J Electr Eng Technol.2016; 11(4): 969-973
http://dx.doi.org/10.5370/JEET.2016.11.4.969

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Thermal Recovery Characteristics of a CO_2 Mixture Gas Circuit Breaker

Yeon-Ho Oh†, Ki-Dong Song*, Hae-June Lee and Sung-Chin Hahn*****

Abstract – Interruption tests were conducted using the same circuit breaker for an initial pressure of SF_6 0.5 MPa (gauge pressure) and CO_2 mixture 1.0 MPa, 0.8 MPa, and 0.6 MPa. The pressure-rises in the compression and thermal expansion chambers were measured for verifying the computational results using a simplified synthetic test facility. Further, the possibility of the CO_2 mixture substituting SF_6 gas was confirmed. Moreover, in view of the thermal recovery capability, it has also been confirmed that the pressure of the CO_2 mixture can be reduced almost to the same value as that of the SF_6 gas by optimizing the design parameters of the interrupter.

Keywords: Gas circuit breaker, CO_2, SF_6, Thermal recovery, Global warming potential

1. Introduction

In 1994, SF_6 was declared as the gas with the biggest impact on the environment [1], and since then, studies for substituting SF_6 in high voltage switchgears are being actively carried out to use it as a medium of insulation and arc extinguishment. Fundamental results for eco-friendly gases such as CO_2 and N_2 had already been reported in the 1980s before the Kyoto Protocol was established in 1997 [2, 3]. During the late 1990s, there was an attempt to apply CF_3I to switchgears; however, there were issues regarding its price and its dew point temperature [4]. As another attempt to substitute SF_6, the DAIS (Dry air insulated switchgear), which is an interrupter, is replaced by a vacuum valve and the remaining part is insulated by dry air. However, this is difficult because of the current chopping problem of the vacuum valve, the mechanical endurance of the bellows, the limited length of the contact gap, and so on [5]. Recently, in 2012, the development of a CO_2 mixture gas circuit breaker had been announced in a symposium [6]. In addition, new artificial gases such as g^3 and C5PFK (Perfluor Ketone) are being issued; however, there are still problems that need to be fixed regarding their high global warming potential, price, and boiling point [7, 8].

As mentioned above, a few new gases are being developed for substituting SF_6; however, each of them has some limitations. Therefore, it has been predicted that the development of the eco-efficient switchgear will be based on a mixture of the CO_2 gas and a new gas.

This paper compares the test results of the interruption capability of a SLF (short line fault) for the 72.5 kV, 20 kA CO_2 mixture gas circuit breaker with that for the SF_6 gas circuit breaker. Computation analyses were performed to optimize the interrupter design parameters and to verify the computational results, the pressure-rises in the compression and thermal expansion chambers are measured.

2. Basic Structure of the Interrupter and Optimization of the Design Parameter

The specifications of the CO_2 mixture gas circuit breaker used in this study are indicated in Table 1.

For the same circuit breaker, interruption tests were carried out for the initial filled pressure of SF_6 0.5 MPa and CO_2 mixture 1.0, 0.8, and 0.6 MPa. To satisfy the criteria for the optimization of the interrupter design parameter in the conventional gas circuit breaker, only the arc conductance at 200 ns before current zero (namely G200) had been used [9], but in this study, the post-arc current has also been considered. In the prediction of the SLF interruption capability of a circuit breaker, if the post-arc current around current zero is correctly calculated, it will be the best criteria for optimizing the interrupter design parameter. The method has been described in reference [10]. In order to counter the weak insulation and

Table 1. Specification of CO_2 mixture gas circuit breaker

Items	CO_2 mixture gas circuit breaker
GWP	1(SF_6 = 23,900)
Initial Pressure [gauge]	1.0MPa, 0.8MPa, 0.6MPa (0.5MPa for SF_6)
Interrupter Type	self-blast
Mechanism & Motion Type	Motor-spring & Dual Motion
Criterion of interrupter optimization	- G200 - Post-arc current

* G200: arc conductance at 200 ns before current zero

---

† Corresponding Author: Korea Electrotechnology Research Institute, Korea. (yhoh@keri.re.kr)
* Korea Electrotechnology Research Institute, Korea. ({kdsong, kimhk}@keri.re.kr)
** Dept. of Electrical Engineering, Pusan University, Korea. (haejune@pusan.ac.kr)
*** Dept. of Electrical Engineering, Dong-A University, Korea. (schahn@dau.ac.kr)

Received: August 10, 2015; Accepted: March 19, 2016

interruption capability of the CO_2 mixture, the ablation element has been added and the dual motion has been utilized (see Fig. 1).

Fig. 1 shows the basic structure of the model interrupter used in this study. First, the stroke length (=130 ㎜) and the opening speed (≒5 ㎧) are decided, then the other important design parameters of the interrupter model, such as the volume of the thermal expansion chamber, the nozzle shape, and the overlapping length of the arc contacts are decided. Furthermore, the ablation element causes the pressure to rise and the gas to cool in the thermal expansion chamber. The material of the ablation element is filled with MoS2 having 0.1 - 0.2% of PTFE (poly-tetra-fluoro-ethylene).

The interrupter is optimized using design parameters such as 1) the volume of the thermal expansion chamber, 2) the cross section area of the thermal heat channel, 3) the shape of the main nozzle, and 4) the diameter of the 2nd nozzle throat. Almost 30 model interrupters have been examined as shown in Fig. 2. The optimization and final evaluation was conducted by comparing the values of the pressure-rise and temperature in the thermal expansion chamber, G200, and the post-arc current.

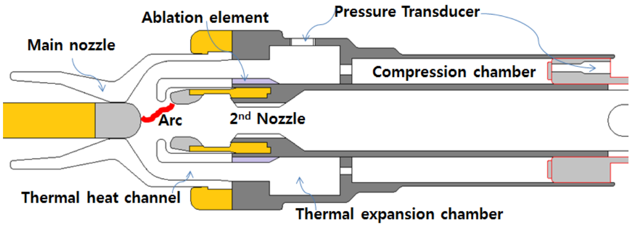


Fig. 1. Basic structure of model interrupter

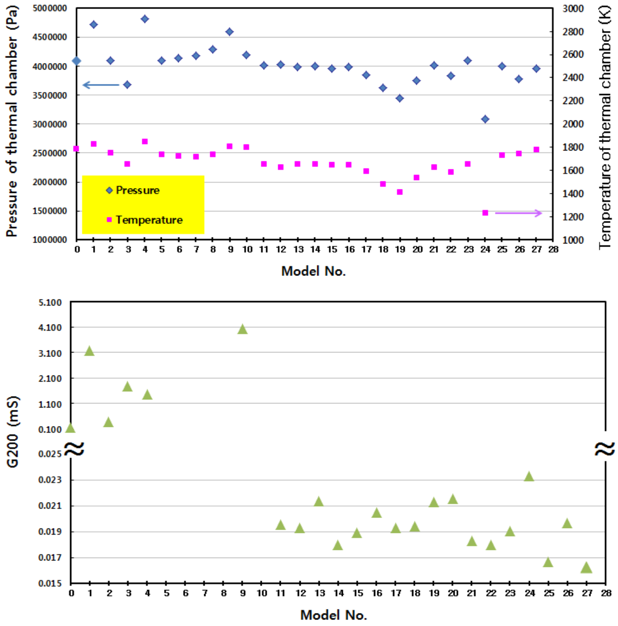


Fig. 2. Comparison of the pressure and temperature in the thermal expansion chamber and G200 for each model interrupter

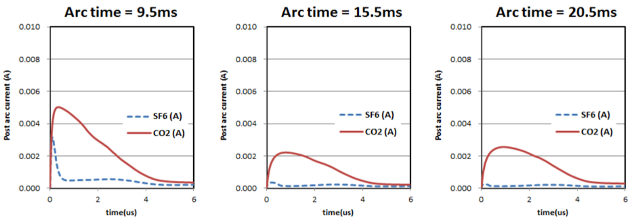


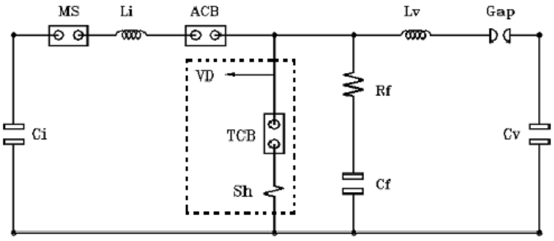
Fig. 3. Example of post-arc current for the final model interrupter (SF_6: 0.5 MPa, CO_2: 1.0 MPa)

The predicted results of the SLF interruption capability (presented by the value of the post-arc current) for the final model interrupter that was selected through the optimization process are shown in Fig. 3. The results had been calculated for the initial filled pressure of SF_6 0.5 MPa and CO_2 1.0 MPa. Although the initial pressure of the CO_2 mixture gas was higher than that of the SF_6 gas, its post-arc current value is high.

3. Tests and Results

The SLF interruption tests for the model circuit breaker were conducted using the simplified synthetic test facility. The test circuit and the actual picture of the model circuit breaker are shown in Fig. 4 and Fig. 5 respectively.

The test results for the SF_6 gas at 0.5 MPa (gauge pressure) are indicated in Table 2. The results show that the circuit breaker has a capability to interrupt above the arc time of 7.0 ms. It means that the minimum arc time of the circuit breaker is 7.0 ms, which is very short, while that of the general circuit breakers is more than 9.0 ms. As an example of the measured results, Fig. 6 represents the stroke, current, and pressure rise in the compression and thermal expansion chambers for the arc time of 8.6 ms and SF_6 0.5 MPa.



Ci : capacitor for current source 45,00 ㎌
MS : making switch
Li : reactor for current source 0.156 mH
ACB : auxiliary circuit breaker
TCB : test circuit breaker
Rf : resistor for TRV (transient recovery voltage) 300 Ω
Cf : capacitor for TRV 3,600 ㎊
Lv : reactor for voltage source 1.396 mH
Gap : discharge gap
Cv : capacitor for voltage source 49.5 ㎌

Fig. 4. Circuit of the simplified synthetic test facility

Table 2. Interruption test results in 0.5 MPa SF_6 100% gas

Current [kA]	arc time [㎳]	Interruption fail/success	Pressure-rise [x10 MPa]		Filename for DAS
			Expansion chamber	Compressor chamber	
No load	-	-	2.2	4.0	D041404
No load	-	-	2.2	3.8	D041405
21.8	10.0	O	11.8	8.3	D041411
22.4	8.6	O	11.2	7.8	D041412
20.8	8.0	O	9.4	7.0	D041413
21.9	6.6	X	5.0	4.8	D041414
21.3	7.4	O	7.1	6.0	D041415

Fig. 5. CO_2 mixture gas circuit breaker used for the test (mechanism + interrupter)

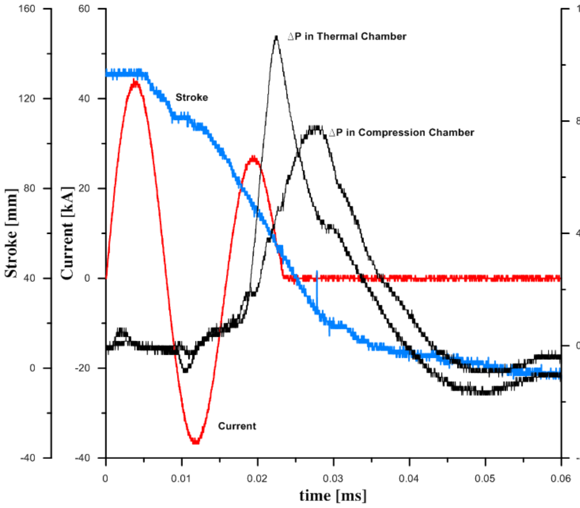


Fig. 6. Example of the measured results (SF_6 0.5 MPa, interrupted current 22.5 kA, and arc time 8.6 ms)

From Fig. 7, it can be observed that the arc time increases as the initial pressure decreases. As the initial pressure in the case of CO_2 0.6 MPa is almost the same as that for the SF_6 gas, the difference in the minimum arc time is approximately 2.0 ms.

Table 3. Interruption test results in 1.0 MPa CO_2 Mixture

Current [kA]	arc time [ms]	Interruption fail/success	Pressure-rise [x10 MPa]		Filename for DAS
			Expansion chamber	Compressor chamber	
No load			2.6	3.4	D041603
No load			2.6	3.3	D041604
14.9	6.8	X	4.2	4.9	D041606
20.8	8.0	O	10.6	9.0	D041607
21.3	7.4	X	9.0	-	D041608
22.2	8.6	O	13.8	11.3	D041609
21.2	9.4	O	15.3	11.8	D041610
20.8	8.2	O	9.8	8.5	D041612

Table 4. Interruption test results in 0.8 MPa CO_2 Mixture

Current [kA]	arc time [ms]	Interruption fail/success	Pressure-rise [x10 MPa]		Filename for DAS
			Expansion chamber	Compressor chamber	
20.9	8.4	O	9.3	8.5	D041613
19.8	10.0	O	11.1	9.3	D041614

Table 5. Interruption test results in 0.6 MPa CO_2 Mixture

Current [kA]	arc time [ms]	Interruption fail/success	Pressure-rise [x10 MPa]		Filename for DAS
			Expansion chamber	Compressor chamber	
21.2	7.8	X	9.6	-	D041615
21.0	8.8	X	10.1	9.8	D041616
22.0	9.4	O	13.4	11.3	D041617
21.9	9.2	O	13.4	11.2	D041618

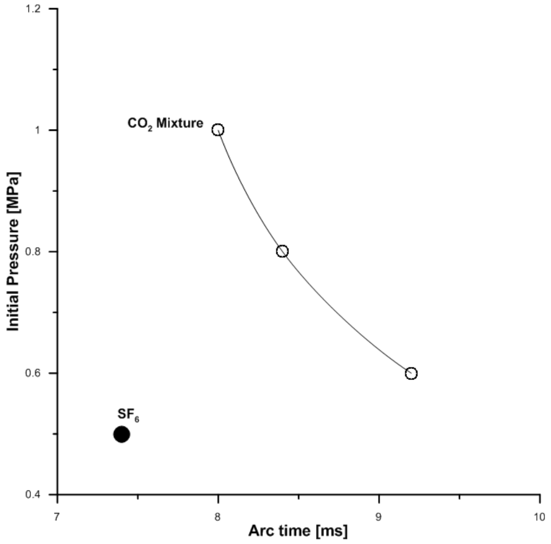


Fig. 7. Change of the minimum arc time according to the initial filled pressure of the CO_2 mixture

The pressure-rise in the thermal expansion chamber plays a very important role in extinguishing the arc and cooling the hot-gas flow in the self-blast interruption-type circuit breaker. Therefore, it deals with the most important design factor in the stage of optimization. The pressure-rises of the CO_2 mixture in the thermal expansion chamber compared with that of the SF_6, according to the arc time, are shown in Fig. 8. The pressure-rise in the thermal

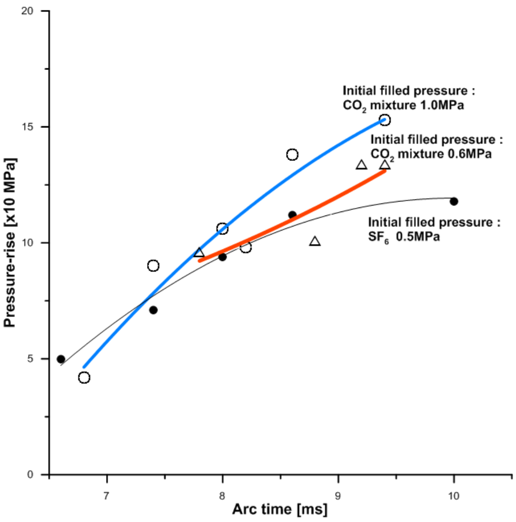


Fig. 8. Pressure-rise in the thermal expansion chamber of the SF_6 and CO_2 mixture according to the arc time (interrupted current 21.0-22.0 kA)

expansion chamber increases as the arc time gets longer; however, it tends to be saturated.

4. Conclusion

It is well known that the dielectric and interruption capabilities of CO_2 are only 20~30% of those of SF_6 [13]. The ablation of the solid insulation material affects the pressure-rise in the thermal expansion chamber [4]. Therefore, it is important to properly utilize the ablation element. Moreover, if the volume of the thermal expansion chamber, the main nozzle shape, and the cross section of the thermal channel is optimized through computer simulation, then its own limitations can be met, and this fact has been confirmed through this paper.

References

[1] T. R. Carter et al., IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations, Working Group II of the Intergovernmental Panel on Climate Change, 1994.

[2] D. T. Tuma, “A Comparison of the behavior of SF_6 and N_2 blast arcs around current zero,” IEEE Transactions on Power Apparatus and Systems, vol. PAS-99, no. 6, pp. 2129-2137, Dec. 1980.

[3] H. Sasao, S. Hamano et al., “Dynamic behavior of gas-blasted arcs in SF_6-N_2 mixture,” IEEE Transactions on Power Apparatus and Systems, vol. PAS-101, no. 10, pp. 4024-4029, Oct. 1982.

[4] H. Katagiri, H. Kasuya, “BTF interruption capability of CF_3I-CO_2 mixture,” Gas Discharges and their applications, pp. 105-108, 2008.

[5] Japan AE Power Systems Corporation, 72.5 kV Dry Air Insulated Dead Tank Vacuum Circuit Breaker, Japan AE catalog, vol. MAE-027.

[6] ABB, High voltage CO_2 circuit breaker type LTA enhancing eco-efficiency, ABB catalog, 2012.

[7] Alstom Grid Media Relations, Spotlight on g3: Alstom’s alternative to SF_6, Alstom catalog, 2015. [8] ABB, High voltage CO_2 circuit breaker type LTA enhancing eco-efficiency, ABB catalog, 2012.

[9] R. P. P. Smeets and V. Kertész, “A new arc parameter database for characterisation of short-line fault interruption capability of high-voltage circuit breakers,” CIGREE, A3-110, 2006.

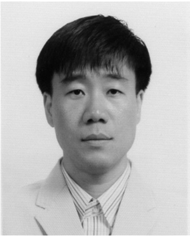
[10] K. D. Song et. al., “Analysis of thermal recovery for SF_6 gas-blast arc within Laval nozzle,” Jpn. J. Appl. Phys., vol. 42, pp. 7073-7079, 2003.

[11] Y. H. Oh et al., “Prediction of thermal recovery of a CO_2 mixture gas circuit breaker” submitted for publication, 2015

[12] W. Y. Lee et al., Development of evaluation technology and system for simplified interruption capability (KOREAN), 1997-EL02-E-41, MOTIE report, Aug. 2000.

[13] M. Taki, D. Maekawa et al., "Interruption Capability of CF_3I Gas as a Substitution Candidate for SF_6 Gas," IEEE Transactions on Dielectrics and Electrical Institute, vol. 14, no. 2; April 2007.

[14] D. Godin, J. Y. Trepanier et al., “Modelling and simulation of nozzle ablation in high-voltage circuit-breakers,” J. Phys. D: Appl. Phys., vol. 33, pp. 2583-2590, 2000.



Yeon-Ho Oh He received the B.S. and M.S. degrees in electrical engineering from Dong-A University, Busan, Korea, in 1991 and 1993, respectively. He is currently a Research Engineer with the Power Apparatus Research Center, HVDC Research Division, Korea Electrotechnology Research Institute (KERI).

Ki-Dong Song He received the B.S. and M.S. degrees in electrical engineering from InHa University, Incheon, Korea, in 1988 and 1990, respectively. He got his Ph.D. degree in electrical engineering from Busan National University in 2003. He worked for Korea Electrotechnology Research Institute (KERI) from 1990 and is now the director of the Power Apparatus Research Center, HVDC Research Division. His research interests focus on analysis and design for AC Power Devices and HVDC circuit breakers.

Hae June Lee Professor Hae June Lee received his B.S. degree with from the Department of Nuclear Engineering at the Seoul National University in 1994, and his M.S. and Ph.D. degrees in physics in 1996 and 1998 from POSTECH. He worked as a post doc. in the Department of Electrical Engineering at the UC Berkeley in 2000 and 2001 and as a research scientist in Korea Electrotechnology Research Institute (KERI) after then. Since 2004, Prof. Lee has been a faculty member in the Department of Electrical Engineering at Pusan National University (PNU), South Korea.

Sung-Chin Hahn He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Seoul National University, Seoul, Korea, in 1979, 1981, and 1992, respectively. He is currently a Professor with the Department of Electrical Engineering, Dong-A University, Busan, Korea. His current research covers multi-physics analysis and optimal design of power apparatus and electric machines.