Gas-Insulated-Substations
SF₆ gas handling

EPA's 2012 Workshop on SF₆-emission reduction strategies
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Power Transmission is a Part of the Power Matrix

High Voltage Substations are the backbone of the Transmission System
Requirements for Gas-Insulated Substations

- High system reliability
- High flexibility of its solutions (modularity, expandability)
- Compact space saving solutions
- Innovative solutions (devices, switchgears)
- Low life cycle costs
- Reliable and competent partners (operator, manufacturer)
- Smart and Power grid adaptation
- Environmental-sustainability
Characteristics of SF₆

- SF₆ is colorlessly, odorless and a chemical neutral (inerted) gas
- SF₆ is 5x heavier than air, is not toxic and has no dangerous components inside
- SF₆ is no hazardous material
- SF₆ has no eco-toxic potential
- SF₆ has no impact for the ozonosphere

- SF₆ is a potent greenhouse gas (GWP* → 22,800** x CO₂)
- SF₆ has excellent electrical characteristics

* Global Warming Potential; ** according to EU-F-Gas regulation
SF₆-emissions in the lifecycle process of switchgear

SF₆ is used in a closed cycle

- Producing SF₆
- Development Tests
- Manufacturing
- Commissioning

Recycling of SF₆ for reuse

Use

decommissioning

(↓ = possible emission)

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Definition of SF₆ – Emission

**SF₆-handling losses** + **SF₆-leakage**

Technical recommendation in e.g. Cigré SF₆-Handling Guide No. 276

Definition in IEC-standards, like IEEE C37.122, IEC 62271-203, Cigré SF₆-Tightness Guide No. 430
Permanent CO₂-footprint reduction of GIS

The developments within the last decades have led to smaller gas compartments of the switchgear and thus to considerably less used amount of SF₆ at the same performance data.
A significant reduction of SF$_6$ was reached by using modern development tools, new materials and optimized production processes since the introduction of the GIS-technology in 1968.
Reduction of SF$_6$-emissions in the factory – Type testing internal arc

- Test object is inside test box
- Test box is equipped with inspection windows
- All connections are gastight
- Operation of rupture disc will allow SF$_6$ to emit in the test box only
- SF$_6$ will be collected in a closed cycle after testing
Reduction of SF6-emissions in the factory

The component testing must assure very low SF₆ emission by using state-of-the-art-handling equipment in the factories.
Reduce SF$_6$-emissions in the factory

State-of-the-art-handling equipment …

…regularly checks and trained staffs…

Achieving low SF$_6$ emission during production
Reduce SF$_6$-emissions in the factory

Environmentally responsible behavior and state-of-the-art equipments leads to low SF$_6$-emission in the factory

Source: GIS Factory Berlin
Optimized gas work needs
„State-of-the-Art“ equipment – especially on site

1 mbar SF₆-maintenance unit

SF₆-measurement device
%-SF₆, dew-point temperature, SF₆-byproducts

SF₆-collecting device for measurement of gas

Source: DILO
SF₆ Recollection
during measurements of gas quality

Gas flows through the instrument into recovery bag (SF₆-recollecting pipe)
No emission!

Source: DILO, GAS-WIKA-Siemens
Handling of SF$_6$ on site

- Use of “strong and big” maintenance units - should be able to recover gas to a residual pressure of < 1mbar
- Minimum Residual pressure to be achieved < 20mbar - according to IEC 62271-303
- Target → below 1 mbar - nevertheless due to the design and size of gas compartments it's not always possible.
Optimized SF₆ handling

SF₆ residual quantity (emission) dependence on the SF₆ rated filling pressure / compartment size / SF₆ residual pressure

- **420 kV-circuit breaker, 3-pole**
  - volume: approx. 7000 l
  - working pressure: 6.6 bar abs.
  - SF₆-amount: approx. 300 kg
  - SF₆-density: 43 g/l

- **420 kV-disconnector, 3-pole**
  - volume: approx. 870 l
  - working pressure: 4.8 bar abs.
  - SF₆-amount: approx. 27 kg
  - SF₆-density: 26.7 g/l

Source: Cigré-Guide no. 276; Application of table 25

With State-of-the-art-handling equipment SF₆ recovery of each gas compartment till very low pressure (1 - 20 mbar) is possible, thus securing losses of at least less than 2% during maintenance and end of life.
Gas-tightness – Functionality and environmental protection

- Gas-tightness essential for the functionality ➞ static and dynamic solutions
- Design and material assure extreme low leakage rate

IEC 62271-203 High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV (09/2011)
  ➞ required leakage rate <0.5% / year / gas compartment
  ➞ state-of-the-art design <0.1% / year / gas compartment

- Extreme low emissions protect the environment
- Proven tightness on installed GIS for decades
Type testing on SF$_6$-tightness according to IEC/IEEE part of the quality assurance process

Nowadays SF$_6$-tightness can be confirmed (integral measuring process with state-of-the-art measurement devices) in the range of $<0.01\%$/year/gas compartment compared with the required $<0.5\%$/year/gas compartment in the relevant standards.
Expected life-time of GIS

1968

145 kV

145 kV

State-of-the-art

2012

GIS evolution

Number of installed bays

Today's experience

Acc. to CIGRÈ study

- No generic life limitation
- Issues of aging and deterioration
  - Gas leakages
  - Specific material design issues
  - Secondary systems
  - Corrosion

First Installation

Originally expected life-time

Continuous development assures the sustainable performance

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GIS-Concepts for low SF$_6$-emission

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<th>In the Past</th>
<th>State-of-the-art-technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large gas compartments</td>
<td>Optimized gas compartments</td>
</tr>
<tr>
<td>Short maintenance intervals (frequent opening of gas compartments)</td>
<td>2 openings during life time: once after 25 years of service, once during end-of-life procedure after 40-50 years.</td>
</tr>
<tr>
<td>Limited SF$_6$-handling instruction</td>
<td>Detailed explained SF$_6$-handling instruction and regulations</td>
</tr>
<tr>
<td>SF$_6$-maintenance units with a minimum SF$_6$-recovering pressure of 50-100 mbar</td>
<td>High power SF$_6$-maintenance units with SF$_6$-recovering pressure till 1 mbar</td>
</tr>
<tr>
<td>Insensitive SF$_6$-leakage detectors</td>
<td>Sensitive SF$_6$-leakage detectors to find smallest leaks</td>
</tr>
<tr>
<td>SF$_6$-measuring instruments without collecting the used gas</td>
<td>SF$_6$-measuring instruments collecting the gas are now offered</td>
</tr>
<tr>
<td>Fundamental tests and implementation of new production processes</td>
<td>Using Helium for leakage detection where possible (e.g. housing leakage test)</td>
</tr>
</tbody>
</table>

Since the implementation is a continuous improvement
SF₆ History – 2005 Implementation of the German Voluntary Commitment

- Based on the previous voluntary commitment (1996)
- Agreed with and recognized by the German Government in 2005
- Scope: Switchgear and Components >1 kV
- Quantified and dedicated targets for 2020 by lifecycles and responsibilities
- Annual monitoring of activity data and emissions according to IPCC 2006 Guidelines for verification

**Mission:**

SF₆-emissions should be avoided wherever possible. The specific quantity of SF₆ used to fulfill functions is to be minimized.
German SF₆ data bank

Emission on electric power equipment 2000 - 2010

Source: ZVEI (Zentralverband Elektrotechnik- und Elektronikindustrie e.V.)
SF₆-emissions in the lifecycle process of switchgear

SF₆ is used in a closed cycle

The EU-F-Gas regulation concentrates on the individual processing

(↑ = possible emission)
EU-F-Gas regulation 842/2006 ("a bit" like new regulation of CARB*)


$\text{SF}_6$ is considered in limited products only

The use of $\text{SF}_6$ in electric power equipment is permitted

Certain measures to be carried out by manufacturers and users have been implemented

Amendments have been released to describe measures more in detail

*California Air Resources Board
European F-Gas-regulation 842/2006 -
Main articles for SF$_6$ electric equipment

Regulation (EC) Nr. 842/2006
on certain fluorinated greenhouse gases*

Article 4 „Recovery“
Recovery by certified staff only

Article 5 „Training and certification“
(EC) 305/2008 definitions, minimum requirement on certification of staff

Article 6 „Reporting“
(EC) 1493/2007 definitions, format of reporting

Article 7 „Labelling“
(EC) 1494/2007 definitions, form of labels

*) “certain fluorinated greenhouse gases” means hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF$_6$)
European F-Gas-regulation 842/2006, article 2 „Definitions“

Definitions for SF₆-handling

- **Recovery**
  Collection and storage of SF₆ from electric power equipment or containers
  → *in practice: taking out SF₆ from equipment and putting it into a container*

- **Recycling**
  Reuse of recovered SF₆ following a basic cleaning process
  → *in practice: recycling of SF₆ on site*

- **Reclamation**
  Reprocessing of recovered SF₆ in order to meet a specific standard* of performance
  → *in practice: used SF₆ is reprocessed (e.g. SF₆-production plant)*

- **Destruction**
  Transformation or destruction into one or more stable substances which are not fluorinated GHG
  → *in practice: burning of SF₆*

*) - IEC 60376 “Specification of technical grade sulfur hexafluoride (SF₆) for use in electrical equipment”
- IEC 60480 “Guidelines for the checking and treatment of sulfur hexafluoride (SF₆) taken from electrical equipment and specification for its re-use”
European F-Gas-regulation 842/2006, article 5 „Training and certification“ together with regulation 305/2008*

„Commission regulation No. 305/2008 establishing minimum requirements and the conditions for mutual recognition for the certification of personnel recovering certain fluorinated GHG from HV switchgear“

Process and responsibilities

<table>
<thead>
<tr>
<th>Training (not subject to conditions of regulation)</th>
<th>Evaluation body/ Examination (content defined)</th>
<th>Proof of competence</th>
<th>Certification body issues certifications</th>
</tr>
</thead>
</table>

Evaluation body and Certification body have to be independent

*) regulation refers to HV switchgear only

The reporting is a must to do in case of…

- Import \( \text{SF}_6 > 1 \text{ t} \) in container or bottles from country A outside EU to country B outside EU
- Export \( \text{SF}_6 > 1 \text{ t} \) in container or bottles from country B outside EU to country A outside EU

The reporting is not necessary for…

- Import / export \( \text{SF}_6 \) in equipment inside EU countries
- Import / export \( < 1 \text{ t per year and company} \) inside EU countries

In some countries additional voluntary commitments regarding reporting exist.

Standards required SF₆-weight already in the past: declaration of „weight of gas“ according to IEEE C37.122 or IEC 62271-203

The label shall be placed clearly, indelibly and adjacent to the service point of the equipment

*) Content defined in the regulation but the form can vary between the different manufactures
Review EU F-Gas-regulation in progress

- Review required 5 years after implementation (7/06→7/11)
- Report of the commission published on September 26, 2011
  - includes 26 substances, one is SF₆
  - positive results regarding our electrical power applications
  - strong reduction of F-gas-emission demanded in general
- No modification for electrical power equipment, very small adjustments
  - mainly reporting, no restriction on SF₆-electrical power equipment
- Other branches/ substances strongly affected
- Draft of modified EU-F-Gas-regulation
  - will be available autumn 2012 (planned by EU-commission)
- Final decision by the EU Parliament
  - Scheduled until beginning of 2014

Cigré publications on SF$_6$

SF$_6$ RECYCLING GUIDE
No. 234
2003

Assure long term use of SF$_6$

SF$_6$ HANDLING GUIDE
No. 276
2003

Avoid SF$_6$ handling losses due to state-of-the-art handling

SF$_6$ TIGHTNESS GUIDE
No. 430
2005

Guarantee of SF$_6$ tightness due to state-of-the-art equipment and testing

Cigré SC B3 delivers and bundles all technical and environmentally aspects on SF$_6$

2012

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Current CIGRÉ activities on SF₆

- WG B3.17 “Residual life concepts applied to HV GIS“ (Finished, will be published in 6/2012)
- WG B3.25 “SF₆ analysis for AIS¹/GIS and MTS² Condition Assessment”
- WG B3.30 “Guide to minimize the use of SF₆ during routine testing”

¹ Air Insulated Switchgear
² Mixed Technology Switchgear

Brochures can be downloaded on [http://www.e-cigre.org/](http://www.e-cigre.org/)
Standards

- IEC 62271-1 Common specifications for SF₆-insulated and air-insulated high-voltage switchgear and controlgear
- IEC 62271-200 Standard of medium-voltage SF₆-GIS
- IEC 62271-203 High-voltage switchgear and controlgear >52 kV
  Revision published in 9/2011
- IEC 62271-303¹ Use and handling of SF₆
- IEC 60376² Specification for new SF₆-gas
- IEC 60480² Checking and treatment of sulfur hexafluoride (SF₆)
  taken from electric equipment
- IEEE C37.122 Gas Insulated Substations
- IEEE C37.122 IEEE Guide for Sulphur Hexaflouride
- ASTM D2472-00 SF₆-gas

¹ Revision in progress: IEC 62271-4
² Maintenance of the standard scheduled until 2014.
  Target: 1 standard only, SF₆-Gas mixtures to be included, recommendation on monitoring
Conclusion

- Implementation of adequate maintenance strategy for aged equipment
- Evaluation of each SF$_6$-leakage for systematical or individual failure
- Gas tight equipment and low SF$_6$-emission reduce life-cycle costs
- Residual Life of equipment goes in line with low SF$_6$-emission
- For end-of-life procedures, SF$_6$ has to be kept in a closed cycle
Thank you for your attention!

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