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Study Committee A3
Transmission and Distribution Equipment
Paper 10643_2022

Recent Development of SF_6 Alternative Switchgear Using Natural-Origin Gases in Japan

T. Uchii *1, D. Yoshida *2, S. Tsukao *3, K. Taketa *4, K. Tsuboi *5
*1: Toshiba Energy Systems & Solutions Co. *2 Mitsubishi Electric Co.
*3: TEPCO Power Grid, Inc. *4: Kansai Transmission and Distribution, Inc. *5: Chubu Electric Power Grid Co., Inc.

Motivation

- The "7 requirements" as evaluation criteria of SF_6 free switchgear has been developed by the "SF_6 Alternative Gas Study Group" composed of Japanese 11 utilities, 7 manufacturers and 6 academia and CRIEPI, together with TDGC and JEMA as observers.
- This paper reports the current status and progress of SF_6-free switchgear development in Japan based on the "7 requirements".

Conclusions

- There are no disadvantages of natural-origin gases from the viewpoints of EHS, gas handling and utilization under normal service condition.
- In most cases, aged GISs installed in the 1970s and 1980s are replaceable with natural-origin gas switchgears.
  On the other hand, design improvements and technological innovations should be continuously necessary to meet future replacement needs for later generations of existing SF_6 equipment.
- Developments of HV switchgears using natural-origin gases have been actively ongoing in Japan.
  The first pilot installation of the 72 kV GISs adopting synthetic air insulation will be completed by the end of 2022.
- While further coverage up to 550 kV must be a great technical challenge, the authors, as Japanese manufacturers and utilities, will aim to complete it by the end of 2029.

Summary of the evaluation of natural-origin gases based on "7 requirements"

No.	Categories	Requirements	Relevant technical items	Outlook with natural-origin gas solutions
1	EHS	Lower risk of toxicity of decomposition gas and by-product than SF_6.	A, B, C, D	For CO_2/O_2, arced gas includes CO or O_3, but the acute toxicity level stays in Category 6 (harmless) even after abnormal heavy fault interruptions. For synthetic air no harmful characteristics including arc decomposed condition.
2	Service Condition	Normal use conditions specified in the standard. (e.g. operation in -25 °C)	E	Service condition even in cold regions below -40°C is not a concern based on low liquefaction temperature for wide pressure range in case of natural-origin gases (N_2, CO_2 and O_2).
3	Stable Supply	Stable supply of the gas, preferably by multiple suppliers.	G	Natural origin gasses such as CO_2/O_2 and Synthetic air are quite commonly supplied by a lot of general industrial gas manufacturers.
4	Gas Handling	Simple gas handling.	H	Evaluated that the impact of dispersion in mixture composition on dielectric performance is limited to the range of +/-1%, which is well manageable by a design role and verified by a type test.
5	Life Cycle Cost	Reasonable life cycle cost, including equipment, installation, maintenance, etc.	F, I, J, K	Expected life time and operation cost with natural-origin gas equipment can be equivalent compared to the existing SF6 equipment, while design improvements and technological innovations to minimize initial cost should be necessary.
6	Footprint	Possible to replace in restricted locations, such as outdoor and underground substations.	J, K	Possible to replace currently aged GIS manufactured in the 1970s and 1980s with natural-origin gas equipment.
7	Voltage Coverage	Feasibly scalable up to the extra high voltage (EHV) rating 550 kV.	K, L	New design approaches and specification rationalizations will be studied and positively adopted to minimize equipment size. Both 72/84kV kV 31.5 kA GIS and 168 kV 40 kA VCB using natural-origin gases will be piloted soon by 2023 in Japan. The authors, as Japanese manufacturers and utilities, will aim 550 kV by the end of 2029.

A) Physical properties and environmental potentials
B) Decomposed gases and solid by-products
C) Toxicity including decomposed products
D) Safety
E) Operating pressure and temperature range
F) Material compatibility
G) Gas availability
H) Gas mixture quality control
I) Erosion of arcing contacts and nozzles
J) Dielectric performance
K) Interruption performance
L) Feasibility studies for higher ratings and compactness

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Selection of gases

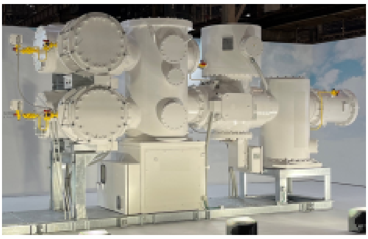
- Practical alternative gases that can be used as single gas or a base gas of mixtures are N_2, CO_2 and O_2.
- Artificial fluorinated gases such as C4-FN have not been directly selected so far, mainly because of still existing concerns on EHS aspects, stable supply, potential environmental and regulatory risks.
- In the present study, mainly focused on (i) Synthetic air and (ii) CO_2/O_2 mixture

Screening of alternative gases

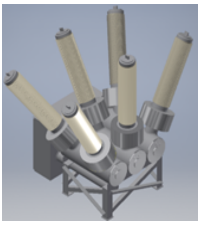
Criteria of selection	Remaining quantity
Total number of surveyed material (from Chemical Handbook)	8,568
Being Gas state at room temperature (Boiling temperature under 25 deg C.)	189
Not contain chlorine element (Cl)	163
Not contain bromine element (Br)	149
Having no toxicity and explosibility	69
Not having high reactivity	50
Omitting gases of unknown properties	20
GWP <=1	9
Dielectric strength > 10% of SF6	3 (N2, CO2, O2)

Pilot projects and future plan

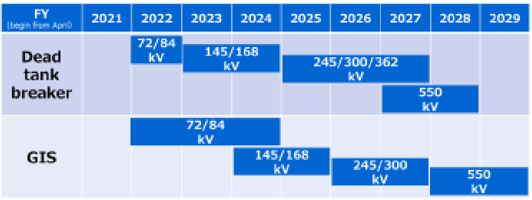
- 72/84 kV F-gas free GIS consisted of a VCB with synthetic air insulation has completed the type test and will be installed by the end of 2022 as the first pilot in Japan.
- Developments of 168 kV VCB are also ongoing and will be in operation in 2023.
- The roadmap of natural-origin gas insulated switchgear developments above 72 kV was presented. Although coverage up to 550 kV must be a great technical challenge, the authors, as Japanese manufacturers and utilities, will aim to complete it by the end of 2029 for the future sustainable T&D systems.



F-gas free 72/84 kV GIS

F-gas free 72/84 kV VCB (left) and 145 kV VCB (right)



The roadmap of natural origin gas-insulated switchgear releases above 72 kV (as of August 2022) cigre PARIS 2022

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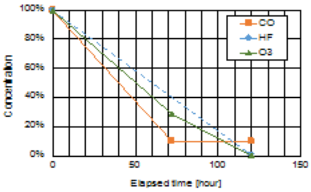
Background data on (1) EHS aspects

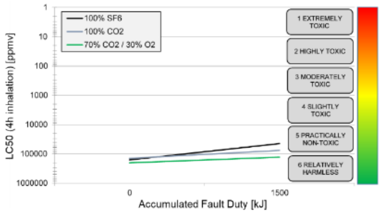
(Unit: ppmV)

	Toxicity LC50	Pure CO_2	CO_2/O_2(30%)
CO_2	141,618 /4h	(Balance)	(Balance)
O_2	-	196	299,880
CO	2,612 /4h	7,000	120
HF	642 /4h	100	250
O_3	11 /4h	35	25
H_2	> 15,000/1h	15	4
CH_4	> 500,000/2h	2	2

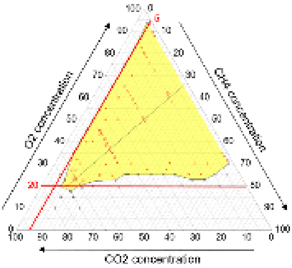
Decomposed gases detected after arcing in pure CO_2 and CO_2/O_2 mixture. (490 litter enclosure after 1,500kJ of arc energy)



Reduction of decomposed gas concentrations in CO_2/O_2 gas mixture with a specific absorbent

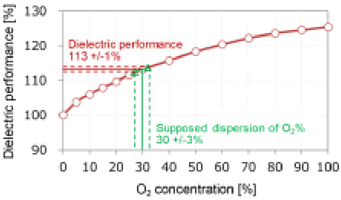


Acute toxicity assessment: Accumulated fault duty vs. LC50(4h) on Hodge-Sterner scale, up to 1,500 kJ in 490 liter enclosure



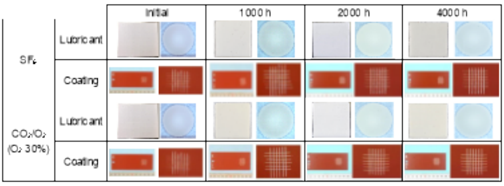
Experimental assessment result of flammable range of a combustion gas CH_4 in CO_2/O_2 (yellow area indicates the flammable range)

Background data on (4) gas handling



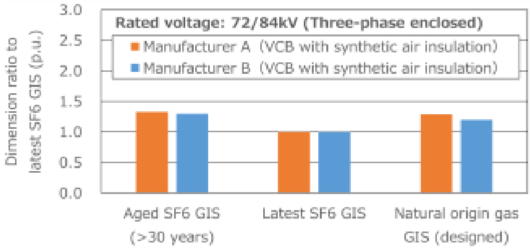
Impact of O_2 % dispersion on dielectric performance of CO_2/O_2 gas mixture equipment. (Supposing dispersion of 30 +/-3%)

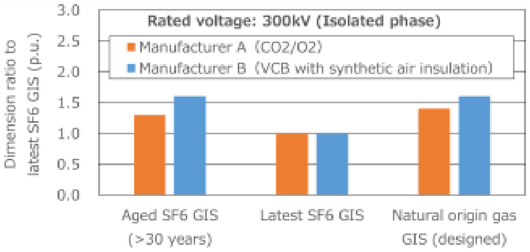
Background data on (5) life cycle cost



Examples of long-term material compatibility test (lubricants and coatings in CO_2/O_2(30%))

Background data on (6) footprint





Estimated equipment dimensions using natural-origin gases compared with aged and the latest type of GIS

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