DESIGN, MANUFACTURING, PRACTICE AND INFORMATION TO MINIMIZE SF_6 RELEASE FROM ELECTRIC POWER EQUIPMENT

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INTRODUCTION

Although the effective contribution of SF_6 to the man-made greenhouse effect is less than 0.1%, action has already been taken by the electrical industry to reduce the SF_6 emissions from electric power equipment to an insignificant level.
In the meantime, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (10th December 1997) has included sulphur hexafluoride (SF_6) in the list of greenhouse gases, for which an overall emission reduction of at least 5% below 1990 levels is planned in the period from 2008 to 2012.
This paper summarizes the measures taken to reduce the emissions of SF_6 gas used in MV and HV electrical power equipment.
Particular attention is being paid to reducing gas leakage during operation by adequate equipment design and assembling and to optimizing gas handling procedures over the whole product life cycle.
The latest design, with the drastically reduced quantity of SF_6 used, as well as improved gas handling procedures make the use of SF_6 gas in electrical power equipment unproblematic.

DESIGN FOR MINIMIZING LEAKAGE DURING OPERATION

The trend in the development of electrical power equipment is towards sealed pressure systems, which over a 30-40-year-life-cycle will have total leakages lower than 10% within which full performance of the equipment is guaranteed. This objective has already been reached for MV distribution switchgear which only has small sized gas enclosures and is gas-filled and sealed for life in the factory.
Switchgear with large size enclosures can not be factory-filled but must be assembled and gas filled on-site. Presently, this type of equipment can be designed and assembled such as to avoid the necessity of gas refilling for at least 10 years. Such equipment has to be equipped with pressure/density monitoring devices.
This gas containment performance is reached by reducing the enclosure dimensions with a consequent reduction of the surfaces to be joined. In particular, the following design measures are taken to achieve low leakage:

- Enclosure design:

It is to be considered that in HV switchgear the gas is used at a pressure up to 750 kPa (the maximum pressure is necessary for the circuit breakers; a pressure of 350/450 kPa is sufficient for bus duct, terminal boxes and isolators), whereas in MV switchgear the pressure does not exceed 150 kPa for GIS and RMU, apart from the circuit breakers which are generally enclosed in high pressure resistant resin housings.
As far as HV switchgear are concerned, 5 mm is the minimum thickness for sheet material and 9 mm for cast enclosures; regarding MV switchgear enclosures, 3 mm is the minimum thickness for high quality steel, and 2.5 mm is the minimum thickness for stainless steel. Thanks to the above and to the proven welding technology the housings are gas tight to a technical value that is usual in high vacuum applications.

- Design of sealing systems:

All static sealings use high quality EPDM-O-rings, proven for more than thirty years, and are designed to optimize pressing in the elastic region leading to two or more sealing lines. Double sealing systems are used for the dynamic sealings for the shafts of the operating mechanism.

- Design of gas filling valves

Filling and pressure control valves are equipped with a self-sealing device and with a further manually tightened cap provided with a gasket and usually sealed.

The valves are suitably dimensioned and positioned to simplify gas reclaiming operations. An international standardization of valves/adapters will further simplify gas reclaiming operations to be carried out by both users as well as third-party companies.

GAS EMISSION MONITORING DURING TESTING, MANUFACTURING AND COMMISSIONING [1]

During type testing a bust test is applied with every type of enclosure and a sample of every supplier (five times the design pressure for cast, three times the design pressure for welded housings). During the mechanical type tests of the switching devices, the gas density is monitored. With this test the gas tightness is checked within a sequence of at least 10,000 operations for the circuit breaker, 5,000 operations for the disconnector/and earth switches and 2,000 operations for the fast acting earthing switch. These values are approximately twice those indicated by the IEC, proving the gas tightness under high mechanical stress.

The manufacturing process oriented to minimize gas emissions follows these guidelines:

- SF_6 enclosures are pre-checked by pressure testing with eco-compatible gases
- The surfaces to be sealed (e.g. flange connections) are properly covered during equipment handling and transport
- Enclosure assembling is carried out in compliance with severe procedures and with accurately calibrated tools so as to guarantee hermetic sealing connections
- After carrying out system assembling in the workshop as well as on site, gas tightness is checked through molecular sensitive sensors
- All tightness and functional tests are carried out minimizing SF_6 transfer operations and handling gas in closed circuits. The target is to reduce leakage, probability and rate, and releases caused by defects of both switchgear or gas handling equipment
- The connection pipes of gas handling equipment have terminals provided with self-retaining valves
- In order to verify the target values, gas weight is controlled during each fundamental step of the manufacturing process; in particular, SF_6 weight of gas supply containers is checked on arrival and before returning to the gas producer, so as to avoid that the residual gas, which is returned to the producer, is recorded as gas emission into the environment.

GAS LOSS MONITORING IN SERVICE

In HV power electrical equipment the essential means for leakage monitoring in service consist in equipping all gas compartments with pressure or gas density sensors. The MV power electrical equipment, sealed for life in the factory, can be supplied with pressure or gas density sensors upon request.

In case of maintenance or other gas handling operations on site, the same sealing quality can be reached as in the factory. This is possible because the equipment manufacturer specifies adequate handling procedures and offers personnel training and direct service, whenever necessary. The handling of SF_6, in particular, is supported by a product related SF_6 handling guide.

GAS RECOVERY AND RECYCLING PROCEDURES

The CIGRE SF_6 Recycling Guide [2] is a reference document on which product related handling guides have to be based. It describes the whole SF_6 recycling process, involving gas recovery from the equipment, purification, quality checking, storage, recycling of gas with insufficient quality and final disposal.

As pointed out in the CIGRE guide, the following points are of particular importance:

1) The residual pressure which after recovering the gas is left back in the enclosure and is released upon opening should be lower than 50 mbar;

2) After purification the gas results reusable if the contamination in it does not exceed certain limits. The following three types of contaminants are accounted for:

- The total of non-reactive gaseous contaminants (mainly air, nitrogen and CF_4)
- The total of reactive gaseous decomposition products (mainly HF, SO_2 and SOF_2)
- Humidity.

Table 1 shows the maximum admissible impurity levels for new SF_6 as defined by the IEC Standards 376 [3] and, in comparison, the maximum levels for reusable gas according to the CIGRE SF_6 recycling guide. These latter limits are in the process of being introduced into the IEC Standard 480.

It can be noticed that for reusable gas the limits for non-reactive and reactive gases are higher than for new SF_6. New SF_6 is being manufactured for various applications which also include biological and medical applications, the latter requiring the low values given in IEC 376.

For use in electric power equipment, the criteria only have to be based on functional and safety considerations: The non-reactive gases must not deteriorate the insulation and switching performance of the gas. The reactive gases must not constitute a toxic health risk during gas handling and must not deteriorate the functionality of the equipment. These considerations lead to the substantially higher admissible contamination levels for reusable gas. Details on the derivation of these levels are given in Appendix 1 of the CIGRE SF_6 Recycling Guide.

The humidity content of reusable gas is required to be the same as for new gas.

Table 1 – Maximum impurity levels acceptable for the re-use of SF_6 gas

Contaminants	Detection principle	Maximum acceptable impurity level for reuse (CIGRE SF_6 Rec. Guide and revised IEC 480)	Maximum acceptable impurity level for new gas
Non-reactive gases (air + CF_4)	Speed of sound or heat conduction	2% vol total (circuit br.) 5% vol total for insulation	0.34 %vol
Reactive gases (SO_2 + SOF_2 as indicator gases)	Color change by chemical reaction (reaction tubes)	12 ppmv	7 ppmv
Humidity	Dew-point meters	120 ppmv at liquefaction pressure (2MPa) or, equivalently, dew point –18°C	120 ppmv at liquefaction pressure (2MPa) or, equivalently, dew point –18°C

GAS CONTENT IN SF_6 INSULATED ELECTRICAL POWER EQUIPMENT [4]

Typical SF_6 contents of the major types of electric power equipment are shown in Table 2. The values refer to present design and the values in parentheses refer to the previous design generation.

These table highlights the relatively low gas content of MV equipment and the considerable reduction of SF_6 required per function. This reduction has essentially been reached by the latest generation development, particularly for high voltage equipment.

The figure 1 shows the new generation of MV GIS equipped with SF_6 or vacuum circuit breakers. To be noted the very small dimensions of gas handling equipment

Table 2 – Weight (kg) of SF_6 per 3-phase switchgear unit

Switchgear	Medium Voltage	High Voltage		
	24 kV	145 ÷170 kV	245 kV	420 kV
Switch-disconnector	0.3	-	-	-
Circuit breakers	0.5 (0.8)	7 (8)	19 (26)	27 (41)
Ring main unit - RMU	2.6	-	-	-
Metering Transformer	-	9	13	32
GIS metal-clad switchgear	2.2 (3.6)	110 (120)	210 (500)	700 (1380)

Fig. 1 – SF_6 24 kV GIS - Reclaiming gas operation

a) '70s generation

b) new generation

Fig. 2 – 420 kV GIS

The figure 2 shows old and new generation of 420 kV GIS. The overall dimensions of the new generation have been reduced by almost 50%.

GAS RECOVERY FROM EQUIPMENT

HV switchgear

Gas recovery from HV switchgear has always to be carried out on-site by commercially available mobile SF_6 reclaimers. Most of the gas can then be purified to the requirements in table 1 to be reused on-site.
Non-arced gas is always re-usable on site unless it has been contaminated with large quantities of air or nitrogen by handling errors. Gas arced by normal circuit breaker operation can be rendered reusable in most cases. Only strongly air contaminated gas and gas resulting from rarely occurring heavy failure arcs may not always be reclaimable on-site but may require further treatment off-site by a specialized company. SF_6 producers and CFC recyclers are now taking back used SF_6 for recovery or final deposition.
Real situations are more favourable than the recycling process described above; two verifications carried out recently on the gas coming from HV circuit breakers which had been in service for more than 10 years have confirmed the reusability of this gas without further treatment, except for the usual filtering during the recovery phase.
In each of the two above mentioned events, about 600 kg of gas were recovered during ordinary maintenance operations on circuit breakers installed in ENEL transmission and distribution networks with very low contamination level and SF_6 content of 99.75% and 99.6% respectively.
The last figure confirms that gas handling carried out with the utmost care also eliminates the problem of a presence of air or nitrogen higher than 2%, which could hamper easy gas reuse.

MV distribution equipment

The equipment design is normally "sealed for life": small dimensions and low weight allow easy transportation. The SF_6 therefore does not have to be recovered on-site but the equipment can be transported to the manufacturer where the gas is handled professionally.
Two typical examples for the characteristics of used SF_6 are given below:

- SF_6 gas was recovered from fifteen 24 kV circuit breakers which had been in service for twenty years and were installed in primary stations as feeder protection breakers, as which they where exposed to severe operating conditions. After normal filtering in a commercial SF_6 reclaimer, the following contamination levels were measured:
  - Non-SF_6 gases: 1.7 %
  - Reactive gases (SO_2+SOF_2): 12 ppmv
  - Dew point - 47°C

  As these values were below the limits given in Table 1 the gas was re-used.
- SF_6 was recovered from five 24 kV circuit breakers which had been installed for ten years in primary stations for feeder protection under very severe operating conditions.
  After normal filtering, the following contamination levels were measured:
  - Non-SF_6 gases: 1.8 %
  - Reactive gases (SO_2+SOF_2): >50 ppmv
  - Dew point - 45°C

  Since the reactive gases exceeded the limit values for reuse in Table 1, the SF_6 was transferred to the SF_6 producer Ausimont for further treatment. An extract from the Ausimont receiving test report is shown in Table 3. The impurity levels, though no longer complying with the reuse criteria in table 1, were still acceptable for successful gas regeneration and therefore it was not necessary to thermally destroy this gas which was reused after processing.

Table 3 – Figures from AUSIMONT Test Report on used SF_6

Characteristics	Concentration (by mass)	Concentration (by volume)
Purity (% SF_6)	--	98.31 % vol
Air (N_2 and O_2)	--	1.64 % vol
CF_4	430 ppmw	730 ppmv
Water	not detected	not detected
Total acidity as HF	371 ppmw	2700 ppmv
Hydrolyzable fluorides as HF	2.48 ppmw	1800 ppmv
Mineral oil	not detected	not detected
S_2F_{10}	< 10 ppmw	< 7 ppmv
SO_2	100 ppmw	365 ppmv

LOGISTICS OF SF_6 RECYCLING

As part of its product responsibility, equipment manufacturers provide to:

- inform users of his products that SF_6 cannot be released into the atmosphere,
- inform users on environmentally correct SF_6 handling,
- SF_6 handling service to those who do not have gas handling know-how.

ABB provides information on SF_6 on an INTERNET homepage with the address http://www.sf6.abb.com/. This homepage provides, among other, the following information:

- Answers to basic questions related to the use of SF_6 in electric power equipment
- SF_6 handling training courses
- Gas supply
- Rental of SF_6 handling equipment
- Gas handling service
- Electrical power equipment management at end of product life
- Gas takeback.

CONCLUSIONS

- SF_6 used in electrical power equipment is environmentally unproblematic from the greenhouse effect point of view, for the following reasons:
  - The absolute quantity of SF_6 is very small when compared to other greenhouse gases (CO_2, CH_4, etc.).
  - The state of the art of sealing and tightening systems allow to reach negligible gas leakage rates.
  - The investments made by electrical industry for environmentally correct gas handling and recycling practice allow to reduce SF_6 losses to an insignificant level.
  - SF_6 handling support service and gas handling know-how is now made available from manufacturers of electrical power equipment and from manufacturers of gas handling equipment.
  - For applications in electric power equipment, the environmental life cycle of the gas is closed. SF_6 gas can be directly rendered reusable on-site, the residue can be recovered for use through further treatment by specialized recycling companies and gas which is no longer needed can be destroyed by a thermal process. So far, according to experience, it has been never necessary to destroy the gas by thermal processes.
- Modern equipment design has considerably reduced the quantity of SF_6 per function.
  The equipment compactness, only possible by using SF_6 gas, allows a very substantial reduction of other materials required and of total lifetime energy losses.
- In view of the Standard ISO 14040 (Environmental Lifecycle Analysis), this leads to a substantial reduction of the total environmental impact of the equipment because the impact of the small SF_6 quantity is greatly overcompensated by savings in materials, lifecycle energy losses and the associated emissions.

REFERENCES

[1] IEC Technical report 1634 (1995), “High voltage switchgear and controlgear - Use and handling of sulphur hexafluoride (SF_6) in high voltage switchgear and controlgear”

[2] CIGRE SF_6 Recycling Guide, “Reuse of SF_6 gas in electrical power equipment and final disposal”, *Technical Brochure.* no 117, Electra no 173 (August 1997)

[3] IEC Standard 376 (1971), “Specification and acceptance of new sulphur hexafluoride”

[4] M. Marchi, L. Margheritti, G. Pirovano, L. Sfondrini, “Handling of SF_6 power electrical equipment at the end of their lifetime”, in *AEI/CEI/CESI Workshop* (October 1998)