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The CAPIEL¹ Cradle-to-Grave Inventory Methodology for SF₆ –Insulated Electrical High Voltage Switchgear in Europe

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1 SF₆ and the Switchgear Technology

A substantial part of the SF₆ yearly produced worldwide is used in switchgear systems. Based on figures provided by the OEM's in Japan /1/ and Europe /2/ and taking into consideration a volume of SF₆ produced in 1995 (base year in the Kyoto protocol) of approx. 7,500 tons in the USA, Europe, Japan and South Africa, to which is added an approximated volume of 1,000 tons produced in Russia and China, it is estimated that the OEM's in Japan and Europe use approx. 45% resp. 40% of the volume purchased by the OEM's world wide.

2 Situation in the European Union

The contribution of SF₆ -emission from Electricity Sector to man made global warming is less than 0,1%. The European switchgear industry of manufacturers and users contributes only 0,008%. However, European switchgear manufacturers and users are aware that SF₆ is a persistent gas. Therefore, use and emission of SF₆ in electrical switchgear shall be controlled. Voluntary agreements are effectively signed by CAPIEL¹ and eurelectric² in 2001 to contribute to European Climate Change Program (ECCP). The topic of reduction of SF₆ emission related to switchgear is addressed in WG-5 Industry, Fluorinated Gases. Capiel and Eurelectric are participating in this WG-5.

The objective of ECCP is to identify and develop elements for an EU climate change strategy necessary for implementation of the Kyoto Protocol. The ECCP concentrates on improvement of inventories and emission data, developing measures and for emission reduction. Policies to ensure reductions will be achieved. Involved parties are European Commission, Member States, industries and (European) National Green Organizations. Time scale is start in summer 2000, agreed policies and measures expected ready in spring 2001.

The final report on Fluorinated Gases, June 2001, /9/ acknowledges Sector's specific aspects. For production and use of SF₆ – switchgear emissions slightly decrease, despite projected increase of 50% in population. Monitoring and verification are put in place. Reduction options by voluntary actions are initiated by the sector. Policies and measures are discussed for electricity sector aiming to consolidation of monitoring system. Formal recognition of voluntary pan-European action to provide framework for flexible national targets is under way. The EU legislation is now in preparation comprising containment and monitoring. For certain applications using SF₆ that are not able to keep SF₆ in a closed loop cycle as tires, sound insulating glazing and sport shoes marketing and use restrictions are expected. Electrical switchgear will be no subject to market restrictions since closed loop cycle and inventory methodology is introduced successfully.

From a total amount of 6,200 tons of SF₆ emitted world-wide in 1995 /3/, it is estimated that world switchgear related emission in 1995 was some 2,800 tons, representing approx. 45% of the total SF₆ emitted in 1995. Main data for emission figures originate from Japan /1/, Europe /2/, and USA /4/. Figures for Middle East, Far East and Southern Hemisphere are estimated, based on amounts banked and installed in 1995 as well as on erection and handling procedures in place at this time.

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The actual figures for switchgear in electrical transmission and distribution is given in *Fig. 1*. Increase in banked volume of SF₆ refers to installation in switchgear and stock at site. Despite increase in installed volume emissions from switchgear remain constant on a low level. It shall be noted that figures mentioned are approximated. Its purpose is to give a general and broad overview, putting individual figures into a world-wide perspective. Europe is a relatively large consumer of SF₆ for application in electrical transmission and distribution, on the other hand Europe is a moderate emitter of SF₆ in this sector.

3 CAPIEL Inventory Methodology

The CAPIEL Inventory Methodology basic idea may be demonstrated by annual assessment of total SF₆ processed from switchgear manufacturer's (OEM) side *Fig.2*. Total SF₆ purchased is input and total SF₆ delivered with equipment sold as well as re-sent SF₆ to supplier is output. The difference in stock is added or subtracted. The remaining difference of this balance represents emissions at each OEM manufacturer in his own responsibility and includes all handling losses during development and manufacturing. This balance philosophy is extended along total supply chain including life-cycle management of equipment at utilities as a closed loop cycle including recycling and re-use of SF₆ *Fig 3*. Reference to successful implementation of this methodology on national level can be taken from Switzerland *Fig.4* and Germany.

The CAPIEL Inventory Methodology defines as well principles of „Ownership“ and „Transfer of Ownership“ to ensure a clear responsibility in any stage of process of handling SF₆. The Inventory Methodology is based on a Mass-Balance Approach, as given by IPCC Tier 3b /5/, comparing input and output of SF₆ on a calendar year basis. In fact it is the only practical way to determine emissions with a reasonable precision.

Being implemented on a geographical basis, consolidation of information collected from entities identified inside a given country will provide the total emission from the country with no distortion due to international trade.

In order to aggregate national figures for ECCP inventory at European level CAPIEL and Eurelectric condense annually all data reported from their affiliates and take care of harmonisation and balance correctness. Since this process has been recently (year 2001) settled by voluntary agreement on pan-European level accuracy of existing data base may still have a small uncertainty. However, as annual reporting is established revolving procedures and individual inventory-protocols are required from each partner under his own responsibility. As a result, data quality will improve and possible inconsistencies will be eliminated step by step.

4 Options for SF₆ Emission Reduction.

Basically the activities in the European Union are concentrating on the following main issues:

- Improvement of awareness at all levels of SF₆ handling. For that intensive training is necessary at manufacturers and users.
- Improvement of handling equipment and procedures.
- Improvement of leakage detection at user's site and immediate action for repair or refurbishment.
- Improvement of instruction manuals and nameplates indicating contained SF₆ –mass on equipment as a permanent environmental relevant information during total life-cycle.

Since design principles of state-of-the-art switchgear are on a very advanced stage, leakage of new equipment is no matter of concern. This applies for Medium Voltage Distribution Class Switchgear (high voltage level 1...<52 kV) as well as for High Voltage Transmission Class Switchgear (high

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voltage level >52 kV ...1000kV). CAPIEL has been committed to indicate contained SF₆ mass on nameplate. This addresses inventory reporting and re-use of SF₆ as well *Fig.5*.

Another relevant aspect is support of proper handling and reference to state-of-the-art leakage rates in international standards. All standardisation committees of the International Electrotechnical Commission (IEC) are working hard to incorporate SF₆-relevant aspects into switchgear standards. Also CIGRE (International Conference on Large High Voltage Electric Systems) has published several reports for proper gas-handling and recommendations for gas-recycling *Fig 6*. Even a template for voluntary agreement has been designed and published for world-wide use.

Technological improvement and better understanding overall resulted in a significant reduction of typical annual leakage rates of switchgear equipment. Additionally, SF₆ –quantities have been effectively reduced in the last 25 years from the design aspect *Fig7*.

As a matter of fact the emission of SF₆ in the EU is to a large extent (80-90%) due to handling of SF₆ at various stages of its application, further reduction of leakage from switchgear in general is considered as the least effective but most costly option for the reduction of emission since annual leakage rates are on a very high standard, yet. This refers in detail to handling and re-cycling of SF₆ during development, manufacturing and testing.

At substation level leakage detection and leakage repair must be considered, if applicable. However, maintenance and gas-handling in substations is reduced to a minimum since maintenance intervals for High Voltage Transmission Class Switchgear designed as ‘closed pressure system’ is more than 20 years. In practice even High Voltage Equipment will not be opened for maintenance work for total life.

Medium Voltage Distribution Class Switchgear is mostly designed ‘sealed for life’ and will stay in service without any maintenance or gas-handling. This means no gas re-fill from the point of delivery at OEM up to end of life and re-cycling of switchgear under utility’s or users’ responsibility. The destruction will be supported by service companies or the manufacturers themselves. Therefore, handling losses are significantly reduced in this field *Fig.8*.

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5 Further Reduction Potential

Analysing the total chain of use and handling SF₆, it can be seen that (potentially) SF₆ is emitted resulting from unnecessary actions. In particular the present practice to fill new switchgear on site only with SF₆ which meets the requirements of IEC 60376 for new gas, implicates that SF₆ remaining in containers or otherwise is not applied and basically has to be returned to the producer of the SF₆ or the manufacturer of the switchgear. For a number of reasons this is rather impractical, and consequently should be avoided.

The following actions and measures will help to further reduce the emission of SF₆:

- Avoid unnecessary transport of SF₆
- Promote the concept of recycling and re-use of SF₆ on site /6, 7/
- Ensure re-use of SF₆ in the relevant standards:
 - o IEC 60480, presently under revision, stating that SF₆ according to this standard is suitable for first filling of new switchgear.
 - o IEC's 60056, 60298, 60517, 60694 etc. to be revised enabling the use of new SF₆ according to IEC 60376 as well as recycled gas acc. IEC 60480 for first filling of switchgear.
- Promote the use of appropriate handling equipment, ensuring low emissions and re-use of the SF₆
- Promote where feasible setting up of SF₆ handling/storage ventures, country or organisation wise.
- More detailed process description shall be focussed on SF₆ –recycling and re-use from equipment after end of service life.
- Manufacturers are requested to lead development of a sustained End of Life Concept.
- Non-utility users shall also be instructed by manufacturers on proper recycling and disposal.
- The existing voluntary agreements shall be extended to entire Electricity Sector (manufacturers and users). Partnership agreements between government and Electricity Sector in accordance with voluntary inventory system for switchgear equipment shall be settled.

7 Conclusion

Taking into account the positive environmental impact of SF₆ (smaller equipment and safer working operations), the negative environmental effects are clearly turned to a positive balance compared with alternative technical solutions for sustainable power supply, especially since the present contribution of SF₆ from high-voltage switchgear in the EU to non-natural global warming effect is negligible. International recommendations and regulations to limit the losses already exist and have to be respected. The implementation of the identified actions have demonstrated slightly decreases from 1995 emission levels despite increasing installed volume, and in fact ensure a reduction of the emission in the long run.

The CAPIEL inventory methodology developed in co-operation with Eurelectric is agreed and ramps up. National inventories run successfully and have verified industry's voluntary action. As a matter of fact, governmental action which might aim to provide a new systematic for inventory is not expected to create value added to emission control as far as the Electricity Sector is concerned. The voluntary action demonstrates deep awareness of responsibility for environmental sustainability industry definitely has.

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