Summary of T&D Europe's Technical report on alternative to SF_6 gas in medium voltage & high voltage electrical equipment

The report maps:

a) current insulation and switching media for medium voltage (MV) and high voltage (HV) switch gear apparatus, including existing alternatives to SF_6 gas; and
b) emerging alternatives to SF_6 gas used in pilots or first applications.

Characteristics of SF_6 gas:

- reliable gas known for switchgear applications since the early 1960s
- ensures the reliability of power supply in electrical systems
- it is non-toxic, non-flammable and does not have any carcinogenic, mutagenic or repro-toxic characteristics
- it has a high global warning potential (GWP) of 22,800 according to the European F-gas regulation 517/2014.

Required characteristics of alternative gases:

Research has been ongoing to find gas or gas mixtures as alternative to SF_6 gas for use in medium and high voltage equipment. These new gases or gas mixtures must have:

- Sufficient dielectric strength even at low operating temperatures;
- Stable behavior over lifetime, even under electrical stress;
- Good arc quenching and current interruption capability;
- Load current switching capability for MV load switches;
- High heat dissipation and heat capacity for current carrying purposes;
- Applicable for indoor and outdoor switchgear down to ambient temperatures of at least -30°C;
- Compatibility with switchgear materials (the gas must not be degraded by materials and materials must not be degraded by the gas and its by-products during the equipment's life cycle) and low diffusion across sealing materials;
- Low toxicity i.e. be non-toxic or have a low acute toxicity, be non-carcinogenic, nor mutagenic, nor repro-toxic, generate no toxic metabolites;
- Minimal environmental impact i.e. having low GWP and showing no ozone depletion potential (ODP), no water pollution potential, etc.;
- High safety characteristics like: be non-flammable, nor explosive, nor corrosive, etc.;
- Reasonable availability of the gas by multi-sourcing on the market and at affordable costs;
- Allowing equipment design compactness like today's equipment; and
- Easy gas handling.

Advantages and disadvantages of existing and emerging alternatives:

Alternative	Advantages	Disadvantages
Natural origin gases such as dry air, nitrogen, carbon dioxide or a mixture of these:	Low GWP.	Limited dielectric strength (approx. 40% or less compared to SF6. This leads to drawbacks specifically for high voltage switchgear. To compensate for the reduced dielectric strength the size/footprint of the equipment must be increased, thus also

		increasing the material cost of the switchgear.
Oil	In use decades ago for current interruption.	Risk of explosion resulting in limited acceptance for this alternative. Precautionary measures required to avoid any environmental pollution (e.g. soils) during the equipment's life cycle.
CF_3I – trifluoro iomethane	High dielectric strength. High current interruption capability. Low GWP (below 10).	Suspected to be mutagenic and therefore not suitable for widespread application in equipment in contact with public unless escape of gas is ensured to never occur during its entire life cycle.
Gas mixtures that include C_5 Fluoroketones (C_5-FK), C_4-Fluoronitriles (C_4-FN) and hydrofluoroolefins (e.g. HFO1234zeE)	Considerable lower GWP than SF_6 and C_5-FK	The pure substances show low liquefaction temperatures. Therefore a mixture of buffer gas is needed to ensure operation at typical ambient temperatures. Lower current interruption ability compared to SF_6. Equipment design adaptations might be required to reach equal current interruption abilities.
Vacuum	Widely used in medium voltage equipment as a reliable interruption medium. Application in high voltage at 72.5kV is now state of the art and designs up to 145 kV exist.	Due to the intrinsic insulating characteristics of vacuum, its insulation capability is not directly proportional to the insulating gap as it is for pressurized gas. There is saturation of the insulation capability for large gaps in vacuum which means the use of vacuum interrupters for higher voltages is challenging.

Application of SF6 in in medium & high voltage electrical equipment

SF6 is used for two purposes:

a) As an electrical insulating element.
b) As a circuit breaker- it works as an interrupter of current in circuits and switches

In both cases, it can be applied in medium voltage and high voltage applications.

a) <u>Electrical insulating elements</u>

There are SF6-free alternatives for medium voltage applications. This include Air, Solid insulation without earthed screen, solid insulation with earthed screen, Dry air. And there are many other emerging alternatives used in pilots or first applications.

While some of the options have specific limitations (e.g. minimum operating temperature), they are other new gases that pose non-technical limitations. However, the challenge is the very limited number of manufacturers of such gases and existing patents for electrical switchgear applications.

There are no existing alternatives for high voltage electrical insulation. Emerging alternatives such as synthetic air and other gas mixtures are already used in pilots or first applications:

In conclusion: No major technical barrier is foreseen with respect to voltage insultation to develop SF_6-free products for all types of applications and all rated high voltages used in Europe from 72.5 kV to 420 kV. However technical limitations might exist depending on a chosen specific alternative when compared to SF_6 products, for example minimum operating temperature.

b) Arc quenching (switches and circuit-breakers)

Today, vacuum circuit breakers (SF6 free) are commonly used in applications below 50MVA. For applications above 50MVA, SF_6 generator circuit breakers is the most frequently used technology (95%). Vacuum could be used as an alternative to SF6 for applications below 400 MVA with severe limitations in term of asymmetry (or dc constant). For higher performance, typically above 400 MVA, today there is no alternative to SF6 Generator Circuit-Breakers.

Besides vacuum-based solutions, other gas mixtures are also emerging as SF6 alternatives.