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# Study Committee B3

Substations & Electrical installations

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# TSO perspectives on 40 years of GIS evolution, SF6 alternatives strategies and technical specifications recommendations.


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## Motivation

- During the last 40 years, Gas Insulated Switchgear technology has evolved. The years 2020's, will see another major turn in the GIS evolution with a new type of technology using alternative gas to SF6.
- The four authors are employed from four different TSO, share many similar problematics as well as common understanding of technical requirements presents this evolutions and technical specifications recommendations.

## Objects of investigation

- Standard 145kV and 420kV GIS bay
- Double bus bar with one circuit breaker architecture with a cable box feeder.
- Average values collected from all type of all European manufacturers ASEA, BBC, ABB, Hitachi AEG, Sprecher, Alstom, Magrini G, Siemens.

## Method/Approach

- The paper will first be describing the evolutions of GIS through the last 40 years.
  - ✓ footprint evolutions
  - ✓ gas mass evolutions
  - ✓ gas pressure evolutions
  - ✓ interface compatibility
  - ✓ leakage rate evolutions
  - ✓ gas compartment issues
  - ✓ complexity to gas compartment and mechanical work in a vicinity of a close barrier fully pressurized
  - ✓ non-intrusive diagnostic methods
  - ✓ reflections on the consequences of using SF6 alternatives are presented by the authors
  - ✓ authors companies' requirements and recommendations regarding type testing and routine tests
  - ✓ objectives and visions on how the grid decarbonization road maps will be implemented

## Footprint Evolution

- 420kV Operating voltage

In the late 70`s and 80`s, most of the manufacturers did not have a complete portfolio product range for each rated voltage.

For example, for a 420 kV rating (and a 362 kV rating) GIS, they usually offered the same product as for 550 kV rating GIS.

The development of horizontal position circuit breakers with single breaking double motion breaking chamber design has represented the biggest improvement.

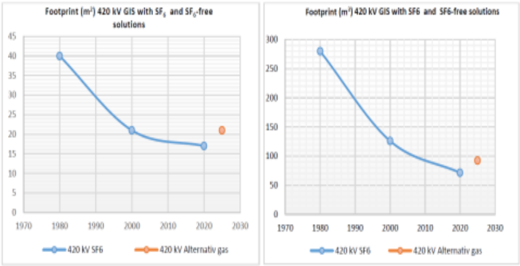


Figure 1: evolution of standard 420 kV GIS bay from late 70's up to now in terms of area and volume.

Alternative gas to $SF_6$ is not yet fully developed for 420 kV but we expect that the enclosures will be bigger. This will most probably in the close future impact the footprint of the substation with $SF_6$ -free solutions.

- 145kV Operating voltage

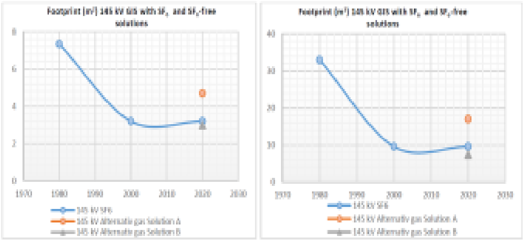


Figure 2: Illustration of standard 145 kV GIS bay evolution from late 70's to up to date.

From 90 kV and above, all GIS were single phase GIS in the early 1970 as presented on the picture above. The major technologically change for 145 kV GIS took place in the early 90`s, where most of the manufacturers changed from a single-phase GIS equipment to a 3 phase GIS equipment.

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## Gas pressure / Alarm pressure

- The pressure of gas for insulation and interruption increased, the gas room are smaller, quantity of gas in each gas room decreases consequently, the GIS is more compact.
- This change on the design implies that the pressure and the corresponding density will reduce faster than before.
- It is important for the end user to have a good control when the alarm for the density switches, will send a signal to the control and protection system as presented in the table below.

| Pression coordination with alarms (MPa) | $SF_6$ | | Alternative to $SF_6$ | | |
|---|---|---|---|---|---|
| | 245kV | 420kV | 145 kV Alternative gas mix 1 | 145kV Alternative gas mix 2 | Alternative gas mix 2 VT |
| Nominal filling pressure Pre | 0,63 | 0,53 | 0,85 | 0,8 | 0,85 |
| Pre-Pae | 0,04 | 0,05 | 0,05 | 0,03 | 0,03 |
| Alarm pressure Pae | 0,59 | 0,48 | 0,8 | 0,77 | 0,82 |
| Pae-Pme | 0,04 | 0,03 | 0,05 | 0,02 | 0,02 |
| Minimum functional pressure Pme | 0,55 | 0,45 | 0,75 | 0,75 | 0,8 |
| Pre-Pme | 0,08 | 0,08 | 0,1 | 0,05 | 0,05 |

Table 1 : Nominal and alarm pressure coordination

Alternative gas mix 1 : Fluronitril based gas, tri-mix gas (C4F7N with O2 and CO2 -as gas porter-).
Alternative gas mix 2 : Dry air in combination with vacuum circuit-breaker

- What is important for the end user is the difference between the nominal filling pressure (Pre), alarm pressure (Pae) and the Minimum functional pressure (Pme). The difference between these pressures will allow the TSO/DSO to first detect that there is a leakage and then to anticipate and organize the reparation to minimize the network disturbance and outages.

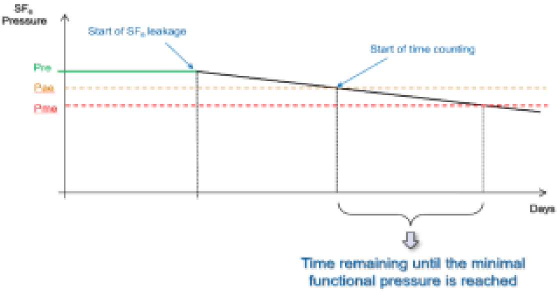

Figure 8: Illustration of a leakage in with estimation of the time remaining before outage.

- Almost all the manufacturers set the first alarm pressure at 10% lower to the Pre (Pre*0,9=Pae). This 10 % comes from the maximum leakage rate 0,5%/year * 20 years = 10 %. It means we allow our switchgear to leak at the maximum leakage rate (0,5%/year) during 20 years without noticing anything until the first alarm occurs...
- Alternatively, online monitoring system is definitely a more comfortable solution.

## Gas Pressure Evolutions

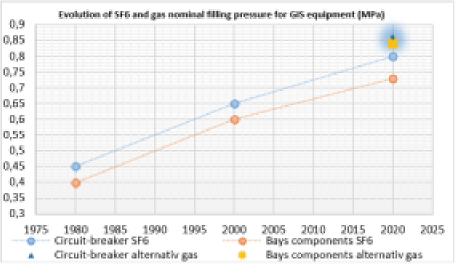

Figure 5: Evolution of $SF_6$ and insulation gas rated filling pressure from late 70`s to up to date.

The pressure of the GIS equipment has continuously increased since late 70`s. A GIS bought in 1970 had a nominal filling pressure almost 70-90% lower than what TSO and DSO could purchase in 2020.

Also, the new GIS product that are $SF_6$ free are expected to use a pressure that will be approximately doubled compared to what was provided in late 70`s .

## Leakage Rate Evolutions

IEC standards and requirements have changed a lot during the last 4 decades.

- ✓ IEC 517 was the original standard for GIS equipment (1990). The maximum allowed $SF_6$ leakage rated was 1% per year at that time.
- ✓ In 2003 the first edition of the IEC 62271-203 was published. One of the major changes was a reduction of the tightness and $SF_6$ leakage from 1% to 0,5% per year.
- ✓ In the edition 2 of the standard published in September 2011, many changes were implemented but unfortunately not any changes regarding the allowed $SF_6$ leakage rate.
- ✓ In the edition 3, published in 2022, many modifications have been implemented. One of the most important is the $SF_6$ leaking rate limit to 0,1% during type test. This change is not yet reflected on the routine tests requirements as most of the manufacturers have issues to demonstrate this low leakage rate with available measuring equipment and with todays' production lines configurations.

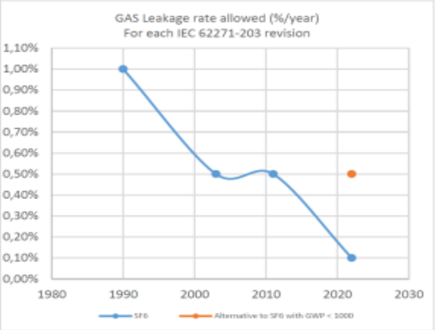

Figure 6: IEC requirements evolution regarding $SF_6$ leakages rates during type test of GIS

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## Measuring of the leakage rate

- According to IEC 62271-1 ed 2.1, tightness type test shall be performed on a complete system when possible and requires a cumulative measurement of the leakage. For routine test and FAT the cumulative method is preferred, but a sniffing device may be used.
- The cumulative method, as described in IEC/TR 62271-306{ed1.1} is from the authors eyes the only method that can be used to determine the leakage rate of an equipment.

Accumulative method test (left hand side) and sniffing device test (right hand side).

## Gas Mass Evolution

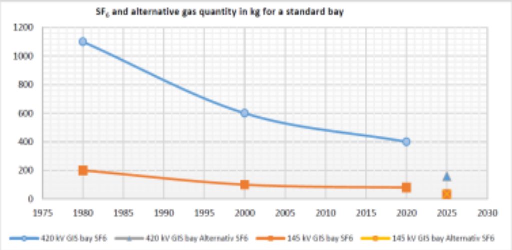
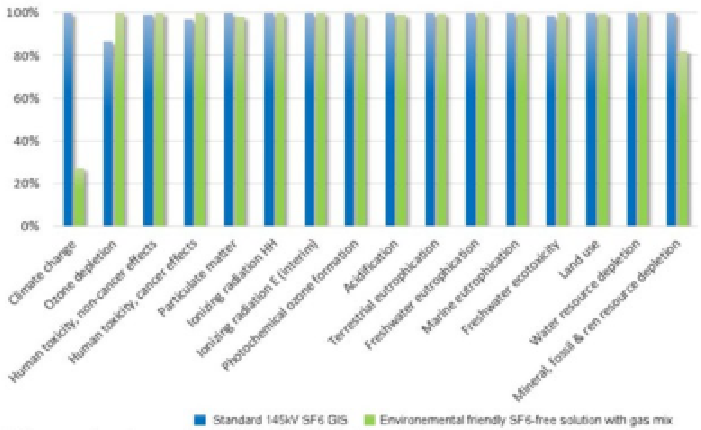



**Figure 4: evolution of $SF_6$ gas mass (kg) on a standard 145 and 420 kV bay from late 70`s to up to date.**

- ✓ At 420 kV a reduction of almost 40% in the $SF_6$ gas mass around the year 2000 has been observed. Dedicated 420 kV GIS for the 362/420 kV market and single chamber circuit-breaker is the reason of this reduction.
- ✓ For 145 kV GIS, a major change took place in the late 90`s, when the GIS design changed from single to three phases GIS, resulting in a reduction of approximately 50% on the $SF_6$ gas mass on the standard bay.

## Life Cycle Assessments (LCA)

- Such an analyses requires precise knowledge and specific software.
- It would be easier for manufacturers to perform it by following standardized methodology.
- As users, we could recommend LCA studies to be supplied by the manufacturers for every tender to facilitate the technical environmental comparison of all proposed solutions.




**LCA comparison of conventional 145kV GIS ($SF_6$) in blue and alternative gas 145kV GIS ($SF_6$-free) in green**

http://www.cigre.org