker. The results are shown in the table 3.

Table 3. Interruption test for commercial GCB

Gas	test RRRV	Filling Pressure	Success/Fail
SF6	14.6kV/us	6.5bar	O
CO2(95%)+ C_4F_7N	5.0kV/us	6.5bar	X
CO2(95%)+ C_4F_7N	5.0kV/us	8.0bar	O
CO2(95%)+ C_4F_7N	5.5kV/us	8.0bar	X

In the case of SF_6, the initial slope of 14.6kV/us was successfully interrupted, but 5.0kV/us was failed under the same filling pressure with SF_6 free gas, so the performance was evaluated to be less than half. In the test in the table 3, C_4F_7N gas was tested under the exact same conditions as SF_6, and it was confirmed that the performance with RRRV 5.0kV/us was obtained by increasing the filling pressure. Based on this baseline test results, the design strategy mentioned in section 4 was applied to improve the interruption performance.

First, in the case of the pressure rise design, the initial RRRV was successful up to 12.7kV/us. The results are shown in the table 4 (b).

RRRV at 1st peak (kV/us)	Success/Fail	Test order
6.5	O	1st
8	O	6th
9	O	9th
10	X	10th

(a) Design for temperature reduction

RRRV at 1st peak (kV/us)	Success/Fail	Test order
9	O	1st
10.5	O	6th
12.7	O	9th

(b) Design for pressure rise

Table 4. Synthetic test result of interruption capability

In particular, it was confirmed that the performance was maintained even after the test had progressed to some extent. The figure 4 shows the measurement results of post arc current in case of success/failure tests. The result of the post-arc current is very different from that of the conventional SF_6 gas circuit breaker. In general, in the case of SF_6 gas, the magnitude of the post-arc current is very small (1A or less) when it succeeds, and it disappears within a few micro seconds. However, as a result of the synthetic test of C_4F_7N gas, there are cases where the post-arc current is up to 20~30 A, and there are cases where the post-arc current maintains over 10μs. This may be due to the difference in arc time constant of the two gases.

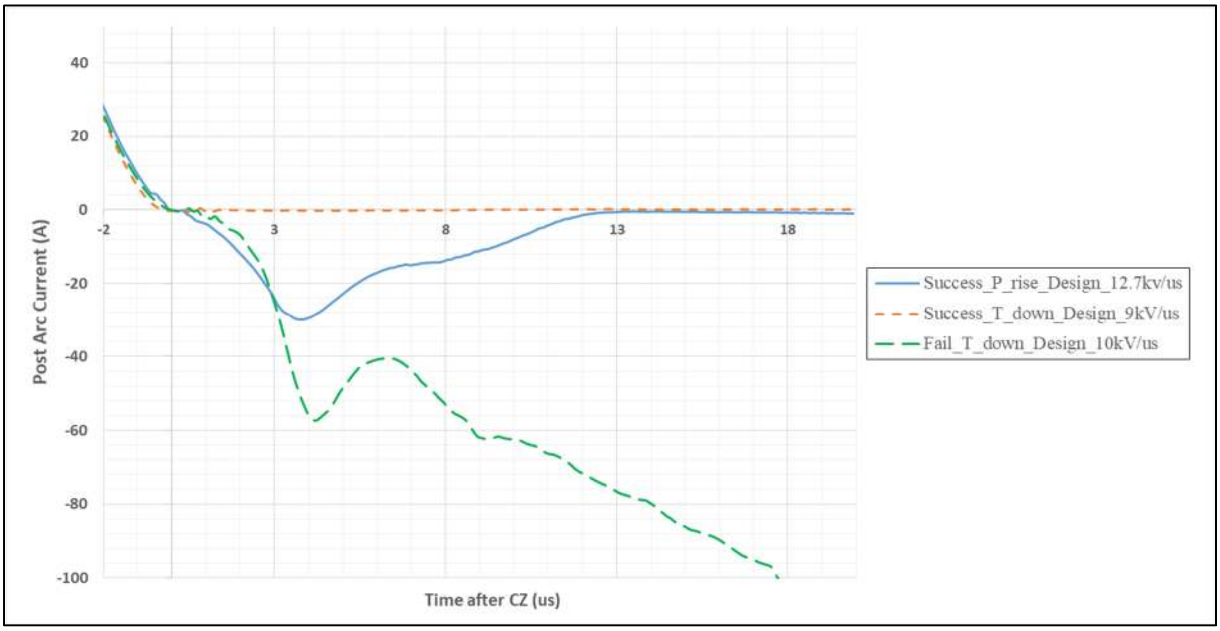


Fig 4. Measurement data of Post arc current for several cases

In the case of SF_6 gas, since the value of the arc time constant is very small compared to that of the CO_2-based gas, electron recombination and thermal recovery occur within a very short time. This causes a rapid decrease in the post arc current in a few micro seconds. In contrast, the CO_2-based gas has a relatively large arc time constant, so the time required for thermal recovery is relatively long. It is possible to accurately evaluate the performance by observing the trend of the recovery voltage after 10us. In this study, the test was conducted using synthetic testing equipment, and only the first peak of the SLF test (occurring within 5μs) was simulated, so the waveform of transient recovery voltage is different from the actual high power lab (HPL) test. In order to succeed in the HPL test, it may be necessary to additionally find a design that can reduce the magnitude of the post-arc current within 5~10us.

For the outflow gas temperature reduction design, the results are presented in the table 4(a). More than 10 tests were conducted to find the accurate interruption performance, and the last test showed a performance of RRRV 9kV/us. It is expected that better performance would have been obtained with the initial shape. The model is a model in which the pressure is slightly raised from the base model, but the outflow gas temperature is reduced as shown in figure 3(b). The reason why the interruption test results of this model are meaningful is shown in the figure 4. Unlike the result of the design of pressure increase mentioned above, post arc current is very small when successful test. Also, it can be confirmed that it disappears completely within 3μs.

Investigating the results of the figure 4, it is possible to find a design that satisfies interruption capability through appropriate pressure rise and reduction of temperature.

6. CONCLUSION

This study includes the results of basic research conducted prior to the development of the 245kV 63kA self-blast type GCB using SF_6 free, eco-friendly gas. Using a commercial GCB developed for SF_6 as a baseline model, the factors related to interruption performance were found, and designs that can improve the performance were determined through CFD analysis. Modification of initial design such as the nozzle shape and thermal heating chamber had been done to increase the pressure and lower the temperature, and the interruption performance was evaluated using synthetic test facility. As a result, the interruption performance was improved compared to that of baseline model. However, we found a problem that does not occur in the existing SF_6 circuit breaker, such as the relatively large post-arc current, and an appropriate optimal design would be needed to reduce it. It is expected that this result can be useful for development of SF_6-free 245kV 63kA GCB.

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