Residual life concepts applied to HV SF$_6$-gas insulated switchgear considering tightness

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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

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Determinant factors for SF$_6$-gas tightness and therefore a major factor for residual life of electric power equipment

- Design
- Material
- Type testing
- Production and installation/commissioning
- Operation, maintenance, service
- International standards

......and trained people for the development of following generation of new equipment as well as experienced people, because of the expected long life-time of the electric power equipment
Equipment design – material
SF$_6$-Tightness of aluminium vessels

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

- Best quality
- Decade-long tightness

Beside requirements on SF$_6$-tightness, pressure vessel regulations apply as well.
Automatic integral gas tightness routine test of complete switchgear vessels with Helium (instead of SF₆) guarantees the highest tightness.
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.
Sealing systems
Design and material

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
High voltage GIS
Type testing on SF$_6$-tightness

Tightness tests of complete GIS and also components according to IEC are part of the quality assurance process (closed pressure systems)

The tightness of SF$_6$-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.
Component design development
Cast-Resin partitions

Beside „external“ $\text{SF}_6$-tightness „internal“ $\text{SF}_6$-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)
Production, installation & commissioning
SF\textsubscript{6}-Leakage detection

**In the factory**
- All assembled connections
- Assured leakage rate of $<0.5\%$/a/gas compartment

**On site**
- All made connections
- Assured leakage rate of $<0.5\%$/a/gas compartment

Special care has to be taken during transportation from the factory to the site
SF$_6$-Tightness – special requirement

Seismic qualification

Even under severe conditions like earth quakes the SF$_6$-tightness has to be assured for functional and environmental reasons.

8DQ1-550kV-63kA-5000A-50/60Hz

Test lab CESI, Bergamo/Italy

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Energy Sector - Power Transmission High Voltage Substations
SF$_6$/N$_2$ Tightness – special requirement
Gas Insulated Lines

Experience on SF$_6$-tightness in various solutions for GIL transmission projects

Inside the GIL for example: 80% N$_2$ & 20% SF$_6$
**Aged equipment**

**SF₆-Tightness and residual life-time of equipment**

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*Date for a systematical change of tightness is not known yet*

*Refurbishment might extent the life-time of the equipment*

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*) Usually transportation issues and handling irregularities on site

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**Today all installed equipment is still gas tight**
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-Gas monitoring system
Density, trend curves, trend forecast

Hardware-structure (example)

Example: Analogue inputs 4…20mA for 366 gas compartments
(Optional: density calculation of pressure and temperature)

HMI+ trend curves (example)

Trend forecast value

Example:
Analogue inputs 4…20mA for 366 gas compartments

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Characteristics of SF₆-leaks (appear seldom)

- Processing usually very slow (individual cases like wrong mounted O-ring, cast aluminium vessel)
  - *Enough time to react before 1st stage or 2nd stage alarm appears*

- Processing very fast (individual case) as component failure, ambient circumstances, malicious damage
  - *Pressure inside gas compartment drops to ambient pressure level*

- Due to corrosion in case of insufficient protective measures during installation (outdoor)
  - *Can process as a little or big leak*

- Due to „ageing“
  - *At this moment in time not reached*

Regardless the type of SF₆-leak, it has to be repaired as soon as possible after detection
Maintenance strategies in general for SF$_6$-HV switch gear

Aim of all maintenance activities: maintenance costs should be minimized, the intervals between maintenance enlarged, the availability of the equipment increased, environmental issues considered → SF$_6$

- **Maintenance steps:**
  - Inspection: determining and assessing the actual condition
  - Servicing: preserving the desired condition
  - Repair: restoring the desired condition
  - Replacement: replacing equipment or systems which are no longer usable

- **Several maintenance strategies are used in electrical systems:**
  - Corrective
  - Time-based
  - Condition-based
  - Reliability-centered
  - Risk-based
Maintenance strategies

CM Corrective Maintenance

- In a **Corrective Maintenance (CM)** strategy, replacement or repair is performed only if a failure occurred.
- In case where equipment investment costs are low and a fault will have only a minor effect, this procedure may result in the lowest overall costs.
- This strategy will be mainly used in systems with lower voltages.
- Only severe failure on certain type of equipment will influence the procedure.

*Not recommended for maintaining of SF$_6$-tightness*
CM Corrective Maintenance
TBM Time Based Maintenance

- A *Time Based Maintenance (TBM)* strategy featuring predefined intervals rooted in empirical feedback, where components are replaced after a specified period of use, has been practiced as the usual maintenance strategy in electrical power systems for many years.

- This approach generally produces satisfactory results.

- It will not, however, be the most cost-effective option in all cases, since the components will usually not remain in operation up to the end of the life-time which is possible.

Partly recommended for maintaining of SF$_6$-tightness
Maintenance strategies

CM Corrective Maintenance
TBM Time Based Maintenance
CBM Condition Based Maintenance

- Since some years, however, there has been a developing shift away from TBM and towards Condition Based Maintenance (CBM)
- CBM is driven by the technical condition of the components
- Under this approach, all major parameters are considered in order to determine the technical condition with maximized accuracy
- For this reason detailed information via diagnostic methods or monitoring systems should be available

Recommended for maintaining of SF$_6$-tightness
Maintenance strategies

CM Corrective Maintenance
TBM Time Based Maintenance
CBM Condition Based Maintenance
RCM Reliability-Centered Maintenance

- A fourth strategy, which additionally include a reliability-based component, is in use
- The aim of this approach is to include the influence on the importance of the equipment in the network and the actual condition of the equipment
- A maintenance strategy is referred to as Reliability-Centered Maintenance (RCM) and it has to be noticed that this RCM-method is different considering other RCM applications which consider equipment only

Partly recommended for maintaining of SF₆-tightness
Maintenance strategies

CM Corrective Maintenance
TBM Time Based Maintenance
CBM Condition Based Maintenance
RCM Reliability-Centered Maintenance

RCM is based on experiences and consequences of failures

- failure causes and failure modes for each component have to be identified and than to be subjected to a failure mode effective analyses (FMEA)
- advantage of this method is expected to have cost savings in preventive maintenance and that the costs of implementation will provide a pay back within one year (according EPRI)
- method depends on the correct judgment of failures with FMEA

Partly recommended for maintaining of SF$_6$-tightness
Maintenance strategies

CM Corrective Maintenance
TBM Time Based Maintenance
CBM Condition Based Maintenance
RCM Reliability-Centered Maintenance
RBM Risk Based Maintenance

- Motto: “operate until it breaks”
- Measure for this method is the Life Cycle Cost LCC
- $LCC = Acquisition Cost + Ownership Cost + Disposal Cost$
- Saving money for maintenance
- Saving money for diagnosis/monitoring
- However... risk of failure, risk of cost for unplanned unavailability, outage cost and risk of $SF_6$-emission

Not recommended for maintaining of $SF_6$-tightness
Maintenance strategy to assure SF$_6$-tightness and to extend the life-time of the equipment

Implementation of maintenance strategy for the equipment -in general- and tightness in particular

→ Gives guidance to end of life decision and has a significant impact on the life cycle cost of the assets
To be checked quantitatively: SF$_6$-pressure gauge, SF$_6$-dew point, SF$_6$-acidity, SF$_6$-density/pressure switch settings, SF$_6$-trend analysis monitoring

To be checked visually: bursting disks, any type of SF$_6$-gas piping, corrosion at bolted flange enclosure joints and other SF$_6$-related components, particularly on outdoor equipment, damaged or degraded seals, adherence of dust or other foreign material to seals, porosity in enclosure castings or welds, painting

Avoid openings, take care when opening measuring connections or gas compartments (e.g. for filter material change)

Use original spare parts only

Contact OEM for further information/clarification
The continuous life-time extension of GIS equipment regarding SF₆-tightness and a very low SF₆-emission was and can be reached by:

- Identifying of small SF₆-leaks and immediate repair (any type of monitoring)
- Fingerprint of equipment (can be done together with OEM)
- Improvement of maintenance strategy (less openings)
- Continuous training of staff
- Using state-of-the-art equipment and measuring devices (observing permanently the market)
SF₆-GIS-concepts for life-time extension regarding tightness and low SF₆-emission

<table>
<thead>
<tr>
<th>In the past</th>
<th>State-of-the-art GIS technology</th>
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</thead>
<tbody>
<tr>
<td>Large gas compartments</td>
<td>Optimized gas compartments</td>
</tr>
<tr>
<td>Short maintenance intervals (frequent opening of gas compartments)</td>
<td>2 openings during expected life-time: once after 25 years of service, once during end-of-life procedure after approximately 50 years</td>
</tr>
<tr>
<td>Limited SF₆-handling instruction</td>
<td>Detailed explained SF₆-handling instruction and regulations</td>
</tr>
<tr>
<td>SF₆-maintenance units with a minimum SF₆-recovering pressure of 50-100 mbar</td>
<td>High power SF₆-maintenance units with SF₆-recovering pressure till 1 mbar</td>
</tr>
<tr>
<td>Insensitive SF₆-leakage detectors</td>
<td>Sensitive SF₆-leakage detectors to find smallest leaks</td>
</tr>
<tr>
<td>SF₆-measuring instruments without collecting the used gas</td>
<td>SF₆-measuring instruments collecting the gas are now offered</td>
</tr>
<tr>
<td>Fundamental tests and implementation of new production processes</td>
<td>Using Helium for leakage detection where possible (e.g. housing leakage test)</td>
</tr>
</tbody>
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Since the implementation of the GIS-technology almost 5 decades ago, manufactures have supported the extension of the life time of installed equipment and continuously improve the design of the GIS.
Conclusion

- Implementation of adequate maintenance strategy for aged equipment
- Evaluation of each SF₆-leakage for systematical or individual failure
- Gas tight equipment and low SF₆-emission reduce life-cycle costs
- Residual Life of equipment goes in line with low SF₆-emission
- For end-of-life procedures, SF₆ has to be kept in a closed cycle
Thank you for your attention!

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