

Study Committee A3

Transmission and Distribution Equipment

Paper 10136_2022

Design considerations for implementing SF₆ alternatives for distribution switchgear applications with focus on toxicity and load break performance

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Motivation

- Environmental regulations and self-imposed goals.
- U.S. MV switchgear lacks research on gas alternatives.
- Requirements:
 - Same footprint as SF6
 - Design flexibility of busbar (custom design)
 - Pressure below 2bar absolute
 - Visual break
 - Service temperature +60C/-30C

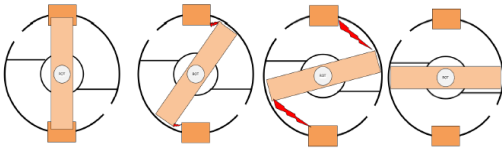
Takeaways

- Linear puffer and rotary puffer C4-FN/CO₂ mixture are feasible for same filling pressure as for SF6.
- Linear puffer and rotary puffer load breaker require redesign to match SF6 performance.
- Decomposition of C4-FN from switching duty doesn't compromise life expectancy.
- Toxicity increases with arcing, remaining low (ATE>20,000, cat.5).

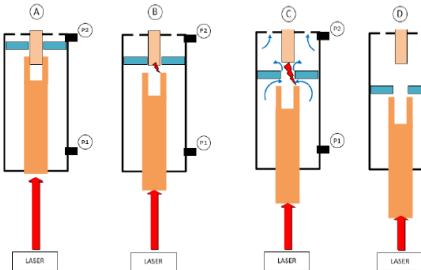
Experimental approach

Current breaking technologies

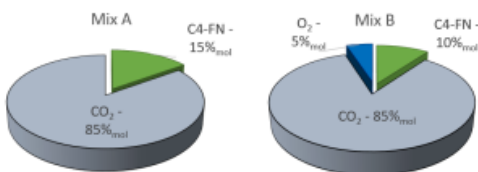
- Rotary switch (RS)



- Linear puffer (LP)



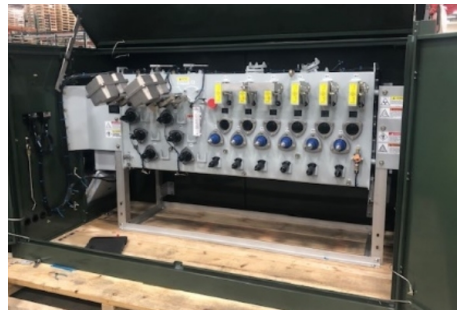
Mixtures evaluated at 1.7bar absolute



- Based on dielectric performance and liquification temp., two mixtures were investigated.
- Addition of O₂ to investigate toxicity and soot formation.
- Gas analysis after switching was performed by GC/MS and FT-IR.

Application

- Vault, underground and padmount, with diverse shapes and exposed to ambient climate.



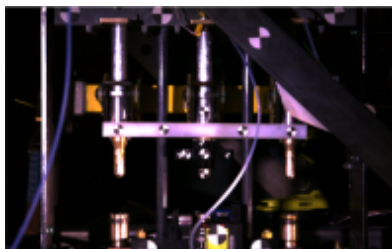
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Advanced data acquisition systems and sensing

- High speed video recording
- Laser speed measurement
- Pressure measurement with optic technology



Test results

Linear puffer switching performance

Load break

- Arcing time similar than for SF6 for $\leq 27kV$
- Longer arcing time for 38kV/630A
- 15% vs 10% C4 has little effect on performance
- Load breaker clears 100% shots

Cable charging

- Restrikes occur 27kV/20A and 38kV/25A
- 15% performs better than 10%
- Load breaker clears 100% shots



Rotary switch switching performance

Load break

- Longer arcing time than SF6 for 10% and 15% for 17.5kV/200A.
- Erosion/ablation on surface of switch enclosure
- Load breaker clears 100% shots

Cable charging

- Single and multiple restrikes for 17.5kV/15A
- Load breaker clears 100% shots



Gas decomposition and toxicity

Based on the arc energy calculated through testing and using a value of 0.5mol/MJ

ATE_{mix} was calculated per OSHA Tier 3 after switching sequence per IEEE C37.74. All gas samples analyzed fall under cat. 5 per ISHA/GHS (low-nontoxic).



	In. C4-FN [% mol]	C4-FN dec. [%]	EoL C4-FN [%mol]
LP	15	2.3	14.6
	10	3.6	9.64
RS	15	3.9	14.4
	10	5.9	9.41



	In. C4-FN [% mol]	Initial. (ATE_{mix})	Volume [m3]	Energy [kJ]	After (ATE_{mix})
LP	15	58,449	0.4	47	49,000
	10	76,285	0.4	65	57,000
RS	15	58,449	0.36	63	38,000
	10	76,285	0.36	62	40,000

Solid deposits and arc-eroded surfaces

- C4-FN creates low amount of soot from load break.
- High temperatures of arc can deteriorate materials.
- Arc ablation can promote electrical breakdown along surfaces.
- O_2 reduces conductivity of arc ablated surfaces.
- Highly sensitive to material selection.



<http://www.cigre.org>

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Conclusions

Switching performance

- C4-FN mixture have similar load break performance than SF6.
- Cable charging it's the most challenging sequence due to restrikes.
- Redesign is required to match SF6 performance.
- Arc ablation of polymers can have impacts in dielectric performance.

Gas decomposition and toxicity

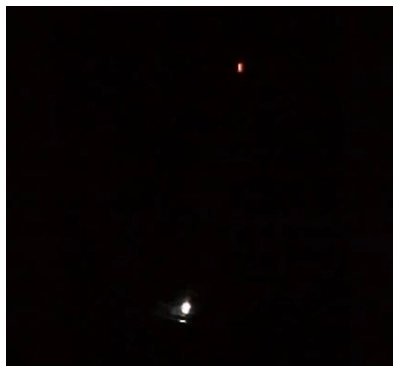
- Decomposition of C4-FN doesn't compromise dielectric performance of MV switchgear.
- Toxicity after arcing increases but remains low after type test.

Linear puffer(LP) 27kV/630A Mix A.



Load break CO 27kV/630A
15%C4/85%CO2 mix

Rotary switch (RS) 17.5kV/200A Mix A.



Load break CO 17kV/215A
10%C4/5%O2/85%CO2 mix

Linear puffer(LP) in switch enclosure



Rotary puffer (RP) in switch enclosure

