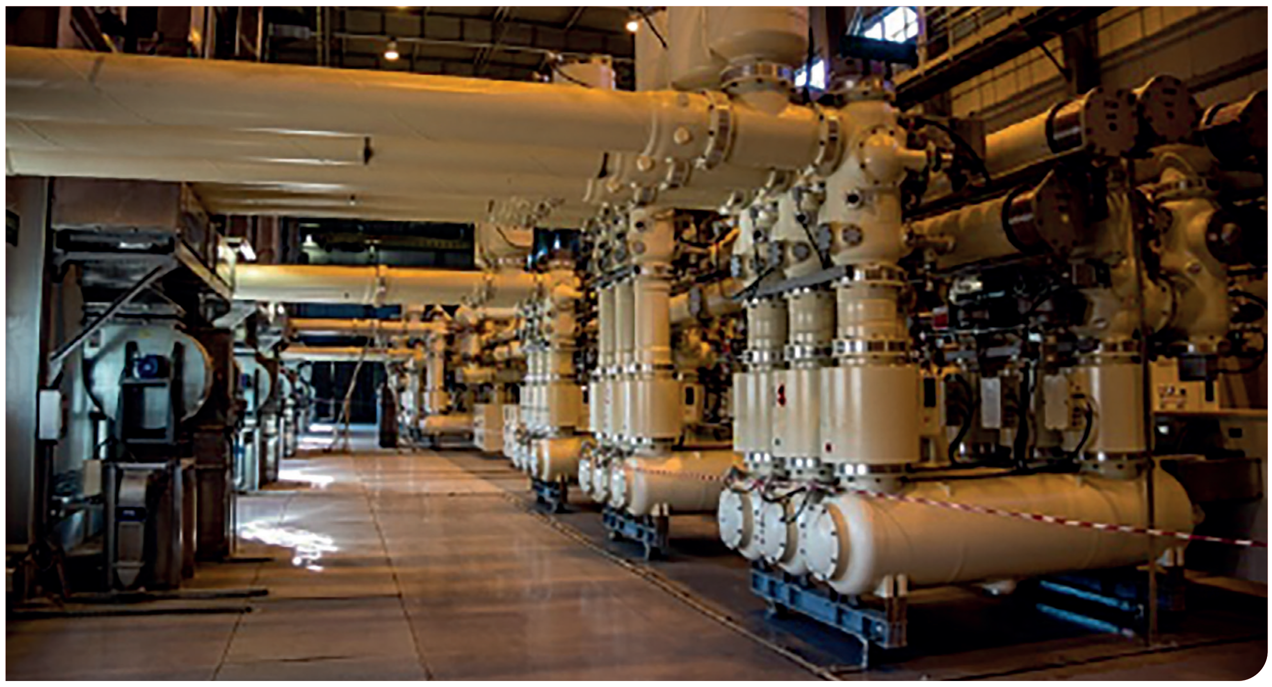
GAS INSULATED SWITCHGEAR (GIS) MONITORING OF SF_6 USING PRECISE NDIR SENSOR TECHNOLOGY

The integrity and safety of electrical switchgear are paramount in any power distribution system. Sulphur Hexafluoride (SF_6) is widely used as an insulating and quenching medium in switchgear because of its outstanding electrical properties and chemical stability. However, monitoring SF_6 gas is critical, as it is a potent greenhouse gas. Cambridge Sensotec stands at the forefront of SF_6 gas analysis, ensuring the safe and efficient operation of electrical switchgear across various industries. This was achieved by using the latest NDIR sensor technology developed and produced by Wi.Tec-Sensorik GmbH.



Introduction

A gas-insulated switchgear (GIS) is a completely gas-tight encapsulated switchgear for high voltage and medium voltage, which surrounds the electrical conductor(s) with sulfur hexafluoride (SF_6) as a protective gas for insulation. In contrast to air-insulated switchgear (AIS), this allows compact switchgear to be installed in confined spaces.

Gas-insulated switchgear is much more compact than air-insulated switchgear because SF_6 has four times the dielectric strength of air at normal pressure. In addition, SF_6 supports the extinguishing of spark gaps more effectively than air. Gas-insulated switchgear is generally designed for indoor use but can easily be converted for outdoor use.

The insulating gas is kept at a pressure of 5 bar to 10 bar to ensure insulation capability. The reason for the higher gas pressure compared to normal pressure is that the average path length of the free electrons in the gas is reduced. Due to the electric field strength, electrons cannot be accelerated as strongly on average at high gas pressure as at normal pressure and collide with the SF_6 molecules.

As SF_6 is a greenhouse gas with a GWP[1] of 23,500 (EPA), great efforts are being made to prevent leaks. However, there are now exemptions for gas-insulated switchgear, which are justified on the grounds of small quantities of escaping gas and proper disposal. Furthermore, various gas mixtures such as nitrogen (N_2) and carbon dioxide (CO_2) can be used to reduce the absolute proportion of SF_6 in the insulating gas. For gas-insulated pipelines (GIL) without switching operations in the pipe sections, the SF_6 content can be reduced to around 5 %. However, these mixed gases are more sensitive to impurities. Impurities lead to a reduction in the insulation strength and require a higher gas pressure, which increases the mechanical effort and system costs.

Sulfur Hexafluoride

SF_6 is an extremely stable, non-flammable and highly electronegative gas with excellent dielectric properties. It is commonly used in medium and high-voltage electrical equipment as an electrical insulator, arc-quenching and cooling medium. However, SF_6 is classified as a greenhouse gas and must be kept within a closed circuit to avoid any deliberate release into the atmosphere. The international Kyoto agreement protocol has mandated reductions to harmful emissions amongst its member states. For the power transmission and distribution network, SF_6 technology remains essential. To protect personnel, equipment and the environment regular SF_6 analysis should be adopted within the maintenance schedule. The early identification of any decomposition products and moisture within the SF_6 gas will help avoid unnecessary shutdowns, outages and failures, in addition to reducing maintenance expenditures.

GIS

Several applications for measuring SF_6 exist in a GIS. The first is the gas concentration in the close GIS chamber. Ideally, this concentration is always 100 % by volume. Due to unavoidable leakages, this concentration can reduce over several years. To record this process reliably, the measuring range between 90-100 vol.% must be particularly accurate. This application is described in this report. This measurement situation is shown in Figure1. This measurement is repeated at regular intervals to determine the course of the SF_6 concentration and to identify leaks. For an online monitoring a gas density meter is also integrated into the system.

It is also possible to detect leaks in the system and the supply lines with a leak detector. In this case, the typical measuring range is 0-1000ppm SF_6.

In the room air control (accumulation of SF_6 in the room), gas concentrations around the zero point are required. the typical measuring range in this case is 0-50ppm SF_6.

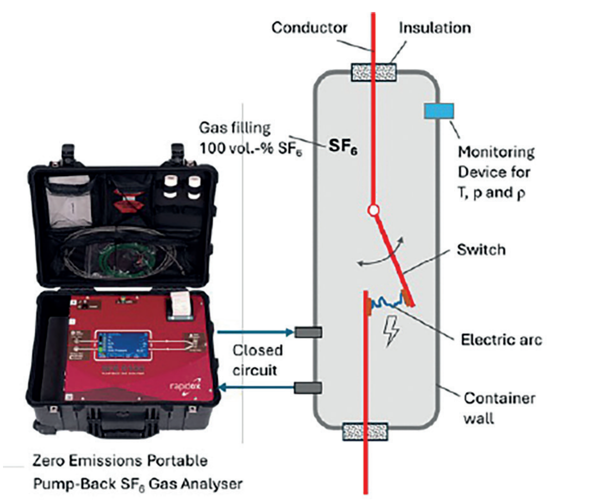


Figure 1: Checking a GIS with a zero emissions portable gas analyzer from the Rapidox series.

Instruments

Cambridge Sensotec Ltd, has been manufacturing a range of SF_6 portable and bench testing equipment for more than fifteen years. Typically, three important gases are measured: SF_6 purity (typically 97-100%), H_2O water content (target <-36°Cdp) and SO_2 arc indicator toxic gas (target < 1ppm). Other gases such as HF, CF_4, O_2, CO and H_2S are measured using electrochemical sensors where required.

In accordance with IEC and CIGRE requirements, the preferred measurement technology for SF_6 analysis is nondispersive infra-red (NDIR), which, unlike other methods such as speed-of-sound or thermal conductivity, is a direct measurement of the SF_6 itself. Most of the modern-day test equipment is highly portable and battery powered so there are huge challenges in obtaining accurate SF_6 readings in differing environmental conditions of temperature and altitude around the World, as well as withstanding mechanical shocks from transportation and rough handling. Furthermore, the new requirements for zero-emissions gas testing mean that the equipment not only has to remove a sample of pressurized gas from the GIS to measure it, but also has to store the sampled gas and then return it back to the pressurized compartment afterwards without any leaks. This makes any zero-emissions SF_6 gas analyzer hugely complicated and internal space is therefore at a premium.

The Rapidox SF_6 gas analyzer range has for a number of years used a Wi.Tec-Sensorik NDIR gas sensor module supplied in an ultra-compact housing with bespoke circuitry supplied on a flying lead to allow insertion into a very tight space. The gas is depressurized before it enters the IR module and flow controllers regulate the flow of test gas to a precise $0.5L.min^{-1}$ allowing for changes in gas density as composition changes. After the gas is tested it enters an internal deflated storage bag which slowly fills until maximum capacity of five liters is reached over ten minutes. In reality, a full test takes a maximum of eight minutes, but this is largely to accommodate the H_2O measurement which has a much slower response. Typically, the SF_6 reading from the IR sensor requires a maximum of two minutes to become stable and reliable.

With the storage bag full of gas, the operator can decide to either remove the gas to an external storage bottle or bag for recycling or, more commonly, pump back the gas to the pressurized vessel where it came from. This is done using a powerful internal compressor which can achieve pressures up to 10 bar on the return. Generally, SF_6 is extremely dry and clean but on occasions where significant toxic gases are detected, safety measures protect the NDIR gas sensor by rejecting contaminated gas before any harm can be done to the equipment.

For a successful and accurate measurement of SF_6, the NDIR module must be fully temperature and pressure corrected over a wide range to accommodate all locations where humans live on planet Earth. For example, the Rapidox analyzer has to work correctly both in the 40°C heat of Dubai and the -10°C cold of Canada, as well as in high altitude places such as La Paz in South America at 3700 meters above sea level where atmospheric pressures fall below 700mbar.

Although the use of SF_6 Worldwide is expected to increase year on year for the rest of this decade, there are greener alternatives now available that are being slowly introduced. Gas mixtures of Novec™ C4 and C5 combined with CO_2 are in occasional use albeit with limited life, as well as mixtures of Dry Air and SF_6 / N_2 mixtures. All these gas types are relatively straightforward to measure using Wi.Tec-Sensorik NDIR gas sensors.

[1] Global Warming Potential

Figure 2: The Rapidox SF_6 Analyzer portfolio using Wi.Tec SF_6 NDIR gas sensors (INFRA.sens®).

NDIR Gas Sensor

Sulfur hexafluoride can be measured with a high selectivity in the IR spectral range of 10-12µm. Cross-sensitivities due to gases present in the ambient air (e.g. CO_2+H_2O) can thus be excluded. In Figure 3 we can see a strong absorption line of SF_6 compared to CO_2 and H_2O. Radiation absorption can be described by the Lambert-Beer law, as shown in Equation 1.

$$I(c) = I_0 \cdot exp - [\alpha \cdot c \cdot L] \cdot \left[\frac{T_0 \cdot p_M}{T_M \cdot p_0}\right] \quad [1]$$

with

I(c) = Intensity at the detector side with Nitrogen (zero gas)

I_0 = Intensity at the detector side without SF_6 gas (I_0=1)

α = Coefficient of absorption [cm^{-1}]

c = SF_6 gas concentration inside the sample cell [vol.%]

L = sample cell length [cm]

T_0 = Temperature during calibration process [K]

T_M = Temperature in the application [K]

p_0 = Pressure during the calibration process [hPa]

p_M = Pressure in the application [hPa]

Since the absorption coefficient α of SF_6 is very high in this spectral range and the concentration is also present up to 100 % by volume, small measuring cells (1-5 mm) are sufficient. The optical arrangement is shown in Figure 4. The IR-radiation source is electronically modulated with a frequency between f=1-10Hz. DC operation (f=0 Hz) is also possible with different type of IR-Detectors. The gas flow through the sample cell is typically 0.1-1 L.min^{-1}. An integrated pressure sensor measured the real time situation of p and T inside the sample cell. Then a very precise compensation of the pressure (p) and temperature (T) influence is possible. The IR-Detector consist of two detector elements for reference and measurement signal generation. In front of each detector element a narrow bandpass interference filter is located.

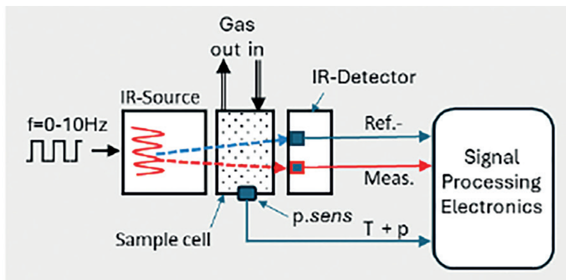


Figure 4: Optical arrangement of the NDIR Gassensor (INFRA.sens®).

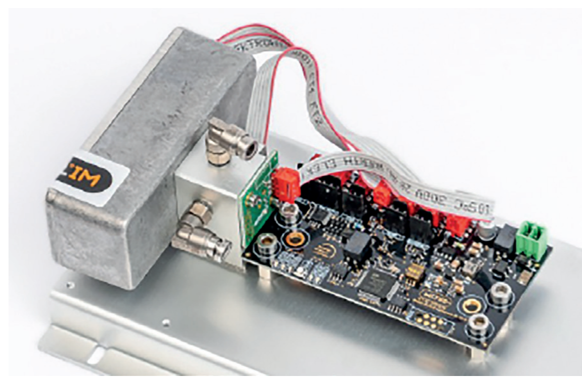


Figure 5: INFRA.sens® for 0-100 vol.% SF_6 including the complete signal processing electronic as well as the temperature and pressure compensation.

The downstream signal processing electronics process the raw signals into a linear display of the SF_6 gas concentration. Typically, the non-linear sensor signals are linearized by a higher order polynomial (see Fig.6). As the measuring range of 90-100 vol.% SF_6 is particularly interesting and important impurity control, particularly accurate compensation calculations are carried out in this concentration range. This means that the individual errors in this important concentration range are all less than 1% F.S.

As the characteristic curve is very steep between 90-100 vol% SF_6, the temperature and pressure influences are very large. Therefore, the compensation of these error influences must be carried out very carefully. The simultaneous pressure and temperature measurement is therefore carried out directly in the cuvette so that the true pressure and temperature values can be measured. Compensation takes place between p=600-1200 hPa and T=5-45°C. This means that error-free measurements can be carried out at high altitudes up to 4000 meters. The detection limit is <0.1vol.% (@zero) and <0.5vol.% (@span).

Conclusion

NDIR technology has proven itself for measuring SF_6 purity in GIS systems. The INFRA.sens® product range is characterized by high accuracy and stability compared to comparable OEM gas sensors. By integrating this technology into the proven Rapidox series measuring devices, the measuring characteristics have been significantly improved. The possible applications of this device technology have also been expanded.

Early Leak Detection: SF_6 leaks can compromise the insulation of GIS, leading to potential failures. Early detection through continuous monitoring allows for immediate rectification, maintaining system integrity and reducing repair costs.

- **Operational Efficiency:** By ensuring that the gas insulation levels are optimal, gas monitoring systems help maintain the operational efficiency of switchgear, thereby preventing unplanned outages.
- **Compliance and Environmental Protection:** With SF_6 being a significant greenhouse gas, monitoring its levels is crucial for compliance with environmental regulations. NDIR Gas monitoring systems facilitate adherence to these regulations by providing accurate and reliable gas measurements.
- **Enhanced Safety:** NDIR Gas monitoring systems contribute to safety by detecting gas leaks that could lead to dangerous conditions, ensuring the well-being of maintenance personnel and the facility.

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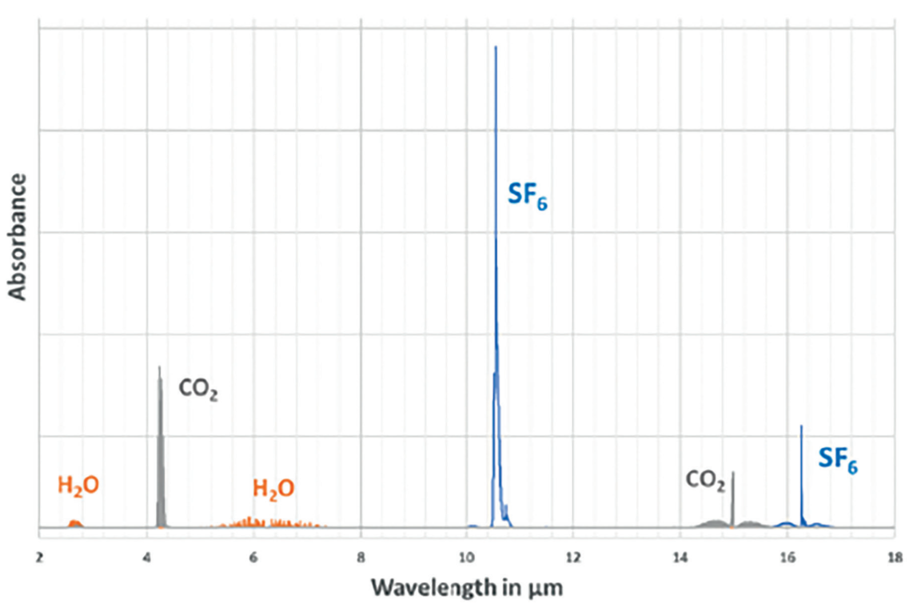

Figure 3 : Infrared Spectrum of SF_6 in comparison of CO_2 and H_2O.

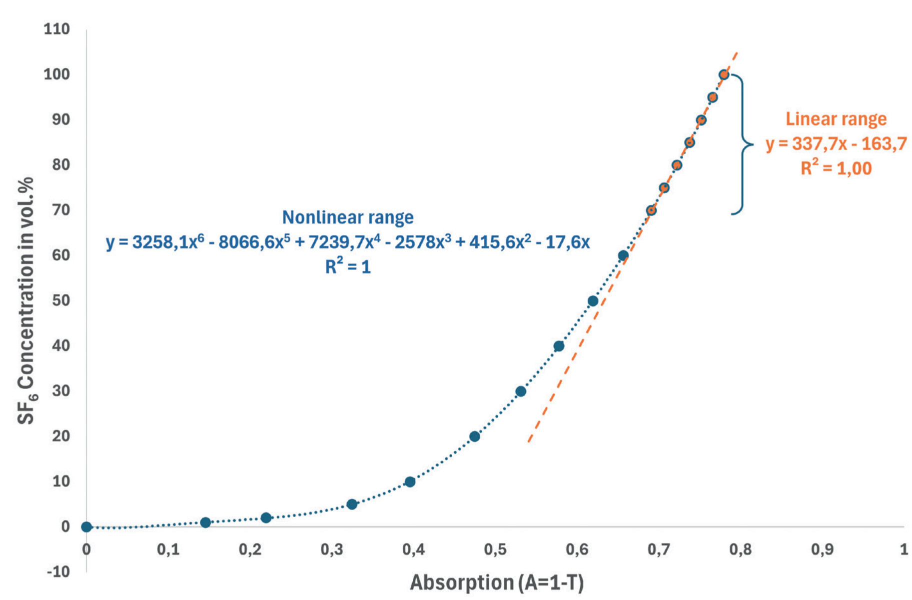

Figure 6 : Calibration curve for 0-100 vol.% SF_6 in nitrogen approximated with a polynomial of 6 degrees (Linearization Fitting).

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