Study Committee A3

Transmission and Distribution Equipment

Paper 10126_2022

Comparative Continuous and Overload Current Performance of High Voltage Switchgear with SF_6 and Alternative Gases

Victor HERMOSILLO
GE Grid Solutions, U.S.A.

Diana LEGUIZAMON-CABRA, Marius CATALA, Ludovic DARLES, Cyril GREGOIRE, Jean-Alain RODRIGUEZ
GE Grid Solutions, France

Motivation

- Comparative continuous current and overload performance assessment of $C_4FN/O_2/CO_2$ in gas-insulated GIS bus and dead-tank circuit breakers.
- Test the validity of coefficients in the empirical equation used by IEC standards for the estimation of temperature rise at various current levels.
- Study the effects of electrical wear in the main current path resistance of a live tank circuit breaker. Implications for joule losses.

Method/Approach

- Theoretical calculation of thermal performance of SF_6, CO_2 and technical air in a GIS busbar. Comparison with experimental results with these gases.
- Experimental tests on dead-tank circuit breakers at currents in the range of 3000 to 4000 A. Comparison between temperature rise results obtained with SF_6 and $C_4FN/O_2/CO_2$ gas insulation.
- Calculation of coefficients for IEC temperature rise empirical equation.
- Measurement and comparison of resistance before and after breaking tests for live-tank circuit breakers.

Objects of investigation

- Gas-insulated GIS busbar
- Dead-tank circuit breaker
- Live-tank circuit breaker.

Simulations

- 2D simulation of a coaxial line.
- Considering effusivity of SF_6, CO_2 and technical air.

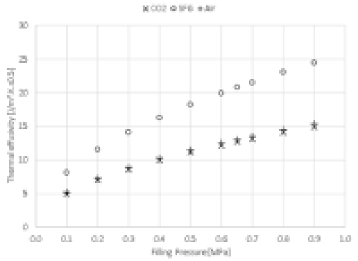
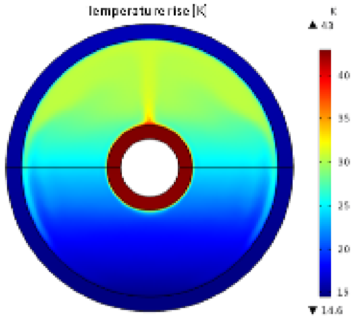


Figure 1: Thermal effusivity of CO_2, SF_6 and technical air in gaseous form over pressure



Gas = CO_2, Pfill = 0.9 MPa and $I_{r.m.s}$=3150 A

Figure 2: Temperature rise, GIS busbar 2D computation

Experimental setup & test results

- GIS bus with SF_6, CO_2 and technical air gas insulation test cases

Figure 4– Picture of GIL under test

Table 1: Temperature rise test summary

Test N°	Busbar	Spacer Electrode	Gas type	Gas pressure (MPa abs.)
1	1	A	SF_6	0.65
2	1	A	C_4FN (5%)/ O_2(13%)/CO_2	0.8
3	2	A	SF_6	0.65
4	2	A	C_4FN (5%) /O_2(13%)/CO_2	0.8
5	2	B	C_4FN (5%)/ O_2(13%)/CO_2	0.8
6	2	B	O_2 (13%) / CO_2 (87%)	0.8
7	2	B	Dry air	0.8
8	2	B	Dry air	0.9

Study Committee A3

Transmission and Distribution Equipment

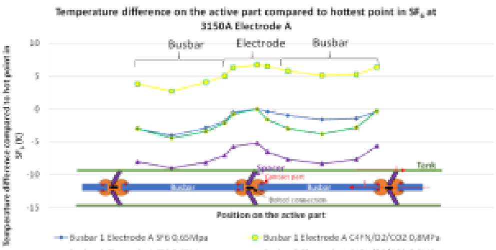
Paper 10126_2022

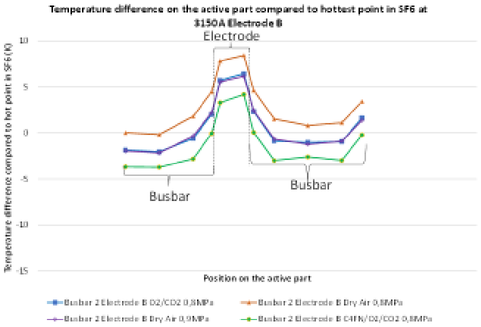
Comparative Continuous and Overload Current Performance of High Voltage Switchgear with SF_6 and Alternative Gases

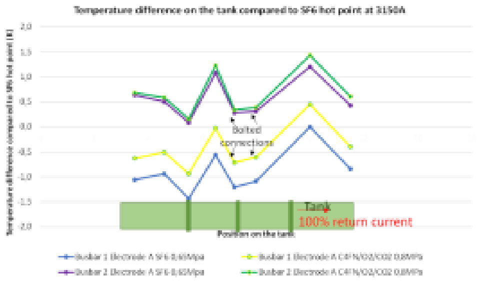
continued

Experimental setup & test results

- Results from GIS busbar testing.







- Overload current equation and coefficients based on GIS bus test results.

$$\theta_a = \theta_{max} - \left(\frac{I_a}{I_r}\right)^{\alpha} \cdot \theta_r$$

with

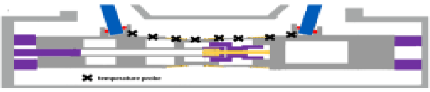
I_a is the allowable continuous load current at actual ambient temperature θ_a [A]
I_r is the rated normal current [A]
θ_{max} is the allowable hottest spot total temperature ($\theta_{max} = \theta_r + 40$) [°C]
θ_r is the allowable hottest spot temperature rise at rated normal current [K°]
θ_a is the allowable or actual ambient temperature, in °C.

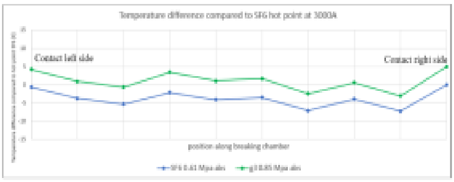
Table 2: Overload coefficients on different parts for SF_6 and $C_4FN/CO_2/O_2$ mixture

	α Electrodes	α Busbar	α Tank
θ Type 1 busbar SF_6	1,68	1,71	1,84
θ Type 2 busbar SF_6	1,71	1,70	1,82
θ Type 1 busbar C4FN / CO_2 / O_2 mixt.	1,69	1,68	1,85
θ Type 2 busbar C4FN / CO_2 / O_2 mixt.	1,71	1,71	1,82

- Dead-tank circuit breaker test results at 3000, 3300, 3500 and 4000 A.

Figure 8. Picture of Dead Tank circuit breaker rated 145 kV under test.





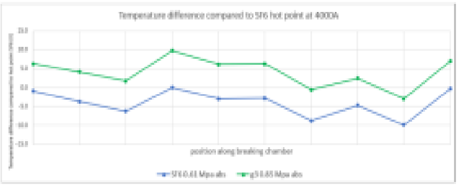


Figure 11. Temperature profile along the breaking chamber at 4000 A with SF_6 and $C_4FN/CO_2/O_2$

http://www.cigre.org

For Official use only

cigre | PARIS 2022

Study Committee A3

Transmission and Distribution Equipment

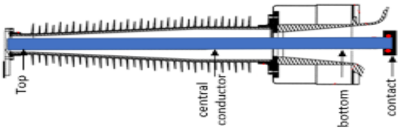
Paper 10126_2022

Comparative Continuous and Overload Current Performance of High Voltage Switchgear with SF_6 and Alternative Gases

continued

Experimental setup & test results

- Dead-tank circuit breaker test results for the bushing. Calculated overload coefficient (α).



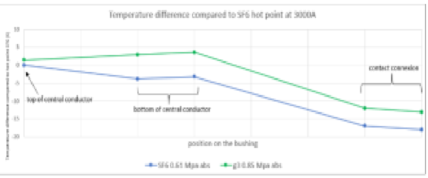


Figure 12. Temperature profile along the bushing at 3000 A with SF_6 and $C_4FN/CO_2/O_2$

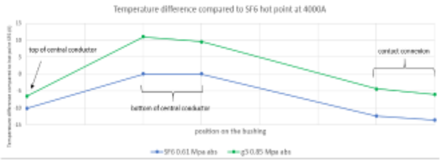


Figure 13. Temperature profile along the bushing at 4000 A with SF_6 and $C_4FN/CO_2/O_2$

Table 4: Overload coefficients on different parts for $C_4FN/CO_2/O_2$ mixture

$C_4FN/CO_2/O_2$ 3000-3300 A	α	ΔT_{max} calculated - measured
Breaking chamber	1,82	0.3 K
Bushing with central conductor		0.7 K

C4FN/CO_2/O_2 3500-4000 A	α	ΔT_{max} calculated - measured
Breaking chamber	1,71	0.3 K
Bushing with central conductor		4.7 K

- Live-tank circuit breaker main circuit resistance measurement results after breaking tests

Figure 9 : Main contact resistance variation after type-test from brand new-condition

Conclusions

- Effusivity is similar between CO_2 and technical air for pressures in the range of 0.1 to 0.9 MPa. Both are 60% of SF_6 effusivity.
- From test results C4FN enhances the effusivity of the natural origin gas leading to lower temperature rise
- In a GIS busbar, identical profiles are obtained with $C_4FN/O_2/CO_2$ gas mixture at 0.8 MPa and technical air at 0.9 MPa.
- Similar performance can be obtained with SF_6 and $C_4FN/O_2/CO_2$ gas mixture with design improvements of the GIS bus.
- Overload coefficients obtained from GIS bus measurements range from 1.68 to 1.71 for internal components and from 1.82 to 1.85 for the tank with full current return.
- Comparing SF_6 and $C_4FN/O_2/CO_2$ in a dead-tank circuit breaker, hottest spot temperature rise is about 12% higher for the bushings and 15% higher for the interrupter for the gas mixture. Temperature profiles are parallel along the interrupter. In bushings the profiles are parallel for inside elements and approximate each other near the terminal.
- Calculated overload coefficients were 1.82 for a 10% overload from 3000 A and 1.72 from 3500 to 4000 A.
- The resistance of the main circuit in a live-tank circuit breaker stays within 20% increase from the value in new condition after various breaking tests.
- Allowance for resistance increase after breaking tests of +100% in IEC and +250% in IEEE seem excessive.
- The overload coefficient of 1.8 considered for SF_6 insulated switchgear is also found as valid for $C_4FN/O_2/CO_2$ gas mixture-insulated switchgear.