Limiting SF_6 Gas Emissions by Optimization of Design and Handling over the Life Cycle of HV Switchgear.

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Abstract

SF_6 gas is widely used in the high-voltage electrical industry because it is an excellent dielectric and has a very good electrical arc switching characteristic. It is also chemically inert, non-toxic and non-flammable, making it the most suitable gas for circuit-breaker applications. But, it is a greenhouse gas (GWP of the SF_6 gas is listed 23,900). The Kyoto Protocol, has designated SF_6 as one of the gases whose release to the atmosphere needs to be limited.

Fortunately, there is not too much of it around, and it is thought to be responsible for only 0.1 per cent of man-made global warming, SF_6 coming from the electrical industry representing only a tenth of the total.

Many efforts are done to reduce and master to the lowest level possible the emissions of SF_6 during the life cycle of the circuit breaker, from the development phase, the manufacturing process, then during its service life, particular during maintenances and at the end of life of the equipment. This paper describes all the steps taken in our company from this point of view.

First, SF_6 management during development and the manufacturing of a circuit breaker in plants, including the SF_6 inventories complying with CAPIEL methodology are described.

Second, SF_6 tightness technological solutions in modern design are described, including the material selection, the advantages of profile-gaskets or double sealing-systems, as well as measures to prevent corrosion at the sealing areas. The definition of very precise tightness tests including full tests of the assembled pole-columns with SF_6 (100% recovered) in the worst-case-condition is also presented.

Third, the "use-phase" is also covered, including the use of leak detection in service or improvement of the handling of the SF_6 gas during maintenance, and the stated objective to minimize the need of unnecessary handling. New monitoring gas systems that forecast and schedule maintenance on demand, compared to regular scheduled maintenance on a fixed numbers of years are also described.

Finally the management of the end of life of a circuit breaker is discussed, in particular the treatment of the SF_6 gas in a recycling manner "cradle to cradle" or, if the pollution of the gas is too high, from "cradle to grave".

I. INTRODUCTION

SF_6 gas is widely used in the high-voltage (H.V.) electrical industry because it is an excellent dielectric and has a very good electrical arc-switching characteristic. This gas was first synthesized in 1900. It is used inside circuit breakers to extinguish the electrical arc when the contacts inside the circuit breaker are pulled apart, thus enabling the electrical circuit to be broken. The gas is also a very good insulant to withstand electrical dielectric stresses. It is not the only gas that can be used, but it has become the industry's standard over the past 30 years as it allows equipment to be much smaller and more efficient.

It is also chemically inert, non-toxic and non-flammable, making it the most suitable gas for circuit-breaker applications. However, there is just one problem, it is a greenhouse gas. The Global Warming Potential of SF_6 gas is listed as 23,900 compared to CO_2 that is 1, (as recommended by UNFCCC Guidelines).

Fortunately, there is not too much of it around, and it is thought to be responsible for only 0.1 per cent of man-made global warming. However, the Kyoto Protocol, has designated SF_6 as one of the gases whose release to the atmosphere needs to be limited [1].

However many efforts are done to reduce and master to the lower level possible the emissions of SF_6 during all the life cycle of the equipment, from the development phase, the manufacturing, during service life, during maintenances and at the end of life of the equipment.

As proven in various symposiums, the emissions during manufacture represent an average of 4.5% of the SF_6 used in the apparatus. This amount is now under reduction with all manufacturers and may reach 1% in the future years, as a stated objective.

In service, the emission rate, for actual designs is about 0.3% for HV equipment (for voltage above 52 kV), i.e. 10% during the life of the equipment, and lower than 0.1% for MV equipment (from 1 to 52 kV – especially for sealed for life equipment). So huge and specific efforts have been made during the last years [2].

During maintenance, the leakage is keep to a minimum, or near zero. For example today (compared to 15 years ago) it is required to not to leak the test volume of the SF_6 gas pressure gauge calibration, when commissioning or performing maintenance on the equipment.

At the end of life, disposal of the used SF_6 gas is either recycled, if good enough or it is disposed of by burning it, but the used gas is never released to the atmosphere .

II. SF_6 MANAGEMENT DURING DEVELOPMENT OF PRODUCTS AND MANUFACTURE

In the past, compressed air was used to break the contacts in circuit breakers, but the performance and size of these kinds of circuit breakers makes them three times as expensive as modern SF_6 circuit breakers. Using other alternatives, such as nitrogen or carbon, or simply vacuum interrupters, would cost today twice as much to obtain the same performance as circuit breakers made with SF_6, especially at 72.5 kV and up.

Utility customers are not in a position to make this level of investment in alternatives, so manufacturers and the industry in general are concentrating their efforts in minimizing the loss of SF_6 gas into the atmosphere as per the various recommendations of the local agencies as EPA and the European Commission.

By example, in our Medium Voltage factory in Regensburg (Germany), three different manufacturing areas, and a separate storage area, are defined in the workshop:

A. SF_6 Storage & distribution in workshops

A SF_6 dedicated shop is operational next to the workshops. The 600 kg tanks are located in this shop and connected to copper SF_6 distribution pipes going in the shop through the walls. A SF_6 detector is running (threshold value : > 2% SF_6).

The tanks of liquefied SF_6 are weighted at the beginning, and then when they are empty (down to 500 mb). A storage tank filled at 20 bars of SF_6 gas is used before the distribution, and a SF_6 counter is placed between this storage tank and the SF_6 distribution departure. A total of 13 counters were installed.

From the storage area, the distribution of the SF_6 is done via 600 m copper pipes (at 3 to 5 bars of pressure) running in the shops. A total of 13 counters are placed on the individual lines. Some SF_6 concentration measurements were done in the shops. The level was found to be lower than 10 pptv. The monitoring of the SF_6 pipeline system is continuous, and the transmitter limiting value has a threshold value of 0.011 kg of SF_6 gas per second.

Control of tightness is performed via a monitoring system during the weekends (once per week). Maintenance and inspection are performed 4 times per year. The SF_6 pipeline system includes one main stop valve and 12 stop valves on the counters and 3 additional stop valves for service are part of the SF_6 pipeline. More over, the tightness of all pipe installations is checked before and after periods with no use of SF_6 (during long weekends or holidays), and the tightness of the pipe system is in the maintenance plan.

B. GHA manufacturing

These medium voltage SF_6 circuit breakers will come into production soon.

The SF_6 tanks are mainly laser welded then tight tested with helium by the supplier. Then at the end of the assembly, the tightness test will be done in the GHA workshop. A test equipment has been designed, and was installed in 2006.

C. FBX manufacturing

These medium voltage SF_6 type FBX circuit breakers are manufactured at the speed of 4,000 three-phase units per year. The tanks are welded by a subcontractor, then finished at the factory. There is a weight varying from 1 to 2 kg (2.2 to 4.4 lbs) of SF_6 in them according to the type of circuit breaker [3].

SF_6 is introduced via a permanent valve (like STS type – Siemens uses a clenched tube).

The equipment are "Helium Tight" tested, and, in case of leak, the leakage point is detected with SF_6. Then the apparatus is filled with SF_6. The counter, placed next to the gas valve gives the mass (weight at sea level) of SF_6 included in the switchgear. Then this mass is hand written on the CAPIEL label affixed to the circuit breaker. The label is shown below.

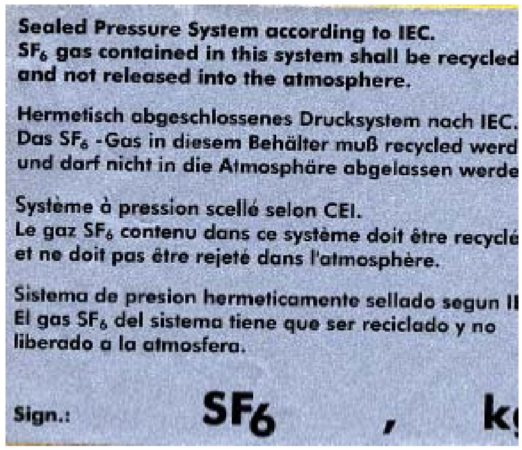

Figure 1 - Typical CAPIEL label.

D. GL31x Manufacturing

These high-voltage SF_6 type GL31x breakers are manufactured at a speed of more than 4,000 three phase units per year. The breaker consists of a support and a chamber insulator, made of porcelain or composite, a mechanism housing with integrated trip-spring at the lower end of the pole-columns and two high voltage terminals. Elastomere sealings, made of EPDM, are used for the sealing of the breaker.

The tightness of each pole-column is tested after assembly with a semi-automatic test facility. The pole-columns are filled with rated SF_6-service pressure and the interrupter-units are in end position ON. This represents the normal service condition of the circuit breaker on site and is the worst-case situation for the shaft-sealings of the mechanism housing because the integrated trip-spring forces on the shaft.

The test facility contains two identical independent test-compartments and two gas-analyzing units. The pole-columns are attached inside one test-compartment and the interrupter-unit is moved in end position ON. The door of the test-compartment is closed and sealed. The next steps includes the evacuation and filling of the pole-columns with SF_6. The air inside of the sealed gas-compartment circulates by help of a fan and the SF_6 content is continuously measured by the gas-analyzing unit. At the end of the test-cycle the leakage rate of the pole-column is calculated.

After the test the SF_6 is removed from the pole-columns and stored in a tank for the next test.

Figure 2: Semi automatic tightness test facility for high voltage circuit breaker.

III. SF_6 TIGHT DESIGN

As seen above, some losses occur when the switchgear is filled and tested, but the primary source of SF_6 gas releases are leaks from aging SF_6 gas-insulated switchgear [4].

More precisely, these leaks occur because the gaskets used in the equipment begin to leak as the gasket material deteriorates with age and use. Many manufacturers have ascertained that the aging effects on gaskets, i.e. sealing two enclosures (aluminum, insulator porcelain bushing or steel) is due to three main problems[5]:

- Hardening of the gaskets. High ambient temperatures and heat produced by the current passing through the circuit breaker in normal use affect the gaskets' elasticity and harden them.
- Chemical attack. After several years of use in substations, SF_6 gas undergoes chemical changes as a result of arcing due to current interruptions. These short circuit interruptions change the composition of pure SF_6 gas and partially decompose it. The by-products produced provoke a chemical attack on the gasket material.
- Corrosion. Filler material used in equipment seals is attacked by the external environment. Corrosion is particularly noted in substations close to sea shores (salty air) and polluted areas, such as a nearby cement plant.

A. Historical development

Over time, there is a decrease in the mechanical, chemical and physical characteristics of the gasket material, which ultimately leads to leaks of the gas. Manufacturers attacked the problem from two sides. In order to understand how manufacturers came up with it solution, it is necessary to understand a little of the history behind the seals on electrical equipment and research done into corrosion. In the late 1950's and in the 1960's, the first sealing technology was a simple O-ring sealed with grease.

In the late 1970's and in the 1980's, this was improved with a second sealing system added to limit the corrosion. Two O-ring seals were located very closed together with a leak checking system between the two. Grease was used on the outer side of the seal to protect against air borne pollutants.

Figure 3. The one-O-ring seal.

Figure 4. The two-O-ring seal.

Today, we use a sealing device in GIS made up of three seals in one seal of a special shape. The main seal is protected from internal and external corrosion by two auxiliary seals. The seal is located in a groove designed to avoid any risk of scratching when the equipment is assembled, but the main seal now has a large surface to limit the risk of leakage if the metal gets caught in the seal assembly.

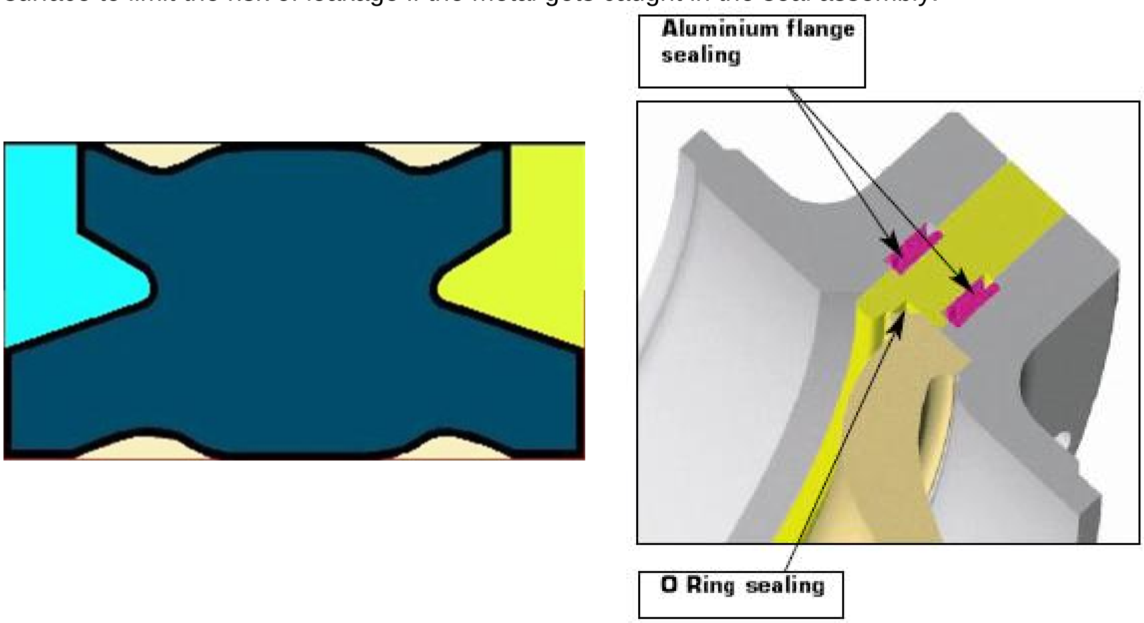

Figure 5. The three-O-ring seal.

In other products than GIS, it is very common to use the "fish-type-seals" or "double-o-rings" for dynamic sealing areas. In this design we have an corrosion protection from the outside but not from the inside.

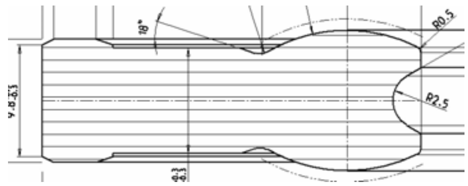

Figure 6. The "fish-type-seals" for dynamic sealing areas.

B. Electrochemical corrosion

In the 1980's and early 1990's, many manufacturers studied the different seal materials (NBR, IIR, FPM, EPDM compounds) used in high voltage circuit breakers and noted the importance of a low electrochemical couple created between the seal material, the aluminum alloy flanges and outdoor rainwater in circuit breakers. This electrochemical couple corroded both the aluminum flanges and the seal.

To avoid this phenomenon, and the findings are all well understood by all manufacturers, the main seal must be protected from water and the potential difference between the seal and the aluminum alloy flanges must be reduced to a voltage between -50 mV to + 50 mV.

The selection of gasket material was also crucial in decreasing this difference of potential. A compound of Ethylene Propylene Diene Monomer (EPDM) was selected to comply with this difference of potential.

C. Tests

1) *Methods of tests*

Many tests were performed on several types of gasket material called EPDM with different formulation. The purpose was to test dynamic tightness, as it is statistically the one that give the most leakage rate with time, in opposition to static seals.

During these tests, several parameters were tested: use of double gaskets, forces were changed in tightening of the rings from Exceptional (19%) to general (11%), aging process on the material was simulated. The design tested uses the ring design of the anti-extrusion type.

The purpose of these tests were to find the best material and erection process that has the least leakage rate within the various temperature cycles that the equipment was subjected to during its life time.

As a prototype of the set up, we took a tank of a column of a circuit breaker type FXT, equipped with his operating rod. The tightness of the turning rod is assured by two ring type listed as R28 made by a subcontractor. The greasing of the system is performed by a standard grease that we use in this type of seal, the Molykote type Plastislip . This grease is recommended by Dow Corning technical people. This is a fairly common silicone grease used by OEM's in the braking industry for use on caliper guide pins but it is also extensively used on pistons and rubber seals, as it is resistant to moisture.

The tightness of the setup is measured by an analyzer type B&K. The process includes the measure of the initial cold tightness, then its tightness during the mechanical endurance and then its cold tightness. After dismantling of the set up we check the wear of the R rings.

The acceptance criteria is based on the fact that no permanent leakage is above the rate of 5 $^{-7}$ bar.cm^3/s.

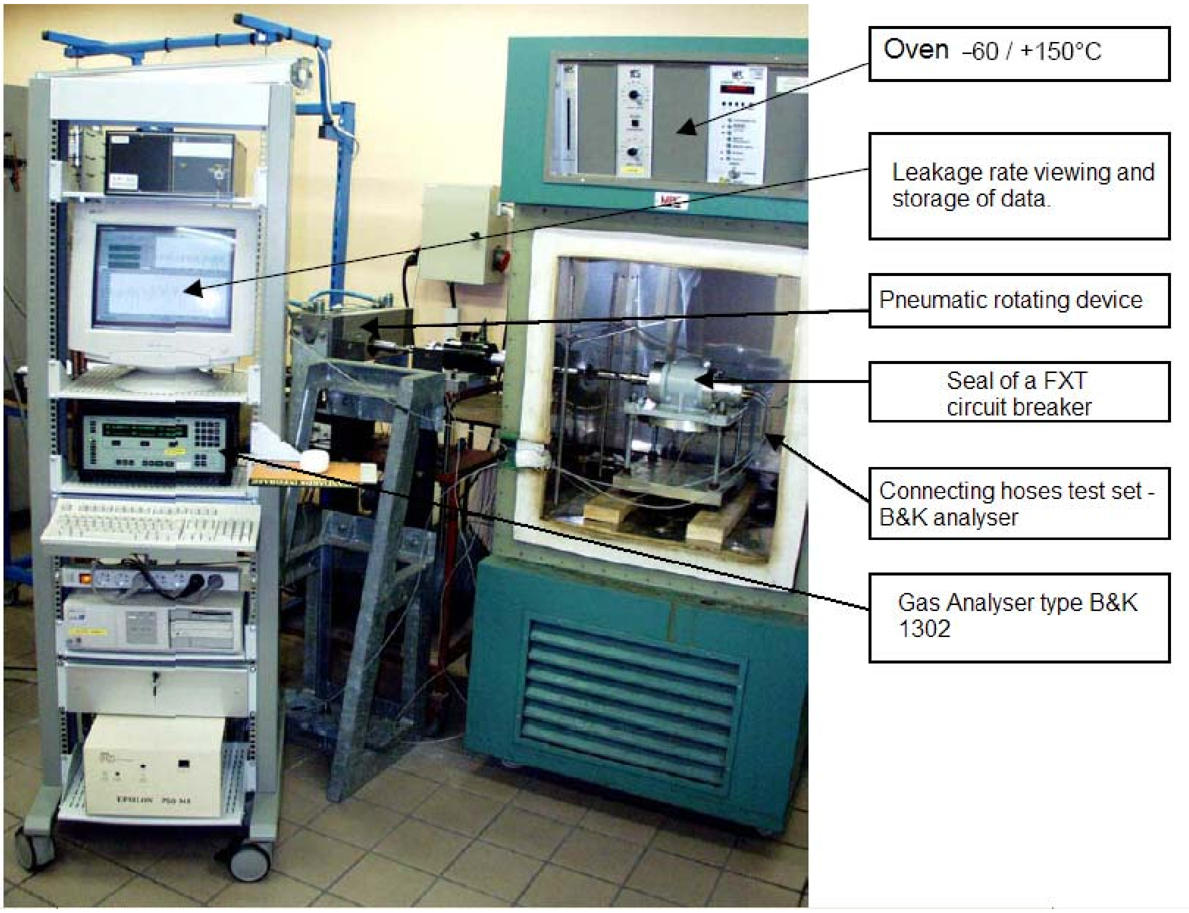

Figure 7 - Test set arrangement.

2) *Conclusions of Tests*

Here follows some simple conclusions to be implemented on new equipment subjected to a -50° C extended time period of cold.

1 - The behavior of a simple or double seal system seems near identical. The added security added by a second seal is a plus if the first one fail, but if one works, the result is the same.

2 - With seals type R brand new, the two type of tightening seems behaving the same at -50° C. For the use at a warm temperature, (this means temperature larger than 80° C), the setting with a general tightness (less stringent than special tightness) is theoretically preferred when the aging of material is taken into account.

3 - The tests conclude clearly that an increase leakage rate of SF_6 when one measure the leakage on used rings. Nevertheless, a withstand at -50° C is assured with all types of rings. This proves the good withstand at cold temperature within the variation of the type of compound material of the O-rings. The withstand at -55° C is assured only with sets made of new rings.

4 - The tests demonstrate that the extrusion of the rings is not a phenomena based on high pressure of SF_6 alone. We have never observed an extrusion of material during the use of the anti-extrusion rings. The addition of anti-extrusion rings does not lower the tightness.

5 - The hypothesis of large change in leakage rate after a temperature based aging process defined by a temperature of +115°C and then a dramatic drop in temperature to -50°C was never verified. It seems that the anti-extrusion seal made of EPDM alleviates this phenomena.

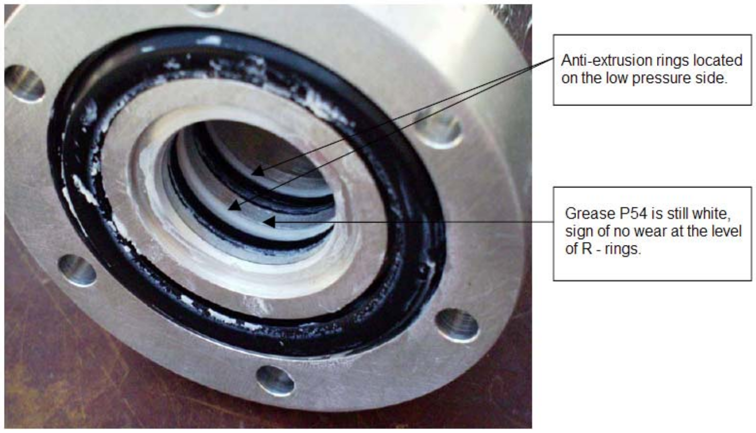

Figure 8 - Test double throat with R-rings aging of 12 months at 80°C.

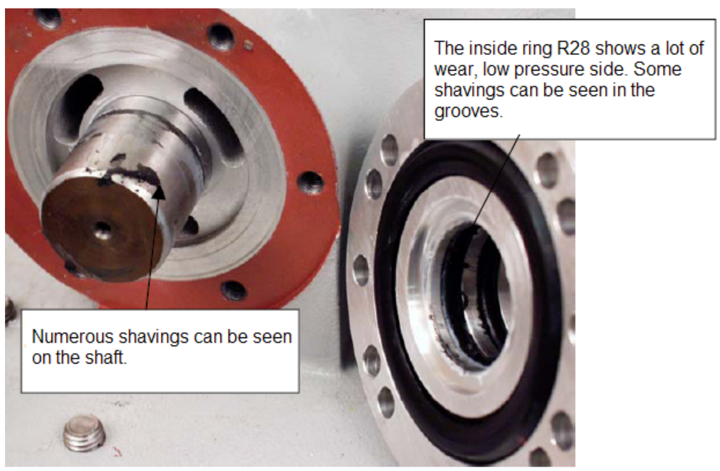

Figure 9 - Problem of extrusion experienced with Ring 38 strongly worn out.

3) *Tests on full circuit breakers for leakage*

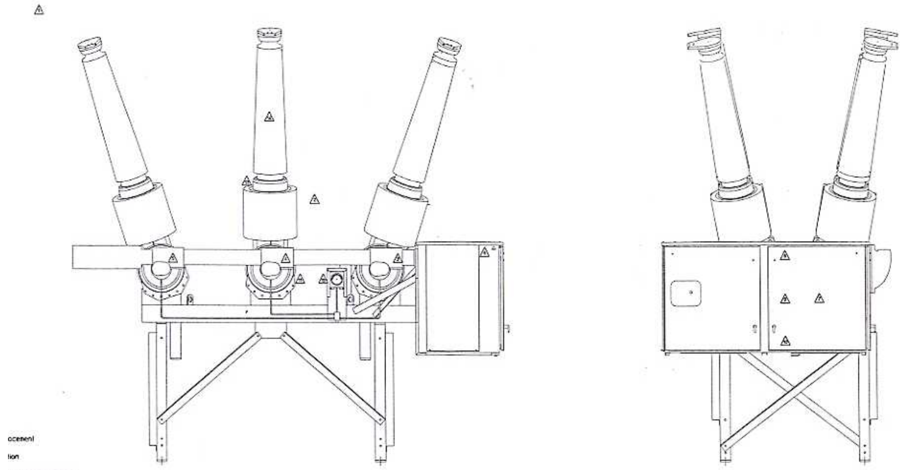

Figure 10. Schematic scheme of a typical dead tank circuit breaker.

Figure 11. Complete dead tank circuit breaker encased in its owned volume for leakage tests at low temperature -50°C.

IV. MAINTENANCE

A. Improved handling of the SF_6 during the maintenance and decomposition products

Instructions for performing work on SF_6 switchgear are given in the appropriate sections of the Specific Instruction Manual for each type of gear. It is recommended that you temporarily store and reuse SF_6 gas during service and maintenance as an environmental protection measure as well as being economical. The type of equipment used for SF_6 gas storage consists of a compressor, vacuum pump, storage tank, evaporator and a filter unit piped together with fittings and valves. Switchgear may only be opened after operations have been completed to remove the SF_6 gas. Maintenance personnel must follow these safety precautions in addition to all safety precautions established by their employer [6] [7].

- Ensure that there is adequate ventilation (natural or mechanical).
- Do not agitate SF_6 decomposition by-products unnecessarily.
- Remove SF_6 decomposition by-products immediately after opening the breaker-pole to prevent moisture combination with by-products. Use a suitable vacuum cleaner with dust filter and wipe off remaining decomposition by-products with a piece of lint free cloth.
- To neutralize SF_6 by-products (arc products), on the desiccant and used cloths, soak them in a 3 percent soda solution for 24 hours. To verify the degree of neutralization after 24 hours, add additional soda to the solution. If the solution is neutralized it will not effervesce; if it does effervesce repeat the neutralization process.

Table 1 - SF_6 Neutralizing Agents

Active agent	Formula	Concentration kg/100 l (water)	Time – Hours
Lime	$Ca(OH)_2$	Saturated	24
Sodium Carbonate (washing soda)	Na_2CO_3	1.1 3 10 (1) 10-14 (1) 3	24 wash 0.25 48 —
Sodium Bicarbonate	$NaHCO_3$	1 (2)	—
Notes (1) When using alkaline solutions at such high concentrations, care should be taken to avoid contact with the skin, eyes, etc. (2) Recommended for washing the skin.			

The above table reflects what is currently published. The treatment methods suggested differ widely with respect to neutralizing fluid formulation and treatment time.

B. Minimizing the maintenance needs to avoid unnecessary SF_6 handling

For any utility, the basic objective is to minimize maintenance costs while maximizing the return on equipment. This main idea is strongly embodied in much acclaimed management techniques as Six Sigma that extract quantum operational performance improvements in all operations of the corporate world. An effective monitoring technique is necessary to provide continuous conditions monitoring assessments, to identify problems, and in some cases, predict failures and problems before they become critical.

Advances in technologies continue to provide more efficient and reliable methods for determining maintenance needs. A working group within the IEEE Power Engineering Society [8] has published a Guide (IEEE C37.10.1-2001) to help the user to select a monitoring system for a specific circuit breaker application based on the many options available today. The description that follows describes the application of the monitoring system called CBWatch-2 applied to a 245 kV dead tank circuit breaker.

The CBWatch-2 design is more involved than the well-known CBWatch-1. It continuously monitors nearly all the circuit breaker conditions. It signals in real time any malfunction and requests/informs about maintenance services. This modular monitoring device was designed with optional functions to be tailored to utilities.

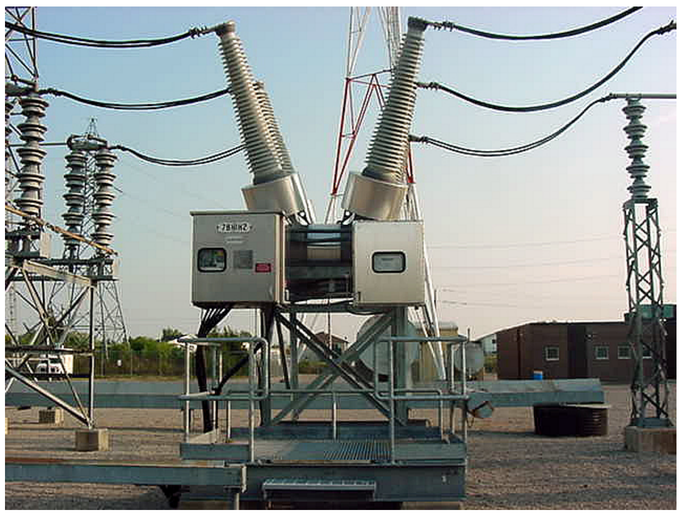

Figure 12. Photograph of a 245 kV dead tank circuit breaker fitted with a condition monitoring CBWatch-2 in a separate cubicle in Belleville substation.

1) SF_6 Monitoring

Figure 13. Picture of the CBWatch-2 installed in a separate control cubicle.

The system has the same functions as the CBWatch-1 for SF_6. The CBWatch-1 was a first attempt to apply simple components of the SF_6 monitoring device and to use it on a circuit breaker [9].
The idea was to locate it as a large relay or as an annunciator in a control cubicle.

The SF_6 characteristics of the CBWatch-2 are quite impressive because it measures directly the temperature and the pressure of the gas in the tank before sending the information to the board where various computation take place. The board can be connected to a PC as various functions can be set and trends can be analyzed, but it can also be connected to the bay module in a serial or digital way (via solid –state relays), or to a gateway broadcasting the information over the customer's Intranet [10].

2) *The CBWatch-2 SF_6 capabilities.*

- It calculates the SF_6 density by the Beattie and Bridgeman algorithm, which is the physical law closest to experimental results.
- It inhibits false alarms in the event of gas liquefaction and indicates liquefaction. It calculates SF_6 leakage rates in order to give advance warning of alarm and lockout threshold levels.
- It operates within the ambient SF_6 temperature range of -50°C to +60°C when heaters are included around the tank of circuit breakers within a dead tank design.
- It has a direct digital communication between the sensor and the main board. With LCD display locally, it uses a proprietary algorithm and has programmable time span alarms.
- The system uses the standard MODBUS protocol to communicate with other digital devices as an option.
- The system performs continuously a self-diagnostic check.
- It can monitor also the gas mix (SF_6/N_2 for example) through time and indicate when the gas mix is not within the required ratio.

Figure 14. SF_6 pressure sensor and temperature probe

V. END OF LIFE

This end of life addresses the case of HV Air Insulated Circuit Breakers (AICB) and Dead Tanks that need maintenance, repairing or dismantling. These products may be old circuit breakers, which clients do not want to use further.
Our company is able to manufacture apparatuses of replacement stocks. The knowledge described here comes from this experience. This includes products with different technologies (Oil, compressed air, SF_6 [including mixtures of gases with SF_6]) used all over the world. For this, all the T&D's experience and know-how are mandatory to handle the end of life properly.
But younger products may also be partially repaired or maintained and every part is then well known.

Its end of life follows a studied way. These types of life duration may be about 40 years or more. Design called "Eco-Design" of past, present and future circuit breakers is very important. That is the reason why company now takes into account products' end of life before the manufacturing stage.

Old circuit breakers may contain SF_6 gas or may be filled with oil. This is a problem, as for transport (in Europe) and for treatment because of pollution. Fortunately, solutions exist for both situations.

Figure 14. Typical old SF_6 puffer circuit breakers type live tanks to be maintained.

A. From the substation where the equipment will be dismantled

This scheme describes the typical procedure used before the transport of such equipment. Fluids and gases must be extracted in safe conditions, then they are analyzed. Once the circuit breaker is fluid-free, it is possible to bring it down, in the substation. The gas analyses may influence the type of transport and the different authorizations may be necessary when corrosive or toxic substances are detected due to short circuit interruption.

In fact, when the SF_6 gas contains too much decomposition products, due to arc switching, the reclaiming of the gas, on site, with the help of the movable devices is not possible. In this case the gas has to be treated in another way and many reclaiming techniques have been developed worldwide that could avoid destruction of the gas.

For example, in Japan, a gas-reclaiming equipment has been developed to separate SF_6 gas from mixed gas. This system concentrates SF_6 gas, which is sent into a gas liquefaction system. Then a filter refines the SF_6. Another type of equipment has also been developed based on different filtering stages, a liquefaction system and also analytical system (Gas Phase Chromatography in particular).

In Germany too, a reuse concept has been developed, based on permanent quality control and a device for purifying and storing of the used SF_6 gas. One can list the Company "Dilo" from Germany, as a manufacturer of handling of used SF_6. This system is used extensively in the USA.

Other systems using several separative membranes for the purification of the SF_6 have also been developed.

These systems could be found in France, Germany, USA, Canada, and numerous references can be found in the catalogue of guidelines and standards for the handling and management of Sulphur Hexafluoride worldwide.

B. Dismantling : Operating method and process

This scheme describes the typical procedure for the dismantling of a circuit breaker coming back to our typical HV factory located in Villeurbanne, France.

Fluids are analyzed and sorted to be valorized in specific ways.

Hazardous substances are well-known of the company, and are especially sorted and eliminated. Other materials like metals follow more classic routes to be grounded and recycled.

When SF_6 has lost its properties of dielectric agent, it is usually taken away from the equipment, and filtered on site in order to take away the humidity and the particles.

At this stage, directly on the electrical equipment, the SF_6 can be analyzed to determine whether it is very polluted or not.

Unfortunately, after a certain period of being subjected to important electrical arcs, it can no longer be purified and the filtration does not allow the user to meet the minimal specifications that are required.

Then the gas is reclaimed and can be analyzed again with on site analytical method to determine whether it can be re-used (if the reclaiming device was efficient enough to filter it) or if it has to be send to the recycling unit.

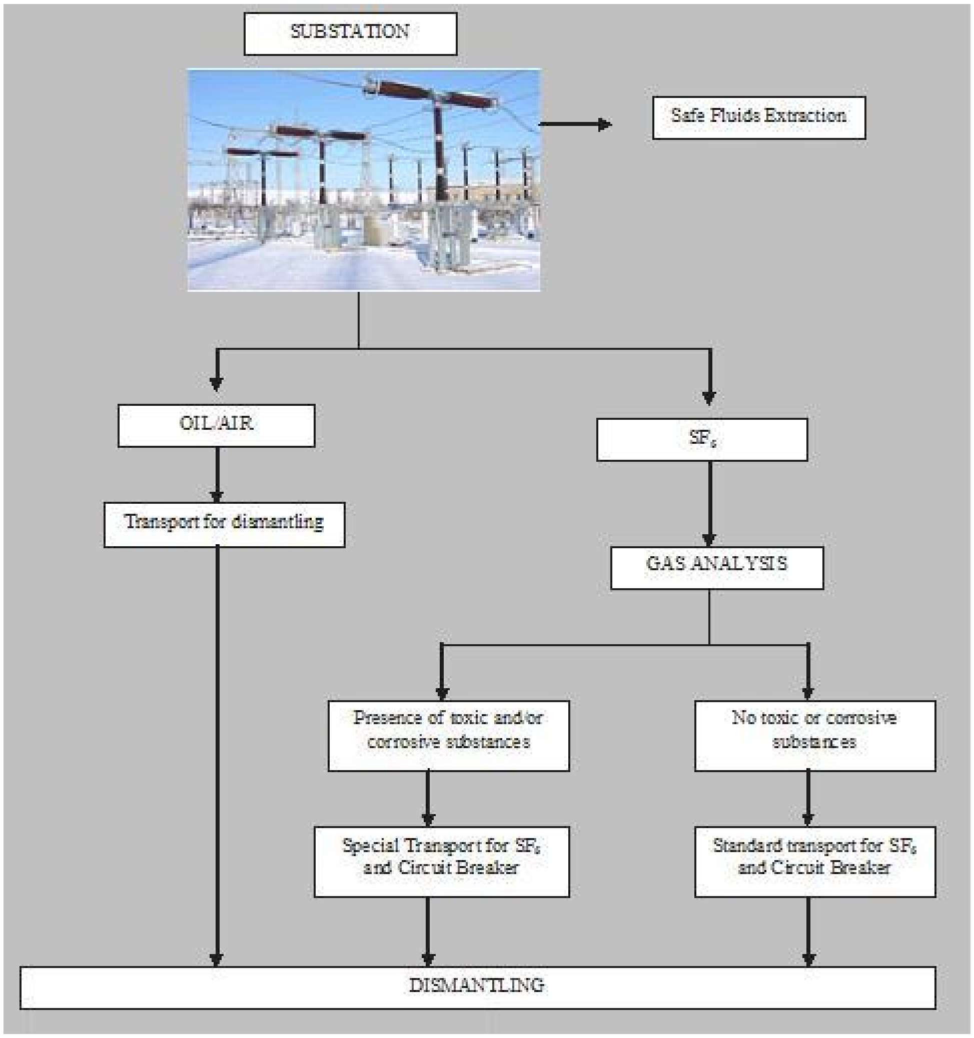

Figure 16. Schematic diagram showing that for SF_6 circuit breakers, the process is more complicated than for Oil/Air circuit breakers. It includes a gas analysis that does not exist with others types.

Indeed, to be purified in the pilot plant, several companies requires that the gas exhibit acidity level less than 5,000 ppm, expressed in HF, and a CF_4 content less than or equal to 7,500 ppm (weight). Other wise, the gas has to be destroyed.

After the recycling and the control of the batches of regenerated product, experience shows that the "typical values" are far below the limits indicated in the specifications in the IEC 60480 Edition 2 standard [11]. So this purification method appears to help the limitation of SF_6 emissions and limits the destruction of SF_6.

Figure 15 describe the whole process of dismantling a circuit breaker and sending it to the original factory of Villeurbanne.

C. Details on operations made on HV circuit breakers

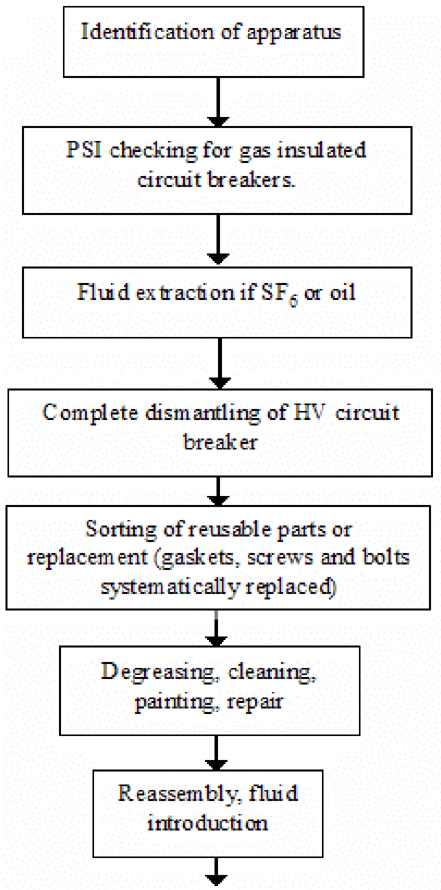

Figure 18. Detailed procedure to treat an SF_6 circuit breaker at the end of life.

This first operation consists in identifying every assembly or sub-assembly coming to the workshop. An identification sheet is then available with all information necessary for the product.

Before being sent to the factory, circuit breakers are reduced to a pressure of 0,3 bars for transport and a control is made.

For SF_6 circuit breakers, gas is extracted till vacuum. Then, the tank is opened and gets back to external pressure. If analyses reveal presence of heavy metals or toxic elements, special handling are made in the “tunnel”. This is a safe working place where special handling is realized on this equipment.

The cells of the circuit breaker are often dismantled at the same time. Operators know the products (they often worked in manufacturing) and plans are available.

Damaged or defective parts are also replaced by stock parts.

D. Wastes Management

Solid wastes are sorted in the workshop, and put in dedicated containers to be collected by different and specialized subcontractors as described below:

- Bulk wastes (resin insulators, gaskets, ceramics, electronic chipsets…) are sent to grinder to be automatically sorted.
- Steel and other metals are first sorted on the factory site. They are then sold to a recycler to be more accurately sorted and sent back to foundry. Steel is very easily recyclable because of its magnetic properties that allow a very good sorting.
- Aluminum is also very easy to recycle. It is a very good solution to recycle aluminum for economic considerations. Recycled aluminum allows to avoid 95% of the energy necessary produce for primary material.
- Copper has a very high value. That’s a reason why its sorting and recycling are very important. Nowadays, about 40% of the total amount of copper used in industry comes from recycled materials.
- PTFE nozzles and molecular sieves sorted inside the workshop (These items were in SF_6 gas in normal operation of the circuit breaker)>.
- Polluted SF_6 is put in an specific identified tank inside the workshop.
- Used oil is put in an identified tank inside the workshop. Paper and cardboard have specific baskets. These materials follow specific routes for treatment.

After this first sorting, circuit breakers wastes are mixed with other sorted wastes of the company at the Villeurbanne site. Each bucket follows a specific way for wastes treatment, described in the table below. This a typical example of available routes for end of life materials in Western Europe.

Table 2. Different Waste Management subcontractors according to the material. The SF_6 gas is the last item.

Channels	Collection		Treatment	
	Sub-contractor	Receipt date for transport	Sub-Contractor	Regulation
Aluminum	EPUR	23/11/2001	EPUR	22/03/1982
Copper	SOBRAL	23/06/1998	SOBRAL	27/05/1994
Steel	CFF Recycling	Not available	CFF Recycling	02/09/1975
Bulky	SITA MOS	21/11/2003	SITA MOS	09/06/1982
Dangerous Industrial Wastes	SITA MOS	21/11/2003	LABO Services	23/09/2003
			SCORI	Not available
Oils	SRRHU	Special agreement	SRRHU	16/10/1990
SF_6 gas	STML	16/02/2004	AVANTEC	14/06/2004

E. Valorization routes and ratios

Wastes follow specific identified channels for their valorization. The perfect knowledge of matters and products allow a real benefit for the environment. The gas SF_6 has a two ways of treatment. If it is suitable for this it is regenerated by the CREALIS laboratories or AVANTEC. As it can been seen from Table 3, its recyclable rate is 99%, which is very high. Only one percent is incinerated in a specialized factory.

Table 3. Recycling rates and qualitative considerations for end of life.

Materials	Recyclability rate (grinding)	Recyclability rate (dismantling)	Energetic valorization
Steel	**80%**	**~100%**	-
Aluminum	**80%**	**~100%**	-
Copper	**95%**	**~100%**	-
PTFE	**0%**	**15%**	**Good**
Oils	-	-	**Very good**
SF_6	-	**99%**	**Not recommended**

VI. CONCLUSION

This paper started with the fact that the gas SF_6 is a greenhouse gas, and as such, there is a need to improve the management of SF_6 coming from the electrical industry. In particular, the Kyoto protocol has designated this gas as one of those gases whose release at the atmosphere needs to be limited due to its GWP.

Many efforts were done to reduce and master to the lowest possible level the emissions of SF_6 to the atmosphere during the life cycle of circuit breakers - medium or high voltage classes.

We have described all the mitigations involved with the development phase, the manufacturing process in various factories, then during its service life at site, particularly during maintenances and finally at the end of life of the equipment. This paper has described all the improvements and steps taken in our company from this point of view.

One of the problem during the life of equipment is leakage, and we described in great length all the tests, including material selection, and the different gaskets that are in the market, to prevent leakage, due to corrosion, and the final design of the gasketing system.

The use-phase also cover the specific equipment available today to improve leak detection sensing, and the handling of the SF_6 gas during operations and maintenance.

Finally, the management of the end of life of a circuit breaker is discussed, in particular the treatment of the SF_6 gas in a recycling manner "cradle to cradle" or if the pollution is too high, from "cradle to grave".

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