TECHNICAL WHITE PAPER

HMP-WP-2502

Why Do GIS Switchgear Need Positive Pressure Gas?

An Engineering Trade-off Between Dielectric Strength, Gas Density and Sealing Cost

ABSTRACT

Gas-insulated switchgear (GIS) is almost invariably filled with an insulating gas above atmospheric pressure inside a metal enclosure. The practice has long been treated as an inherent property of GIS, yet the reason behind it is rarely asked. Starting from the mechanism of gas discharge, this paper shows that dielectric strength is governed by gas density rather than pressure: a higher density permits a higher permissible field strength, shorter gaps and smaller enclosures, and this is the physical basis of GIS compactness. On that basis the paper reviews rated filling pressures across voltage classes and insulating media, together with the conventions used to state them, and explains how the upper limit of pressure is set jointly by liquefaction temperature and manufacturing cost. It then analyses the benefits that positive pressure brings, and the sealing, leak detection, moisture control, density monitoring and compliance costs that follow from them.

1 Introduction: An Engineering Premise Taken for Granted

The nameplate of a 12 kV ring main unit reads a rated filling pressure of 0.04 MPa (20 °C), and the circuit-breaker compartment of a 550 kV unit is marked 0.6 MPa. The two figures differ by an order of magnitude, yet they express the same thing: the gas pressure inside the enclosure is above atmospheric pressure. From product catalogues and type tests to operating procedures and maintenance practice, the entire technical vocabulary rests on the premise that the compartment is pressurised.

This practice is often taken as an inherent property of GIS, but it is neither a necessary condition of insulation nor a result mandated by standards. IEC 62271-1 regulates the tightness performance, monitoring and alarm/interlock requirements that apply once the equipment is pressurised; it does not require that the equipment be pressurised. What really determines the design is three coupled constraints: the insulation level required by a given voltage, the permissible footprint and volume, and acceptable manufacturing and operating cost.

This paper answers four questions only: why positive pressure is necessary, why the pressure differs across voltages and media, what positive pressure buys, and what it costs. The choice of gas itself lies outside its scope.

2 The Physics of Positive Pressure: Dielectric Strength Depends on Gas Density

2.1 The First Fact from Paschen's Law

The first quantitative law of gas breakdown comes from Paschen: in a uniform field the breakdown voltage is not a single-valued function of pressure but a function of the product pd of pressure and gap length. Figure 1 gives a curve fitted to measured air data; its minimum lies at pd ≈ 0.8 Torr·cm (≈ 0.3 kV), and to the right of it the curve enters an approximately linear high-pd region. The operating points of engineering equipment fall almost entirely on this linear section: the larger pd, the higher the breakdown voltage.

This revises a common intuition: evacuating a gap does not raise its dielectric capability, and over a certain range it lowers it; what is effective is raising pd. The electrode gap is fixed by voltage class and structure, so the only adjustable quantity is pressure.

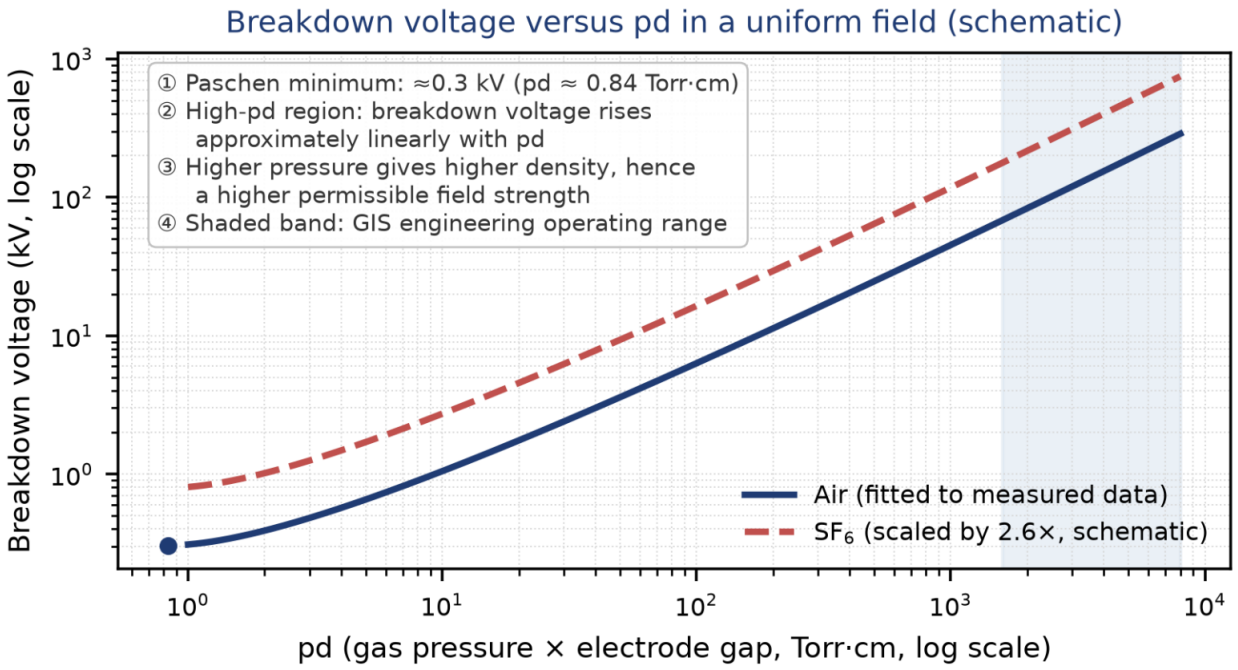


Figure 1 — Breakdown voltage versus pd (pressure × gap) in a uniform field (schematic)

Note: drawn for a uniform field and static gas; the SF, curve indicates the trend only and does not represent measured values of any particular product.

2.2 Why Density and Not Pressure

Breakdown is essentially an electron avalanche: electrons gain enough energy between two collisions to ionise gas molecules. The mean free path is inversely proportional to molecular number density; the higher the density, the shorter the free path, and the higher the field strength required to sustain ionisation. At constant temperature pressure is proportional to molecular number density (p = nkT), so engineering practice controls density indirectly through pressure — pressure can be measured, density cannot be measured directly.

SF6 has a further advantage on top of this: strongly electronegative molecules capture free electrons to form negative ions, weakening the conditions for avalanche onset, and its uniform-field breakdown strength is approximately 2.5 times that of air. Pressure and density must be distinguished: insulation depends on density, and pressure is only a measurable proxy for it; when the temperature changes the pressure changes with it while the density does not.

2.3 From Density to Dimensions: The Physical Path to Compactness

If breakdown field strength rises approximately linearly with density, the gap required, d = U/Eb, shortens accordingly. An order-of-magnitude estimate: the uniform-field breakdown strength of air at atmospheric pressure is approximately 3 kV/mm; the density of SF6 at 0.6 MPa gauge is about seven times its value at atmospheric pressure, and in the high-pd region the breakdown field rises approximately linearly with density, so the theoretical uniform-field withstand is of the order of 20 kV/mm; after the engineering margin described below the practical withstand of the pressurised gas is about 8–9 kV/mm, so the insulation gap can be shortened to roughly one third of that of an equivalent air-insulated design.

Engineering values are far more conservative: the field is non-uniform, electrode surfaces are rough, charge accumulates on insulating surfaces, and free metal particles initiate breakdown where the field is concentrated, so the working field strength is usually held to between one third and one half of the theoretical value. Even so, enclosure diameter, compartment length and insulation distance all shrink together — this is the first meaning of trading gas pressure for volume, and the fundamental reason why GIS could displace AIS in city centres and underground substations. Figure 2 shows what this means at the level of layout.

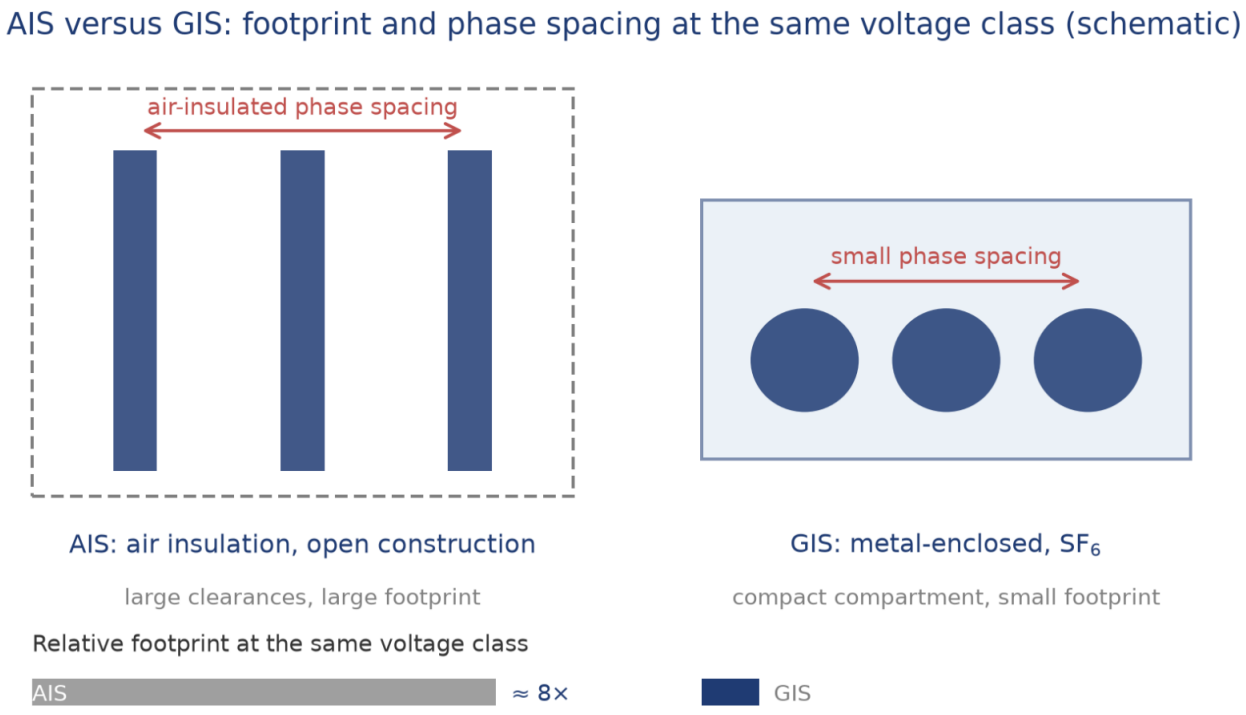


Figure 2 — AIS versus GIS at the same voltage class: air insulation needs large phase clearances and a large footprint, whereas a metal-enclosed gas compartment works at small clearances with a much smaller footprint (schematic, order-of-magnitude comparison).

2.4 Four Secondary Effects of Positive Pressure

Positive pressure brings four further benefits. Heat dissipation: the convective heat-transfer coefficient rises with density and thermal conductivity, so heat from contacts and busbars reaches the enclosure faster and the current-carrying capability is higher for the same cross-section. Interruption: puffer and self-blast arc quenching

depend on gas mass flow, and insufficient density lengthens arcing time and increases contact erosion. Particle suppression: the lift-off force on a particle is proportional to the square of the field strength while the aerodynamic drag rises with density, so the critical field strength for lift-off is raised. Isolation from the external medium: positive pressure drives leakage outward, so moisture, dust and corrosive gases cannot readily enter, and with an IP67 enclosure the interior stays clean over the long term.

2.5 Liquefaction Temperature: The Hard Ceiling on Pressure

The first hard limit on pressure is liquefaction. The triple point of SF6 is -50.8 °C at 0.226 MPa and its sublimation temperature at atmospheric pressure is -63.8 °C; at 1.2 MPa absolute the liquefaction temperature is 0 °C, and at 0.6 MPa gauge (0.7 MPa absolute) it is approximately -26 °C. An 800 kV circuit breaker filled to 0.6 MPa gauge and installed outdoors at -30 °C has already passed its liquefaction point: liquid SF6 no longer provides insulation and accumulates at the lowest points. Three countermeasures are available — compartment heating, admixture of N2 or CF4 to lower the liquefaction temperature, and derating in cold regions — and each carries a cost or a performance penalty.

The second constraint is manufacturing cost. The higher the pressure, the thicker the enclosure wall, the higher the flange rating, the more demanding the seal specification and the burst-pressure design and inspection requirements. The rated filling pressure is therefore never a case of higher being better; it is the intersection of insulation requirement, liquefaction constraint and manufacturing cost. Figure 3 shows how the required wall thickness responds to pressure.

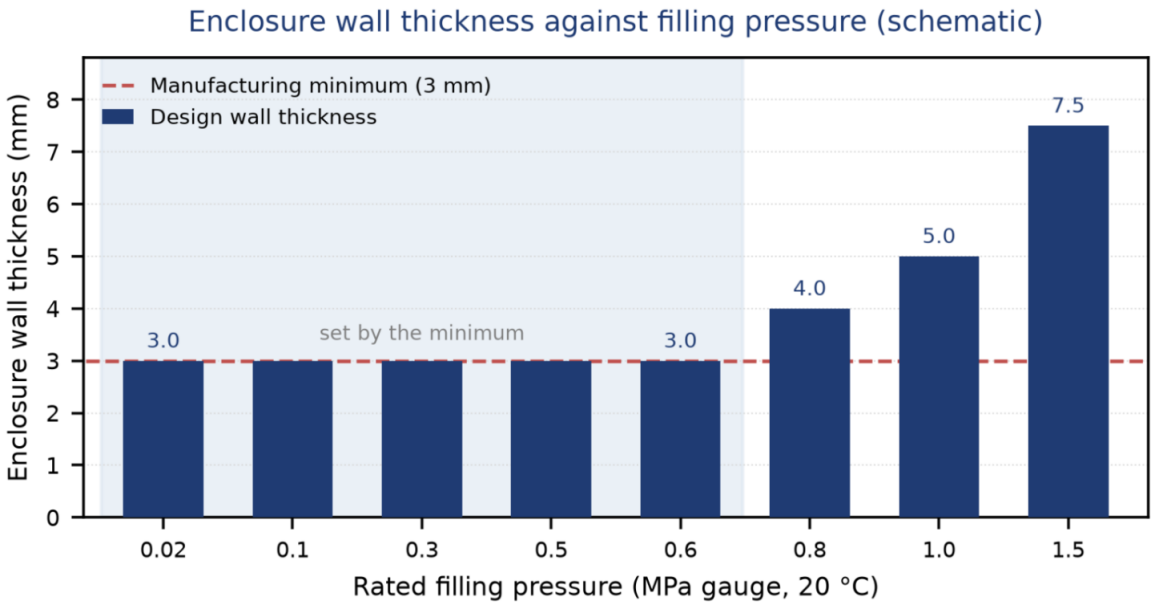


Figure 3 — Enclosure wall thickness against rated filling pressure: in the low-pressure band the wall is set by the manufacturing minimum, above about 0.7 MPa it rises in proportion to pressure (schematic, thin-wall cylinder estimate for a D = 600 mm shell).

Note: thin-wall cylinder estimate, t = pD/2σ, with D = 600 mm and an allowable stress of 60 Mpa; in the shaded band the thickness is set by the manufacturing minimum rather than by pressure. Real designs also depend on stiffness, flange rating and burst-pressure requirements.

3 Pressure Levels Across Voltage Classes and Insulating Media

3.1 Conventions: Pressure Referred to 20 °C and Density

The convention must be settled before pressure is discussed. Rated filling pressure means the relative pressure (gauge pressure) at 20 °C, and it corresponds to a rated density; standards and catalogues state both quantities because what is actually guaranteed is the density. The associated thresholds are the alarm pressure (about -10%), the lockout pressure (about -20%, at which operation is blocked) and the minimum functional pressure. In the field a density relay must be used rather than an ordinary pressure gauge: within a single day the ambient temperature can change the gauge reading by 20%–30% while the density is unchanged, and topping up by gauge pressure would overfill in winter and underfill in summer.

3.2 Medium Voltage: A Slight Positive Pressure of 0.02–0.05 MPa

Medium voltage is the lowest pressure tier. For C-GIS and ring main units rated 12–40.5 kV the rated filling pressure lies between 0.02 and 0.05 MPa gauge: ABB SafeRing/SafePlus is filled to 1.4 bar absolute (20 °C, about 0.04 MPa gauge), Schneider Electric RM6 to 0.2 bar relative (about 0.02 MPa), and Siemens 8DJH to 150 kPa absolute (about 0.05 MPa). All three are designed as sealed-for-life: Schneider Electric states an annual leakage rate of 0.01%, ABB gives a diffusion rate of <0.1% per year, the SF6 compartment of RM6 is rated IP67, and ABB guarantees a pressure of not less than 1.3 bar absolute over the design life.

Why is only 0.04 MPa required? At this voltage level the field strength is moderate and the compartment volume small, so insulation does not call for a high density; the design objective is not higher performance but freedom from maintenance — no gas top-up and no servicing within the sealing life. A low pressure means a small absolute leakage and a light burden on the seals, which is precisely the premise of the sealed-for-life design.

3.3 High and Extra-High Voltage: Stepwise Rise and Plateau

Pressure steps up as the voltage class rises. The ABB ELK-04 series of 145 kV GIS provides a comparable sample: the circuit-breaker compartment has a rated filling pressure of 0.7 MPa (absolute, 20 °C) and the other compartments 0.6 MPa, equivalent to 0.6 and 0.5 MPa gauge — within a single unit the pressure is already graded by function, because the circuit breaker needs density to support arc quenching while the busbar and disconnector compartments need only to satisfy insulation. Public samples for 72.5–145 kV as a whole fall between 0.5 and 0.6 MPa gauge; 252 kV is mostly 0.5–0.6 and 550 kV stable at about 0.6; by 800 kV the samples have still not exceeded the order of 0.6 MPa, and pressure no longer rises linearly with voltage. At the standards level, IEC 62271-1 defines rated filling pressure only as a filling pressure or filling density referred to 20 °C and 101.3 kPa and sets no unified preferred values; the 0.5–0.6 MPa sample band above is precisely the result of manufacturers choosing values between insulation requirement and liquefaction constraint.

Plotted together (Figure 4), the curve rises steeply and then flattens: it climbs quickly from 72.5 kV to 252 kV and then settles on a plateau near 0.6 MPa. The reason is the two constraints of Section 2.5 — further pressurisation pushes the liquefaction temperature towards the lower limit of the operating environment, and the cost rises non-linearly. Above 550 kV, therefore, the insulation level is raised mainly by increasing dimensions, optimising the field distribution and improving assembly cleanliness rather than by further pressurising.

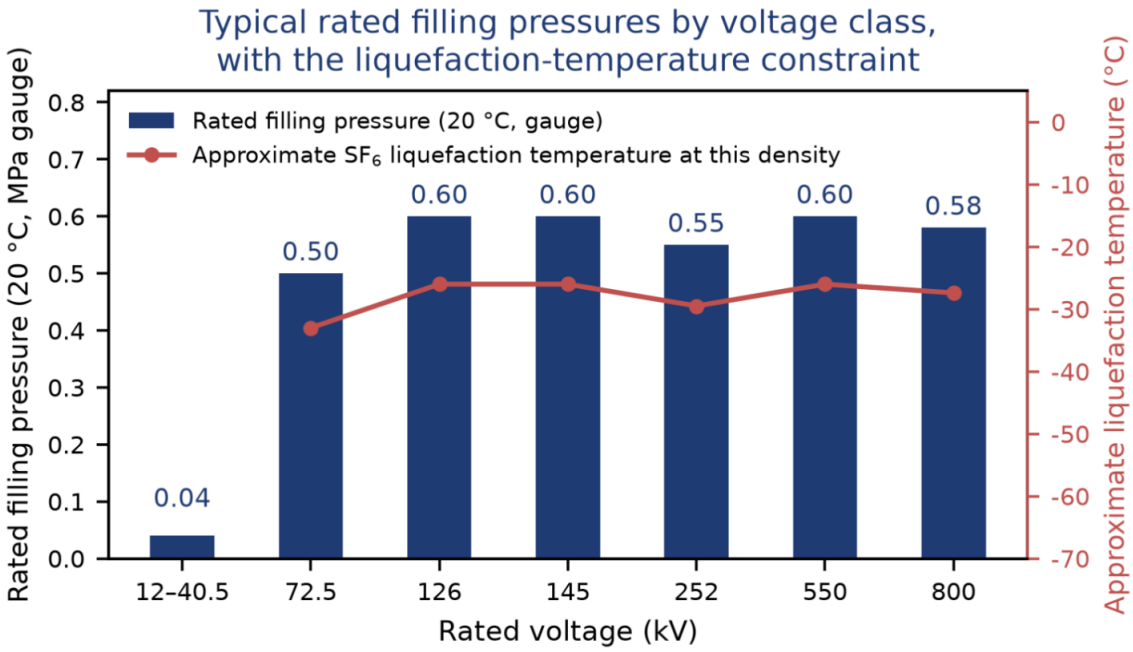


Figure 4 — Typical rated filling pressures by voltage class, with the liquefaction-temperature constraint

Note: pressures are typical orders of magnitude from public samples and manufacturers' data; specific equipment is governed by the manufacturer's data sheet. Liquefaction temperatures follow the SF6 saturation curve.

3.4 Pressure Ranges of Different Insulating Media

The pressure requirement differs greatly with the medium (Table 1). SF6 is the reference; SF6/N2 and SF6/CF4 mixtures are used to lower the liquefaction temperature or to reduce the quantity of SF6, and the low-boiling component dilutes the dielectric strength, so a slightly higher pressure or a larger gap is needed to compensate. g3, a mixture of C4F7N and CO2, has dielectric performance close to that of SF6 and is commonly filled to the order of 0.5–0.7 MPa, operating down to about -30 °C depending on the mixing ratio.

AirPlus, a mixture of C5F10O and dry air, operates at a clearly lower pressure, about 0.1–0.2 MPa, but the condensation-temperature constraint is stronger. Dry air and nitrogen present no liquefaction problem, but approaching the insulation level of SF6 requires 0.7–1.5 MPa; such high pressures mean thicker enclosures and a higher tightness class, which is not economical in engineering terms, and their proper arena is medium voltage and atmospheric-pressure solutions. Vacuum interruption with natural air works at 0 MPa gauge.

Voltage class	Typical equipment	Insulating medium	Rated pressure (20 °C, MPa gauge)	Liquefaction / condensation constraint and tightness
12–40.5 kV	C-GIS, RMU	SF6	0.02–0.05	No liquefaction risk; annual leakage 0.01%–0.1% per year
72.5 kV	GIS	SF6	0.5	Liquefaction ≈ -33 °C, checked against the local minimum temperature
126–145 kV	GIS	SF6	0.6	Liquefaction ≈ -26 °C
252 kV	GIS	SF6	0.5–0.6	Liquefaction ≈ -26 to -33 °C
550 kV	GIS	SF6	0.6	Liquefaction ≈ -26 °C
800 kV	GIS	SF6	≈ 0.6 (typical)	Liquefaction ≈ -26 °C, checked against the local minimum temperature
Above 72.5 kV	GIS	SF6/N2, SF6/CF4, g3	0.5–0.7	Liquefaction temperature substantially lower; g3 down to -30 °C
Above 72.5 kV	GIS	Dry air, N2	0.7–1.5	No liquefaction risk, but higher pressure, sealing class and cost

Note: pressures are typical orders of magnitude taken from public samples and manufacturers' data; the manufacturer's data sheet governs specific equipment. Liquefaction temperatures are read from the liquid–vapour saturation curve for SF6. Liquefaction at 0.6 MPa gauge (0.7 MPa absolute) ≈ -26 °C; 0 °C at 1.2 MPa absolute. Source: NIST Chemistry WebBook, sulfur hexafluoride.

4 What Positive Pressure Buys

4.1 Compactness: An Order-of-Magnitude Change in Footprint and Volume

Compactness is the most direct return on positive pressure. At the same voltage class the footprint of GIS is typically an order of magnitude smaller than that of AIS (the exact ratio depends on the connection arrangement and the number of busbar sections). For a substation on scarce urban land this decides whether the project can proceed at all: the site can move from outside the city back to the load centre, and the incoming line length, civil works investment and line losses fall together. The deeper effect is on civil works — GIS is prefabricated in the factory and assembled on site, turning substation construction from a civil engineering project into an equipment installation project.

4.2 Siting Flexibility and Environmental Isolation

Internal insulation is separated from the outside environment by the enclosure, so pollution, salt mist, humidity and altitude no longer act directly on insulating parts; the enclosure can reach IP67 and the equipment can be installed in basements, cable rooms, coastal plants and high-altitude sites. For a city-centre substation this matters more than small volume.

4.3 Heat Dissipation and Current-Carrying Capability

Convective heat transfer in a pressurised compartment is stronger than in an atmospheric one, so heat reaches the enclosure faster and a higher current is permissible for the same conductor cross-section; conversely, the same current can be carried with a smaller conductor. For high-current busbars the thermal benefit adds to the dielectric benefit in supporting compactness.

4.4 Integrated Insulation and Interruption

In circuit breakers that interrupt by gas, the same gas performs both insulation and arc quenching, so two media and two sets of components are not required. By comparison, a vacuum-plus-air solution must interrupt in a vacuum interrupter and insulate in air, and its components and their coordination are more complex — which is what it compensates for with no leakage and no monitoring.

4.5 Quantifying Tightness Reliability

Positive pressure turns an insulation problem into a tightness problem, and tightness can be designed, tested and quantified. IEC 62271-1 gives standard values of 0.5% per year and 1% per year for the relative leakage rate of SF6 and SF6 mixtures in closed pressure systems; IEC 62271-203:2022 classifies by GWP and tightens the type-test tightness requirement for gases with a GWP above 1,000 to 0.1% per year per compartment. Medium-voltage sealed-for-life equipment performs better still, with 0.01%–0.1% per year commonly quoted in public samples.

5 The Price of Positive Pressure: Sealing, Leak Detection and Operating Cost

5.1 Sealing Structure and Process

Sealing is the first cost. Seals are mainly O-rings, usually of EPDM or fluororubber, with a compression ratio typically 15%–30%: too little gives insufficient contact stress, too much accelerates compression set; groove dimensions, flange surface roughness and assembly cleanliness all bear directly on the leakage rate. Important compartments use double seals, the primary seal providing tightness and the secondary one redundancy, with a leak-detection passage between them.

The enclosure is usually a welded aluminium-alloy or stainless-steel structure, and welds are a high-risk region for leakage; they must be examined by X-ray or ultrasonic testing and the assembly subjected to an overall tightness test. One factor is often underestimated: thermal cycling. Metals and rubbers have different coefficients of linear expansion, so diurnal and seasonal temperature swings make the sealing faces move microscopically; over time the seals creep and the contact stress relaxes, and the leakage rate rises with age — which is precisely why leakage must be measured per year.

5.2 Leak Detection: From Factory to Site

At the factory, helium mass-spectrometer leak detection predominates: the enclosure is filled with helium or a helium-nitrogen mixture and scanned from outside with a mass spectrometer, with sensitivity down to the order of 10-9 Pa·m3/s; an SF6 leak detector locates positions at ppm-level concentrations; and an overall tightness test yields a quantitative annual leakage rate, which is the acceptance criterion.

Leak detection on site is more difficult: 0.01% per year for a compartment holding tens of kilograms of gas amounts to a few grams per year, and a faint leak is quickly diluted by air movement. The usual methods are the bagging method (local quantification), infrared imaging (broad initial screening) and a quantitative leak detector (confirmation of the leak point). The difficulty lies in locating it — a compartment has many flanges, welds, bushings and interfaces, and isolating sections one by one, pressurising them separately and repeating measurements often requires the equipment to be taken out of service.

5.3 Moisture and Decomposition Product Control

Moisture lowers the surface flashover voltage of insulating parts and, under the action of the arc, forms corrosive products such as hydrofluoric acid. Control starts at assembly: evacuation, filling with dry gas, and built-in molecular sieve or activated alumina; the factory moisture limit is commonly ≤150 μL/L, corresponding to a dew point of about -40 °C. Moisture in service comes from inward diffusion and material outgassing, the capacity of the adsorbent is finite, and after any opening of the compartment the equipment must be re-evacuated and the adsorbent replaced. Arc decomposition produces SO2, SOF2, HF and metal fluorides, so SO2 must be monitored and the gas recovered before the compartment is opened for maintenance.

5.4 Pressure Monitoring and Temperature Compensation

Pressure monitoring is a standing cost. The core element is the density relay, which compensates for temperature change with a double bellows or double spring and outputs density rather than pressure. Settings fall into three levels: alarm at about -10%, calling for a top-up; lockout at about -20%, blocking opening and closing; and the minimum functional pressure, the floor at which insulation and interruption can still be performed. The cost is not only the instrument — calibration intervals, signal wiring and remote transmission, and inspection labour are a continuing expense for a distribution network with hundreds of units.

5.5 Operating Cost, Compliance Cost and Systemic Risk

Gas top-up is a long-term expense: at 0.5% per year with a 20 kg charge, the cumulative quantity over twenty years can reach the order of 2 kg. At maintenance, modification or decommissioning the gas must be recovered rather than vented; recovered gas must be dried and analysed before reuse, and cylinder transport and on-site work qualification both carry cost.

Compliance cost is rising. Regulation (EU) 2024/573 imposes explicit obligations on the frequency of leak detection, on records and on reporting; on a GWP-100 basis 1 kg of SF6 is equivalent to 23.5 t CO2e, which is why the targets keep tightening. Safety is a further dimension: SF6 is heavier than air and, after a leak, accumulates in cable trenches and basements to cause oxygen deficiency; decomposition products are toxic; and the enclosure, as a pressure vessel, must be designed for burst pressure and pressure relief in accordance with IEC 62271-1.

5.6 Whole-Life Cost

Taken together, the whole-life cost of the positive-pressure solution has six components: equipment purchase, seal maintenance, leak detection and testing, gas top-up and gas handling, the compliance record, and end-of-life recovery. An air-based solution can dispense with five of them, at the price of weaker dielectric capability, which must be compensated by larger dimensions or a different interruption principle.

6 Technical Boundaries and Alternative Routes

6.1 Three Cases That Require Positive Pressure

Positive pressure is a means, not an end. Whether it is necessary can be reduced to three cases: high voltage — above 72.5 kV, where air cannot provide sufficient insulation at a reasonable size; tight compactness constraints — city centres, underground substations and refurbishment of existing buildings; and high breaking capacity — circuit breakers that interrupt by gas, whose capability is directly supported by density.

6.2 Where Positive Pressure Can Be Dispensed With

Where none of the three applies, positive pressure loses its necessity. Medium-voltage secondary distribution at 12–24 kV is the typical case: the voltage is not high, insulation can be provided by air at atmospheric pressure, interruption is performed by a vacuum interrupter, and the footprint constraint can be met by structural design. The atmospheric-sealed natural air (ASNA) solution is based on this: natural air insulation, vacuum interruption, zero gauge pressure. Without leakage there is no top-up and no recovery. The footprint of such solutions is comparable to that of a pressurised dry-air enclosure.

6.3 Slight Positive Pressure: A Compromise

Another compromise is slight positive pressure: the pressure is held 10–20 kPa above atmospheric. At this level the gas density is some 10%–30% higher than at atmospheric pressure, so the dielectric strength gains a comparable margin but still cannot support high voltage classes; the more important benefit is that leakage flows outward and moisture is kept out. Once the pressure falls, the dielectric capability falls with it, so although the sealing requirement is lower than for a 0.4 MPa-class compartment, pressure monitoring and leak detection are still required.

7 Conclusions and Key Takeaways

Returning to the question with which this paper opened: why do GIS switchgear enclosures need positive pressure gas? Because under a given voltage and volume constraint only a higher density can raise the breakdown field strength far enough to reduce dimensions; and the dielectric advantage of SF6, together with the sealing levels achievable in engineering, made a metal-enclosed compartment at 0.4–0.6 MPa the most economical technical solution of the past half century. Positive pressure brings compactness, heat dissipation, interruption and environmental isolation, and it also converts an insulation problem into a sealing one, with the attendant costs of leak detection, moisture control, density monitoring and compliance.

1. Positive pressure is an industry convention and the engineering optimum, not something mandated by standards; standards specify the tightness performance, monitoring and alarm/interlock requirements that apply after pressurisation.

2. Dielectric strength is governed by gas density, not by pressure: the high-pd section of the Paschen curve is approximately linear, and a higher density raises both the breakdown field strength and the permissible field strength, which is the physical path to compactness.

3. Rated filling pressure is referred to 20 °C and stated on a density basis: 0.02–0.05 MPa at medium voltage, 0.5–0.6 MPa at 72.5–145 kV, about 0.5–0.6 MPa at 252 kV, about 0.6 MPa at 550 kV and about 0.6 MPa at 800 kV (the circuit-breaker compartment slightly above the others; typical values, subject to the manufacturer's data sheet).

4. The upper limit of pressure is capped jointly by liquefaction temperature and manufacturing cost: at 0.6 MPa gauge the liquefaction temperature of SF6 is approximately -26 °C, and cold regions require heating, admixture of a low-boiling gas or derating.

A Appendix A — Glossary

- 1. GIS: gas-insulated switchgear, i.e. metal-enclosed switchgear insulated by gas. Cubicle-type medium-voltage equipment is often called C-GIS, and a ring main unit is called an RMU (Ring Main Unit).
- 2. Paschen's law: in a uniform field the breakdown voltage is a function of the product pd of pressure and gap length; the curve has a minimum and is approximately linear in the high-pd region.
- 3. Rated filling pressure: the relative pressure (gauge pressure) inside the compartment at 20 °C, corresponding to a rated gas density; the state quantity actually guaranteed is the density.

- 4. Density relay: a gas density monitoring device with temperature compensation that reflects density rather than pressure, used for alarm, lockout and top-up decisions.

- 5. Closed pressure system and sealed-for-life: the former permits a small leakage and requires periodic top-up; the latter denotes a sealing system that needs no top-up or maintenance within its design life.

- 6. Minimum functional pressure: the lowest gas pressure at which the equipment can still perform its rated insulation and interruption duties; below it the equipment must not remain in service.

- 7. Liquefaction temperature: the temperature at which a gas begins to condense at a given pressure; for SF6 at 0.6 MPa gauge it is approximately -26 °C, one of the main limits on rated pressure.

B Appendix B — References

- [1] Standard values of relative leakage rate for closed pressure systems in IEC 62271-1: 0.5% per year and 1% per year for SF6 and SF6 mixtures, and 0.5%, 1% and 3% per year for other gases. Paraphrased from BEAMA, The conditions of gas tightness of gas insulated switchgear according to standards versus warranty aspects. https://www.beama.org.uk/static/uploaded/a4921acf-4469-4c4f-9c4142db04a25ca5.pdf

- [2] IEC 62271-203:2022 classifies closed pressure systems by GWP into ≤1,000 and >1,000, tightening the type-test tightness requirement for the latter from 0.5% to 0.1% per year per compartment. https://webstore.iec.ch/preview/info_iec62271-203%7Bed3.0%7Db.pdf

- [3] IEC 62271-1:2017, 3.6.5: filling pressure is referred to 20 °C and 101.3 kPa and may be expressed as a pressure or a density, absolute or gauge, that is, the pressure to which the equipment is filled before commissioning or automatically topped up; the standard sets no unified preferred rated pressures for SF6 circuit breakers. https://webstore.iec.ch/publication/23180

- [4] ABB, SafeRing/SafePlus installation and operating guide: rated absolute SF6 pressure 1.4 bar at 20 °C (about 0.04 MPa gauge), sealed-for-life, diffusion rate <0.1% per year, pressure not below 1.3 bar absolute over the design life. https://cn.library.e.abb.com/public/03c333d60c804daaae8cc62fc3960898/1YVA000130_Safe-SG_Manual_ZH_REV%20A%2008-2019.pdf

- [5] Schneider Electric RM6 ring main unit technical FAQ: SF6 filling pressure 0.2 bar (relative) at 20 °C, annual leakage rate 0.01%, SF6 compartment protection IP67. https://www.schneider-electric.cn/zh/faqs/FA261940/

- [6] Siemens 8DJH (≤24 kV, gas-insulated) technical data: rated filling pressure 150 kPa (absolute, 20 °C), design pressure 180 kPa. https://assets.new.siemens.com/siemens/assets/api/uuid:12f25a8292c4f8abe699b340fed1ea8fab86077c/sic_00018055.pdf

- [7] ABB, now Hitachi Energy, ELK-04 145 kV GIS catalogue (1HGD008100M0040): circuit-breaker compartment rated filling pressure 0.7 MPa, minimum functional pressure 0.6 MPa, other compartments 0.6 / 0.52 MPa (absolute, 20 °C). http://sarvnirou.com/files/3.1-4%20cataloge.pdf; https://www.hitachienergy.com/us/en/products-and-solutions/high-voltage-switchgear-and-breakers/gas-insulated-switchgear/gis-for-72-5-1200-kv/gis-elk-04-up-to-170-kv

- [8] SF6 saturation and phase-change data: triple point -50.8 °C at 0.226 MPa; sublimation at atmospheric pressure -63.8 °C; liquefaction temperature 0 °C at 1.2 MPa absolute and about -26 °C at 0.7 MPa absolute (0.6 MPa gauge). Source: NIST Chemistry WebBook, SRD 69, sulfur hexafluoride (CAS 2551-62-4). https://webbook.nist.gov/cgi/cbook.cgi?ID=C2551624&Mask=4

- [9] Medium-voltage sealed-for-life leakage rate 0.1% per year, 0.5%–1% per year for equipment not sealed for life. T&D Europe, Technical report on alternative to SF6 gas in MV & HV electrical equipment. https://tdeurope.eu/wp-content/uploads/TDEurope-technical-report-on-alternative-to-SF6-gas.pdf

- [10] Regulation (EU) 2024/573 on fluorinated greenhouse gases: obligations for leak detection, record-keeping and reporting, and restrictions on placing switchgear on the market. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32024R0573

- [11] GWP-100 of SF6 approximately 23,500 and atmospheric lifetime approximately 3,200 years (IPCC AR5 basis), consistent with HMP-WP-2601/2602/2603. https://www.ipcc.ch/report/ar5/wg1/

- [12] HM Power technical documentation and product information. https://www.hmpower-global.com

C Appendix C — Further Reading

- History and origins of SF6: HMP-WP-2601

- The evolution of RMUs and their typical products by period: HMP-WP-2501

- Series note: the HMP white-paper numbers are intentionally split into two sub-series — 25xx covers engineering-and-product topics (this volume, HMP-WP-2502, with HMP-WP-2501 on RMU evolution), and 26xx covers SF_6 policy-and-transition topics (HMP-WP-2601/2602/2603). The numbering difference is a deliberate series division, not a gap.



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