SF₆ in electrical power equipment - Ecology and Economy

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- Applications for the use of SF$_6$ equipment
- SF$_6$ as a greenhouse gas – Emissions
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- Criteria for the use of SF$_6$ equipment and application
- Environmental friendly design and production of SF$_6$ equipment
- Overview of latest standards and publications
- Market trends
- Summary
Introduction

- **SF₆ in application in power engineering since the middle of the 60ies**
  - First at high-voltage level >52kV:
    High-voltage switchgear, circuit-breakers
  - Since the beginning of the 80ies, also at medium-voltage level ≤52kV:
    Primary distribution switchgear, secondary distribution switchgear (RMU)

- **New technical possibilities**
  - Compact design saves space and volume:
    Conventional systems / SF₆ technology
  - Higher switching capacities:
    Minimum-oil circuit-breakers, air-blast breakers / SF₆ circuit-breakers (>110kV)

- **At the beginning of the 90ies, ecological awareness**
  - Contribution to greenhouse effect
Introduction
More than 40 years of operational life-time experience

Since more than 40 years in service
Berlin, UW Wittenau, Vattenfall Europe, 123 kV, 31.5 kA

State-of-the-art
145 kV, 40kA GIS

The equipment is gastight
Introduction
More than 27 years of operational life-time experience for MV switchgear

Since more than 27 years in service
UW Kulmbach Mitte, E.ON Bayern AG, 24 kV, 16 kA

State-of-the-art
24 kV, 25 kA, Double Busbar, Type NXPLUS

The equipment is gastight
Properties of SF₆

- SF₆ is a colorless, odorless and chemically neutral (inert) gas.
- SF₆ is 5 times heavier than air, non-toxic, and contains no dangerous components.
- SF₆ is not a hazardous material.
- SF₆ has no ecologically toxic potential.
- SF₆ does not endanger the ozone layer.
- SF₆ is a potent greenhouse gas.
- SF₆ has excellent electrical properties.
Applications for the use of SF$_6$ equipment

- **Switching devices and switchgear**
  - High voltage (>52kV):
    - Insulating and switching functions in compact design (GIS, HIS, MTS)
    - Outdoor circuit-breakers with SF$_6$ as insulating and arc-extinguishing medium
  - Medium voltage (>1kV up to 52kV):
    - Primary distribution level:
      - Circuit-breaker switchgear with SF$_6$ insulation and vacuum circuit-breaker
    - Secondary distribution level: Load break switchgear with SF$_6$ as insulating and arc-extinguishing medium

- **Outdoor instrument transformers (>52kV)**

- **Gas-insulated transmission lines (GIL)**

- **Power transformers (outside Europe in conurbation)**
SF₆ as a greenhouse gas – Emissions

Technical recommendation in Cigré SF₆-Handling Guide No. 276

Definition in IEC-standards

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Energy Sector
### SF$_6$ as a greenhouse gas – Emission

#### Atmospheric Composition

<table>
<thead>
<tr>
<th>Gas</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide CO$_2$</td>
<td>380 ppm (0.038%)</td>
</tr>
<tr>
<td>Helium He</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Neon Ne</td>
<td>18 ppm</td>
</tr>
<tr>
<td>Methane CH$_4$</td>
<td>1.8 ppm</td>
</tr>
<tr>
<td>Hydrogen H$_2$</td>
<td>500 ppb (5 e$^{-5}$%)</td>
</tr>
<tr>
<td>Nitrous Oxide N$_2$O</td>
<td>310 ppb</td>
</tr>
<tr>
<td>Carbon Monoxide CO</td>
<td>100 ppb</td>
</tr>
<tr>
<td>Ozon O$_3$</td>
<td>30 ppb</td>
</tr>
<tr>
<td>Other</td>
<td>5 ppt</td>
</tr>
<tr>
<td>Oxygen O$_2$</td>
<td>0.93%</td>
</tr>
<tr>
<td>Argon Ar</td>
<td>0.93%</td>
</tr>
<tr>
<td>21% Oxygen O$_2$</td>
<td></td>
</tr>
<tr>
<td>Other Trace Gas</td>
<td></td>
</tr>
<tr>
<td>0.07% Trace Gas</td>
<td></td>
</tr>
<tr>
<td>78% Nitrogen N$_2$</td>
<td></td>
</tr>
</tbody>
</table>

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Situation of GHG in Europe before the regulation
Greenhouse gas emission in the EU-15, 2002

Total SF$_6$-emission contribution only 0.28%
SF$_6$-emission from electric power equipment: 0.05%
Closed and sealed pressure systems in Germany: 0.03%

Other SF$_6$-emission sources were: magnesium and aluminium industry, footwear, tyres, window noise insulation, military applications, semiconductor industry, medical devices (mainly „open applications“)
“Reductions of SF₆ emissions from electrical high and medium voltage equipment in Europe”

- In 2002 in the EU-15 the SF₆-emission of electrical power equipment was 0.05% of all greenhouse gases → Slide 10
- Volunteer actions of manufacturers and users of electrical high and medium voltage equipment in Europe realized a reduction of 40% SF₆-emission in the last 10 years
- Additional reduction of SF₆-emission possible – improve tightness, gas-recycling; complete & Europe-wide realization of this activities in the future
- Environmental life cycle assessments show a relief of the CO₂-balance by using SF₆-technology

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1) Coordinating Committee for the Associations of Manufacturers of Industrial Electrical Switchgear and Control gear in the European Union (now renamed/reorganized to “T&D Europe”)

2) European Union of the Electricity Industry (utilities/users)

SF$_6$ as a Greenhouse Gas

History – IPCC and the Climate Conference at Kyoto (1988-1997)

1988 The Intergovernmental Panel on Climate Change (IPCC) was founded by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO).

Main task:
Evaluation of the risks of climatic change and compilation of preventive strategies by means of expertise reports.

1997 First “Voluntary Commitment” of the German manufacturers and operators concerning reduction of SF$_6$-emissions in switchgear.

1997 Definition of greenhouse gases with a high Global Warming Potential (GWP) at the climate conference in Kyoto (Japan)

Gas types: Carbon dioxide (CO$_2$), methane (CH$_4$), dinitrogen monoxide (laughing gas, N$_2$O), hydrochlorofluorocarbons (H-FKW / HFCs), perfluorohydrocarbons (FKW / PFC) and sulfur hexafluoride (SF$_6$)

- **Kyoto target, Europe** (issue 1997): Reduction of greenhouse gas emissions in the EU by 8% in the period 2008-2012* (in Germany 21%) based on the emission level of 1990.

Within the EU, the member states have agreed on different targets for the reduction or increase of emissions from greenhouse gases.

*) Follow-up agreement to be signed in 12/2009 in Copenhagen.
05/1999 Publication of the ecological balance
“Power supplies by using SF₆ technology”

Result: The use of SF₆ technology leads to considerable environmental advantages over the use of SF₆-free switchgear. Therefore, SF₆ technology makes sense for electric power supplies, even from the environmental viewpoint. This supports the use of GIS installations that ensure appropriately low SF₆ emissions, on the one hand, and rigorous application of the SF₆-ReUseConcept of a closed SF₆-cycle, on the other.
**SF₆ as a Greenhouse Gas**


01/2004 Publication of the ecological balance in medium voltage (ordered by ZVEI, VDE FNN, Solvay, supported by BMU / UBA, TÜV, RWTH Aachen)

Result  Transmission losses (I²R losses) causes the main part to the greenhouse effect. Every switchgear – regardless of the insulating medium – contribute to the greenhouse effect to a low extent. The only difference is the contribution of the respective drivers to the total emission.
02/2005 The Kyoto Protocol comes into effect after having been signed by 55 countries - including finally Russia as one of the 3 biggest CO₂ emitters - which together caused more than 55% of the greenhouse gas emissions of the year 1990. Some countries like the USA, Croatia and the Principality of Monaco have signed the protocol, but are not going to ratify / implement it.
SF₆ as a Greenhouse Gas
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 life cycles 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.
SF₆ as a Greenhouse Gas

History – 2005 German Voluntary Commitment (Examples for Participants)

**Voluntary Agreement Participation**
- SF₆ Producer: 100% ✓
- Operator High Voltage: 100% ✓
- Manufacturer of Power Equipment: 98% ✓
- Operator Medium Voltage: 90% ✓
SF₆ is considered in some articles only

The use of SF₆ 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
European F-Gas-regulation 842/2006
Relevant articles for SF₆ electric power 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 (SF₆)
European F-Gas-regulation 842/2006, article 4 „Recovery“
Optimized gas recovery needs „State-of-the-Art“ equipment

### Example for typical HV equipment

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mbar SF$_6$-maintenance unit</td>
<td>For evacuation of SF$_6$ without losses from a MV RMU</td>
</tr>
<tr>
<td>SF$_6$-measurement device</td>
<td>SF$_6$-collecting device for measurement of gas</td>
</tr>
<tr>
<td>SF$_6$-collecting device</td>
<td>Evacuation of SF$_6$ without losses from a MV RMU</td>
</tr>
</tbody>
</table>

Source: DILO
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.

Source: Cigré-Guide no. 276, application of table 25; Example: GIS Siemens
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

- **Training** (not subject to conditions of regulation)
- **Evaluation body/Examination** (content defined)
- **Proof of competence**
- **Certification body issues certifications**

Evaluation body and Certification body have to be independent

*) regulation refers to HV switchgear only
European F-Gas-regulation 842/2006, article 5
„Training and certification“ together with regulation 305/2008

Minimum requirements
- to be known by technicians
- to be tested by evaluation body

(a) theoretical test with one or more questions testing that skill or knowledge, as indicated in the column ‘Test type’ by T

(b) practical test where the applicant shall perform the corresponding task with the relevant material, tools and equipment, as indicated in the column ‘Test type’ by P

<table>
<thead>
<tr>
<th>No</th>
<th>Minimum knowledge and skills</th>
<th>Test type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic knowledge of relevant environmental issues (climate change, Kyoto Protocol, Global Warming Potential), the relevant provisions of Regulation (EC) No 842/2006 and of the relevant Regulations implementing provisions of Regulation (EC) No 842/2006</td>
<td>T</td>
</tr>
<tr>
<td>2</td>
<td>Physical, chemical and environmental characteristics of SF₆</td>
<td>T</td>
</tr>
<tr>
<td>3</td>
<td>Use of SF₆ in electric power equipment (insulation, arc quenching)</td>
<td>T</td>
</tr>
<tr>
<td>4</td>
<td>SF₆ quality, according to the relevant industrial standards (1)</td>
<td>T</td>
</tr>
<tr>
<td>5</td>
<td>Understanding of the design of electric power equipment</td>
<td>T</td>
</tr>
<tr>
<td>6</td>
<td>Checking the SF₆ quality</td>
<td>P</td>
</tr>
<tr>
<td>7</td>
<td>Recovery of SF₆ and SF₆ mixtures and purification of SF₆</td>
<td>P</td>
</tr>
<tr>
<td>8</td>
<td>Storage and transportation of SF₆</td>
<td>T</td>
</tr>
<tr>
<td>9</td>
<td>Operation of SF₆ recovery equipment</td>
<td>P</td>
</tr>
<tr>
<td>10</td>
<td>Operation of tight drilling systems, if necessary</td>
<td>P</td>
</tr>
<tr>
<td>11</td>
<td>Re-use of SF₆ and different re-use categories</td>
<td>T</td>
</tr>
<tr>
<td>12</td>
<td>Working on open SF₆ compartments</td>
<td>P</td>
</tr>
<tr>
<td>13</td>
<td>Neutralising SF₆ by-products</td>
<td>T</td>
</tr>
<tr>
<td>14</td>
<td>Monitoring of SF₆ and appropriate data recording obligations under national or Community legislation, or international agreements</td>
<td>T</td>
</tr>
</tbody>
</table>

(1) For instance IEC 60376 and IEC 60480.
European F-Gas-regulation 842/2006, article 6
„Reporting“ together with regulation 1493/2007

„Commission regulation No 1493/2007 establishing the format for the report to be submitted by producers, importers and exporters of certain fluorinated GHG“

- Reporting of producers, importers and exporters in the EU
- Submission of the report by 31 March of the year following the year for which the report applies
- Report shall be submitted to the EU commission and the competent authority of the member state
- For utilities usually not relevant
European F-Gas-regulation 842/2006, article 6
„Reporting“ together with regulation 1493/2007

The reporting is a must to do in case of...

Import
country A outside EU
SF₆ > 1 t in container or bottles

European Union

Export
country B outside EU
SF₆ > 1 t in container or bottles

The reporting is not necessary for...

Import / export inside EU countries
SF₆ in equipment
Import / export < 1 t per year and company

In some countries additional voluntary commitments regarding reporting exist
European F-Gas-regulation 842/2006, article 7
„Labelling“ together with regulation 1494/2007

„Commission regulation establishing the form of labels and additional labelling requirements as regards products and equipment containing certain fluorinated GHG“

- It applied from 1. April 2008
- SF₆ labelling on the product itself
- Information in the instruction manual
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
Labelling of products

The instruction manual must contain a note in the sense of…

“This equipment contains the fluorinated greenhouse gas SF\textsubscript{6} covered by the Kyoto Protocol and with a global warming potential (GWP) 22 800. SF\textsubscript{6} shall be recovered and not released into the atmosphere. For further information on use and handling of SF\textsubscript{6} please refer to IEC 62271-303: High-voltage switchgear and control gear – Part 303 Use and handling of sulphur hexafluoride (SF\textsubscript{6})”

Source: T&D Europe, Guide for Manufacturers of HV Switchgear containing SF\textsubscript{6}…
European F-Gas-regulation 842/2006

Article 10: Review

„Paragraph 2“

By July 4, 2011, the Commission shall publish a report based on the experience of the application on the regulation

Current status

- the Consulting company „Oekorecherche“ got in 12/2009 the order from the EU-Commission to prepare this review report

- Support regarding SF$_6$ in electric power equipment is given to Oekorecherche by various organisations in our sector

- A preliminary report is scheduled for autumn 2010
Criteria for the Use of SF₆ Equipment (1)

High Dielectric Strength

- **High insulating and breaking capacity**
  - At the same atmospheric pressure (100 kPa = 1.0 bar)
    - Dielectric strength approx. 3 times higher than that of air insulation
  - At double atmospheric pressure (200 kPa = 2.0 bar)
    - Dielectric strength approx. 6 times higher than that of air insulation
  - Filling pressure in medium-voltage switchgear:
    - 50 kPa to 120 kPa
    - Depending on voltage level and requested dielectric strength

![Graph showing disruptive discharge voltage vs electrode distance for different pressures of SF₆ and air.](image)
Criteria for the Use of SF$_6$ Equipment (2)

Reduced Dimensions

- **Compact design**
  - Flexible selection of location close to load centers
  - Utilization of existing buildings with more switchgear panels

<table>
<thead>
<tr>
<th>Year</th>
<th>Air-insulated</th>
<th>Air/solid-insulated</th>
<th>Cast-resin insulated</th>
<th>Gas-insulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>until 1950</td>
<td>83 m$^3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>until 1970</td>
<td>47 m$^3$</td>
<td>29 m$^3$</td>
<td>24 m$^3$</td>
<td>8 m$^3$</td>
</tr>
<tr>
<td>until 1980</td>
<td></td>
<td>5.8 m$^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>since 1982</td>
<td></td>
<td>2.2 m$^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel</td>
<td>19 m$^3$</td>
<td>14.5 m$^3$</td>
<td>8.7 m$^3$</td>
<td>5.8 m$^3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Criteria for the Use of SF₆ Equipment (3)

High Personal Safety

- High personal protection
- Approximation to high voltage by mistake is excluded by the design

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**IAC A FLR 40kA 1s**

- **IAC** Internal arc classification
- **A** Access for authorized persons
- **FLR** Access from front, lateral, rear
- **40kA** Short-circuit breaking current
- **1s** Internal arc duration
Criteria for the Use of SF₆ Equipment (4)
Climate, Service Life, Cost-Efficiency, Availability

- Independence from ambient conditions
  - Hermetic enclosure of the primary conductors

- Sustained utilization of equipment
  - Preservation of resources – reduced use of material
  - Longer service life

- High availability and reliability of supply
  - Aging and impairment by pollution and other external influences excluded by design

- Low fire load
  - Reduced use of plastic material

- Reduced power losses at system and switchgear level
  - Shorter primary circuits
GIS today and in the future
Ecological and economic advantages of GIS (case study)

- Compact design
- HV close by city
- Less amount of material
- Lower energy losses
- Ecological
- Economical

- 27% less amount of material
- 98% lower energy losses
- 21% reduction in GWP

<table>
<thead>
<tr>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>52 TJa</td>
<td>38 TJa</td>
</tr>
<tr>
<td>8000 sqm</td>
<td>8000 sqm</td>
</tr>
<tr>
<td>2.750 tCO2</td>
<td>2.170 tCO2</td>
</tr>
</tbody>
</table>

GWP: Global Warming Potential

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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 SF₆ was reached by using modern development tools, new materials and optimized production processes since the introduction of the GIS-technology in 1968.

Significant reduced amount of SF₆ in the equipment
Equipment design – material
SF₆-Tightness of aluminium vessels for HV switchgear

- State-of-the-art production
- Process optimization
- Reliable partner

- Best quality
- Decade-long tightness

- Ecological
- Economical

Beside requirements on SF₆-tightness, pressure vessel regulations apply as well

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Sealing systems like this assure the tightness of the GIS for decades. However, especially for outdoor equipment this must be supported by an effective corrosion protection.
Dynamic SF₆-sealing systems

1 Bearing  
2 Bearing  
3 Radial sealing packages

Radial sealing packages are an import factor for SF₆-tightness of the GIS
Component design development
Cast-Resin partitions

Beside „external“ SF₆-tightness „internal“ SF₆-tightness (between 2 gas compartments) has to be assured as well

Production and testing in the factory (including gas permissible partitions and other insulating parts)
Equipment SF$_6$-tightness
100% routine testing of vessels
Tightness tests of complete GIS and also components according to IEC are part of the quality assurance process (closed pressure systems).

The tightness of SF₆-GIS can be confirmed nowadays during type testing (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.
SF₆-Monitoring during operation

- The alarm values are based on the electrical functionality of the equipment and used for SF₆-leakage indications as well.
- A SF₆-gas monitoring system can be used for early leakage detection and trend analysis of leakage size.
SF₆- Detection in GIS-Buildings  
General Aspects - Experience

- GIS are gastight for decades - as proved in the field
- GIS-gas compartments are equipped with SF6-densitiy monitors for functionality reasons (SF₆-alarm in case of „small“ leakages)
- SF₆-Detection equipment therefore very seldom required by customers
- Air condition not common in GIS-buildings
- Possible SF₆-gas will accumulate on the ground (6x heavier than air)
- SF₆-Detection equipment not recommended in papers or standards
- No incident known regarding leaking SF6-gas

However, SF₆-detector for GIS-buildings are available
SF₆- Detection and Signalling in GIS-Buildings Equipment

Detection
Evaluation
Signalling

Source: DILO

SF₆-Network Monitor
SF₆-Network Monitor
SF₆-Network Controller

measurement is carried out
alarm is triggered off

ready for measurement

SF₆ in electric power equipment

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SF$_6$- Detection in GIS-Buildings
Possibilities

► 12 Detectors (SF6 Network Monitors) can be connected to 1 Controller
► Principle: permanent supervision of ambient air for SF$_6$
► Output of Controller can be used for various functions: signalling lamp, remote control, release for door opener, operating of ventilation system,….
► Ventilation system can be combined with air condition system (e.g. air circulation)
► Extraction by suction of gas-mixture at lowest point of the building another option
► Size of ventilation and extraction system are designed individually with regards to GIS
► Installation not necessary for functional reasons (leakages) but can be part of EHS-policy
The reduction of SF₆-emission has been achieved by:

- permanent investments in state-of-the-art equipment
- continuous staff training
- constant process optimization

*) Output means delivered GIS bays
The manufacturers of SF₆ electrical power equipment are certified concerning their compliance of environmental norms and standards (e.g. Siemens).

External accreditation of manufacturers

Environmental Management Systems (DIN EN ISO 14001) and Quality Management Systems (DIN EN ISO 9001)

as well as manufacturers verifications regarding Greenhouse Gas Inventory

Criteria for the Use of SF₆ Equipment
Manufacturers awareness regarding environmental responsibility
Overview of the Latest Standards and Publications

- **IEC 62271-1** Common specifications for SF₆-insulated and air-insulated high-voltage switchgear and controlgear
- **IEC 62271-200** High-voltage switchgear and controlgear >1kV up to 52kV
- **IEC 62271-203** High-voltage switchgear and controlgear >52 kV
- **IEC 62271-303** Use and handling of SF₆
- **IEC 60376** Specification for new SF₆ gas
- **IEC 60480** Checking and treatment of sulfur hexafluoride (SF₆) taken from electrical equipment

IEC: International Electrotechnical Commission for Standards
Overview of the Latest Standards and Publications
EU commission, Cigré and T&D Europe

- Information for operators and technical personnel working with equipment containing fluorinated greenhouse gases
  - no. 234, Recycling of SF$_6$
  - no. 276, Guide for Handling of SF$_6$
  - no. xxx, SF$_6$-Tightness Guide

- SF$_6$ in electrical equipment. Guide for operators and manufacturers

CIGRÉ: International Council on Large Electric Systems
T&D Europe: European Association of the Electricity Transmission and Distribution Equipment and Services Industry
## GIS in the past, today and in the future (world)

<table>
<thead>
<tr>
<th>Year</th>
<th>GIS Type</th>
<th>AIS Type</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>Indoor AIS</td>
<td>AIS</td>
<td>100%</td>
</tr>
<tr>
<td>1980</td>
<td>GIS</td>
<td>AIS</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>GIS, HIS, AIS Compact, Field Module</td>
<td>AIS</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>GIS, HIS</td>
<td>AIS</td>
<td></td>
</tr>
</tbody>
</table>

### SF₆ in Electric Power Equipment

- **20 m**
- **60 m**
- **200 m**

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Energy Sector
SF₆ has excellent insulating and arc-extinguishing properties. Up to now, there are no alternatives in sight.

SF₆ technology allows for electrical equipment with compact design, with a high personal safety, minimized fire load, preserving the resources and with a high availability and reliability of supply.

Due to their unique electrical properties, SF₆ switchgear and equipment are indispensable for network operation in power transmission and distribution.

Ecological balances show: SF₆ technology is ecologically responsible. Despite a high GWP, the CO₂ balance is better than for conventional designs due to lower transmission losses and reduced use of material.

Due to the high CO₂ potential of SF₆, emissions must be kept as low as possible. This is ensured by low leakage rates and handling losses during operation and at the end of the service life.
Thank you very much for your attention!

peter.glaubitz@siemens.com

Berlin, July 1, 2010
Gas-insulated transmission lines (GIL)

High-power transmission technology

Answers for energy.
Superior technology and excellent knowhow ensure quality and reliability

Siemens GIL systems are based on the successful SF6 tubular conductor technology, which has been around for several decades. GIL consist of a central aluminum conductor with a typical electrical cross section of up to 5,300 mm². The conductor rests on cast resin insulators, which center it within the outer enclosure. This enclosure is formed by a sturdy aluminum tube, which provides a solid mechanical and electrotechnical containment for the system. To meet up-to-date environmental and technical aspects, GIL are filled with an insulating gas mixture of mainly nitrogen and a smaller percentage of SF6. For increased lifetime, the “performance line” product series has a longitudinal particle trap installed over the entire horizontal route section. An automated orbital welding procedure, accompanied by tailored ultrasonic inspection techniques, ensures perfect gastightness of the aluminum tubes.

During service, the fully encapsulated design fully protects the GIL against environmental influences. Thanks to the technologically clear-cut, logical design and the use of high-quality materials, an absolutely maintenance-free product is achieved which requires external inspection only. And at the end of its service life, the issue of de-installation is solved. The GIL tubular system with all its components and the insulation gas mixture are 100 percent recyclable. These factors help to minimize lifetime costs.

Impressive practical record: GIL system in Germany’s Wehr power plant

Siemens installed a GIL in a tunnel in the Wehr pumped-storage power station in the Black Forest as long ago as 1975. With a single-phase length of almost 4 km this installation is still a significant reference among worldwide GIL projects. Notwithstanding its service time, an inspection after 30 years showed that all components were still in top condition, and assured the customer that GIL will provide many more years of reliable operation.

GIL – high-power transmission technology

GIL flexibility: above- or belowground

Second-generation gas-insulated lines for high power transmission are the best option where environmental or structural considerations rule out the use of overhead transmission lines. The outstanding features of a GIL system are its high transmission capacity, superior electromagnetic compatibility (EMC) to any other transmission system, low losses, high safety (no fire hazard) and flexible installation options. GIL can be laid aboveground, installed in tunnels or buried directly in the soil, depending on individual requirements.
Flexible grid connections – optimum grid integration

GIL systems consist of a manageable number of modular elements which can be combined according to defined technical rules. Thus GIL systems are not limited in their entire length. Moreover, they are suited for almost any kind of routing, for instance through built-up areas or road crossings, on marshy ground, etc. To meet these requirements the actual installation of GIL makes use of sophisticated laying techniques. These techniques are based on the well-proven procedures of the pipeline construction industry, adding some product-specific modifications. Consequently project implementation time can be kept to a minimum.

Due to their outstanding design features Siemens GIL are remarkably flexible for different applications. Thanks to their transmission capacity and low losses GIL can be linked directly, one-to-one to overhead lines, continuing the lines underground. As a result of the low electrical capacitance of GIL, compensating reactors are generally not required, even for very long GIL sections of up to 70 km. The technical particulars of Siemens GIL allow for an autoreclosure pattern for the OHL, so that no modification of the protection concept is needed. For the same reasons, GIL are also perfectly suitable for direct connection to substations or transformers.

Outstanding safety in operation

GIL systems by Siemens live up to their reputation not just with their technical specifications, but also by providing excellent operational safety. GIL systems are immune to hazards that are inherent to other power transmission systems. They are safe to touch in operation, as their housing is solidly grounded. They are fireproof and explosion-proof. The electrical insulation system is not subject to aging phenomena, which reduces the risk of internal failures to virtually zero. Siemens GIL are constructed employing separate gastight compartments of variable length, which further increases safety in case of an external impact. GIL systems are gastight and sealed for their lifetime. Consequently they retain their superior operating properties throughout their service life.

Excellent electromagnetic compatibility enables flexible route planning

The construction of the GIL results in much smaller electromagnetic fields – as much as 15 to 20 times smaller – than with conventional power transmission systems. This makes GIL suitable for completely new routings through populated areas (e.g. next to hospitals or residential areas, in the vicinity of flight monitoring systems, etc.). GIL can be laid in combined infrastructure tunnels together with foreign elements (e.g. close to telecommunication equipment). Thus, GIL provides maximum flexibility for the planning of transmission networks in EMC-sensitive environments, where magnetic fields have to be avoided. Siemens GIL systems satisfy the most stringent magnetic flux density requirements, for example, the Swiss limit of 1 μT.

**High EM compatibility**

Magnetic fields in microtesla (μT) for GIL, overhead transmission line and cable (XLPE, cross-bonding) for a 400 kV double system at 2 x 1,000 MVA load, GIL and cable laid at a depth of 1 m.

<table>
<thead>
<tr>
<th>Magnetic flux density B [μT]</th>
<th>GIL</th>
<th>Overhead line</th>
<th>Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
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<td></td>
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<td>20</td>
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<td>10</td>
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<td>0</td>
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</tbody>
</table>

A comparison of the magnetic fields for different high-voltage transmission systems.
Versatility in application and laying methods

Aboveground installation
GIL installation aboveground is a trouble-free option, even for extreme environmental conditions. GIL are unaffected by high ambient temperatures, intensive solar radiation or severe atmospheric pollution (such as dust, sand or moisture). Corrosion protection is not always necessary. Particularly high transmission power can be achieved with aboveground installation.

Tunnel installation
Tunnels made up of prefabricated structural elements are another quick and easy method of GIL installation. The tunnel elements are assembled in a trench, which is then backfilled to prevent any long-term disfiguring of the local landscape. The GIL is installed once the tunnel has been completed. With this method of installation the land above the tunnel can be fully restored to agricultural use. Only a negligible amount of heat is dissipated to the soil from the GIL. The system stays accessible for easy inspection and high transmission capacity is ensured.

Vertical installation
Gas-insulated tubular conductors can be installed without a problem at any gradient, even vertically. This makes them a top solution especially for cavern hydropower plants, where large amounts of energy have to be transmitted from the underground machine transformer to the switchgear and overhead line on the surface. As GIL systems pose no fire risk, they can be installed in a tunnel or shaft that is accessible and can also be used for ventilation at the same time.

Flexibility for your success
Due to their unique properties GIL systems have become well established in all parts of the world, to solve difficult transmission tasks in complex routings.

GIL installations have been realized in every conceivable layout, with shafts mastering straight vertical distances of 200 m, overcoming steeply inclined slopes, passing around buildings both above- and belowground, and smoothly following serpentine routings without angle units.
Direct burial
Siemens also offers GIL solutions designed for direct burial. These systems are coated with a continuous polyethylene layer to safeguard the corrosion-resistant aluminum alloy of the enclosure, providing protection of the buried system for >40 years. As magnetic fields are marginal in the vicinity of all Siemens GIL applications, the land can be returned to agricultural use with very minor restrictions once the system is completed.

Typical references
In the Limberg II pumped-storage power station in Kaprun, Austria, built in 2010, a GIL system was laid in a shaft with a gradient of 42°. It connects the cavern power plant with the 380 kV overhead line at an altitude of about 1,600 meters. As GIL systems pose no fire risk, the GIL tunnel is not only accessible but also used for ventilation purposes. This resulted in substantial cost reduction by eliminating the need for a second shaft in this project.

A typical example of low EMC values is the PALEXPO project in Geneva, Switzerland. A GIL system in a tunnel replaced 500 meters of a former 300 kV double overhead line which had to be moved for the raised exhibition center building. The line owner based his decision to opt for a GIL solution over a cable solution on the GIL’s much better values with respect to EMC. Highly sensitive electronic equipment can now be exhibited and operated in the new hall without any danger of interference from the 300 kV connection located below it.
Minimum effort – optimum result

GIL was developed to meet a wide variety of requirements for installation and operation. A decisive factor in meeting this demand was an installation process that permits assembly of prefabricated modules at the installation site, thus allowing optimum adoption of the selected routing. This concept also has logistic advantages. All elements such as tubes, angles and special modules are lightweight and small enough to be transported by comparatively light standard trucks.

During installation a major focus is providing gastight connections for the components. To accomplish this requirement, Siemens employs a computer-controlled automatic welding process. A welding robot ensures the highest precision and reproducibility of the welding seams. The quality of each seam is verified to 100 percent with ultrasonic tests to ensure perfect gastightness and mechanical strength. As a result, no replenishment of insulation gas is needed during the entire service life of > 50 years.

### GIL – Technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>245 to 550 kV</td>
</tr>
<tr>
<td>Typical rated current</td>
<td>up to 4,500 A</td>
</tr>
<tr>
<td>Rated short-circuit current</td>
<td>63 kA/3 s</td>
</tr>
<tr>
<td>Insulating gas</td>
<td>N₂ and SF₆ mixture</td>
</tr>
<tr>
<td>Typical system length</td>
<td>100 m to 100 km</td>
</tr>
<tr>
<td>Impulse withstand voltage</td>
<td>1,050 to 1,675 kV</td>
</tr>
<tr>
<td>Capacitance</td>
<td>55 nF/km</td>
</tr>
<tr>
<td>Overload capacity</td>
<td>up to 100% depending on design and requirements</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>~375 to 512 mm</td>
</tr>
<tr>
<td>Weight per phase</td>
<td>50 kg/m</td>
</tr>
</tbody>
</table>
Our company founder, Werner von Siemens, had a passion for inventing trendsetting technologies and placing them into the service of mankind. Siemens GIL is very much in line with this philosophy, since its pioneering technological advantages revolutionize energy transmission with extra-high voltage and extra-high current.

Continuously growing world population and urbanization lead to a strongly increased demand for bulk power transmission at extra-high voltage, right into the heart of cities. At the same time the available space for transmission systems has been restricted more and more, and environmental requirements such as EMC and fire protection have gained increased importance. GIL fulfill these requirements perfectly.

Besides these demands in transmission, power generation is undergoing a conceptual change. As natural resources are limited, regenerative power generation systems are becoming more important. Offshore wind parks and solar power plants are being installed, providing a huge amount of energy at remote places. Consequently, transmission systems are needed that can transport bulk power with the utmost reliability and minimal losses.

The answer to these challenges is GIL. At places where overhead lines cannot be used, Siemens gas-insulated transmission lines provide numerous advantages that differentiate them from any other transmission system:

- High power ratings (transmission capacity up to 3,700 MVA per system)
- High overload capability
- Autoreclosure functionality
- Suitable for long distances (70 km and more without compensation of reactive power)
- High short-circuit withstand capability (including internal arc faults)
- Possibility of direct connection to gas-insulated switchgear (GIS) and gas-insulated arresters without cable entrance fitting
- Nonflammable; no fire risk in the event of failure
- Lowest electromagnetic field
- No aging

GIL will undoubtedly also be the backbone of the demanding transmission projects of the future – whether for the transmission of gigawatts of power from very large offshore wind farms through undersea tunnels, as is being considered for the North Sea in Europe; or for a maximally reliable connection of important power stations to outgoing lines, as for projects like Desert-Tec etc.; or for the transfer of bulk power underground right into the megacities of the future, for a continually improving quality of life for mankind.

Challenges now and in the future
Example Tunnel Installation – Munich 400kV TL

Delivery of Material

Installation phase by phase

Welding Platform