Study Committee B3

Substations and Electrical Installations

Paper ID_11079

Feasibility Tests of a 320 kV Gas-insulated DC Switchgear with Clean Air

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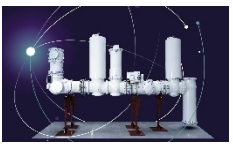
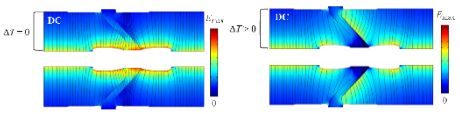
Motivation

- Development of SF_6 technology-based DC GIS was driven by HVDC offshore installations, to enable space reduction of DC switchyards up to 95%
- Increasing demand for greenhouse-gas free solutions for enhanced sustainability of the power systems



DC-specific phenomena and testing

- Basic physical phenomena at DC voltage, for example temperature and time dependent electric field distribution and charge accumulation, need to be considered for design and testing
- Specific test recommendations for gas-insulated DC systems are given in CIGRE TB 842



Properties of Clean Air

- Clean Air consists of 80% N_2 and 20% O_2 (synthetic air)
- No global warming potential (GWP = 0), no ozone depletion potential (ODP = 0), not toxic, very stable, well known material compatibility
- Reduced insulation strength compared to SF_6
- F-gas free: Simple gas handling, no gas recycling required, no greenhouse gas reporting, no risks concerning CO_2 compensation and taxes
- Clean Air is commercially available worldwide, from several manufacturers
- Proven technology in AC applications

Synthetic Air
80% N_2 + 20% O_2

Feasibility Study tasks

- Determine requirements on ±320 kV DC GIS
- Feasibility in terms of rated current
- Gas pressure withstand capability
- Electric insulation performance
  - High-voltage tests
  - Deductions for non-tested conditions
- Clean Air insulation basics
  - Surface charge accumulation
  - Detectability of imperfections in Clean Air
    - Partial discharge measurements
    - Detectability of protrusions
    - Particle movement and detectability

Conclusions

- **A feasibility study examined and confirmed the applicability of Clean Air for DC GIS at a nominal voltage level of ±320 kV.**
- **Relevant requirements were mirrored within calculational and experimental investigations covering dielectric, mechanic, and thermal aspects.**
- **Limit tests on a DC GIS assembly revealed the dielectric performance of the Clean Air insulation.**
- **Furthermore, the partial discharge behaviour of typical imperfections were examined in detail in Clean Air and compared to SF_6 insulation.**
- **Since future projects will increasingly feature the voltage class of ±525 kV, upgrade development needs to be performed to also provide ±550 kV DC GIS using Clean Air insulation.**

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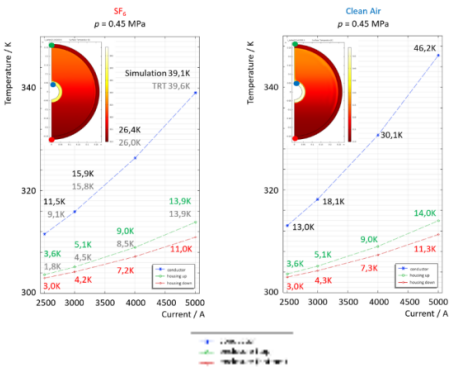
Requirements on ±320 kV DC GIS

Requirement	Value
Nominal voltage	±320 kV
Rated voltage	±352 kV
Rated DC withstand voltage	±528 kV
Rated lightning impulse (LI) withstand voltage	≤950 kV
Rated switching impulse (SI) withstand voltage	750 kV
Rated current (DC)	3000 A (4000 A)

- Considering current and future applications that feature DC GIS, energy transmission is planned via HVDC cables in most of the projects.
- With reference to IEC 62895, IEC TS 61936-2 and CIGRE TB 852 the required LI and SI withstand voltages can be limited to the above given values (cable projects).

Feasibility in terms of rated current



- A rated current of 3000 A is required, 4000 A are also considered in the feasibility study
- All values for SF_6 and Clean Air are within the required temperature rise limits of IEC 62271-1, at 0.45 MPa. The maximum temperature drops further with increasing pressure.
- Further, the temperature gradient between conductor and enclosure was considered due to its influence on the electric field distribution at DC voltage.

Electric insulation performance

- High-voltage tests were conducted.
- The test results and deductions for non-tested conditions confirmed the feasibility.

Voltage type	Value
Rated DC withstand voltage	≥530 kV
Rated LI withstand voltage	950 kV
Rated SI withstand voltage	850 kV
Rated LI withstand voltage, superimposed to DC voltage	950 kV LI + 352 kV DC
Rated SI withstand voltage, superimposed to DC voltage	850 kV SI + 352 kV DC

Gas pressure withstand capability

- The applicability of GIS enclosures and barrier insulators for increased gas pressure (min. functional pressure 0.62 MPa) was proven and confirmed, considering gas pressure coordination (influence of temperature and long-term gas permeation)

Basics: Surface charge accumulation

- Charge accumulation in/at solid insulators under DC depends on the materials involved; comprehensive investigations already performed for SF_6 gas
- To cover potential effects in Clean Air, longer lasting tests at increased voltage were performed in Clean Air (+352 kV for up to 64 hours, ±580 kV for 30 min)
- Further investigations are under consideration

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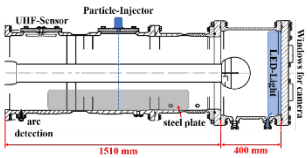
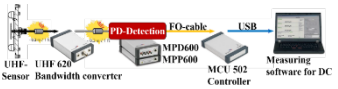
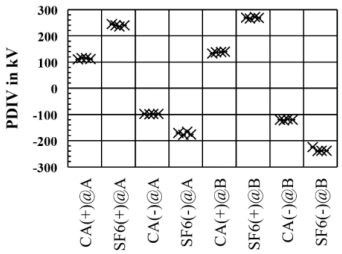
Basics: Detectability of protrusions and particles in Clean Air (PD measurement)

- According to CIGRE TB 730, protrusions and particles may be less critical in Clean Air compared to SF_6, considering the relation between partial discharge inception voltage (PDIV) and AC breakdown voltage
- PD measurements (conventional and UHF) were performed with DC voltage to compare the detectability of imperfections in SF_6 (0.45 + 0.55 MPa) and Clean Air (0.65 + 0.75 MPa)



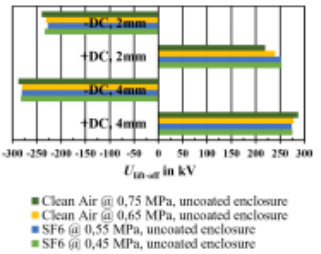


Detectability of protrusions



- No considerable difference between SF_6 and Clean Air, taking the different electric strength under clean condition into account

Detectability of particles

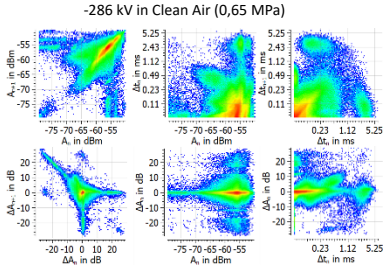


- Lift-off voltage not dependent on gas type
- PDIV corresponds to lift-off voltage
- No lift-off with coated enclosure up to ±352 kV

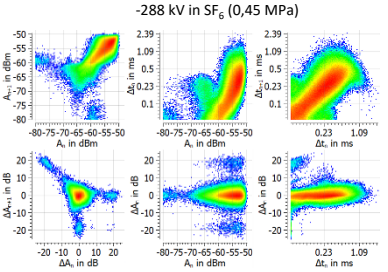
Pulse sequence analysis (PSA)

- Test data evaluation with PSA for the firefly case of a 4 mm particle at the HV conductor

-286 kV in Clean Air (0,65 MPa)



-288 kV in SF_6 (0,45 MPa)



- The PSA shows a good match of the patterns for both gas types