

TNB Reaps Benefits From SF₆ Monitoring

By analyzing the moisture, volume and decomposition of SF₆, the utility is able to maintain performance of SF₆ equipment.

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THE USE OF SULFUR HEXAFLUORIDE (SF₆) IN GAS-INSULATED SUBSTATIONS (GIS), SWITCHGEAR AND OTHER SF₆-FILLED DEVICES (such as transformers and gas-insulated lines) has increased the technical performance of these components. The design of SF₆-filled switchgear is compact, reliability has improved and the electricity industry usage is increasing. SF₆ has excellent insulation and arc-quenching properties, but failures can occur during long-term operation. Failures are caused by variations in gas composition within the encapsulated compartments, resulting in system outages, and costly damage and repairs. That is why the quality of SF₆ gas should be subject to regular inspection throughout the equipment service life to ensure compliance with utility requirements or electrical standards (Fig. 1.). If the gas fails to satisfy standards, it usually must be cleaned or treated in accordance with environmental laws.

QUALITY CONTROL

Partial discharges over long periods or arcs associated with normal switchgear operation lead to the formation of highly corrosive and extremely toxic compounds. The variation and concentrations of these byproducts is dependent on the presence of reaction partners — air, oxygen and moisture. Although the electrical volume stability is not affected, the corrosive decomposition products and residual substances react with the interior surfaces of the GIS.

The International Council on Large Electric Systems (CIGRÉ) published statistics in 1998 confirming that 67% of



Fig. 1. In a substation with GIS equipment, a crew measures the quality of SF₆ gas using the SF₆ Percentage Analyzing Device.

all GIS failures are attributable to gas failure; and therefore, it is imperative to control the quality of SF₆. The presence of moisture and air must be monitored because these contaminants are prerequisites for the formation of the corrosive decomposition products that subsequently reduce the electrical surface strength. For economic considerations, utilities now operate GIS equipment close to the maximum design limits, but a reduction of the electrical surface strength could lead to a breakdown of the whole insulating system. Examples of



Fig. 2. Examples of faults due to flashovers at insulating surfaces when the SF₆ quality has degraded.

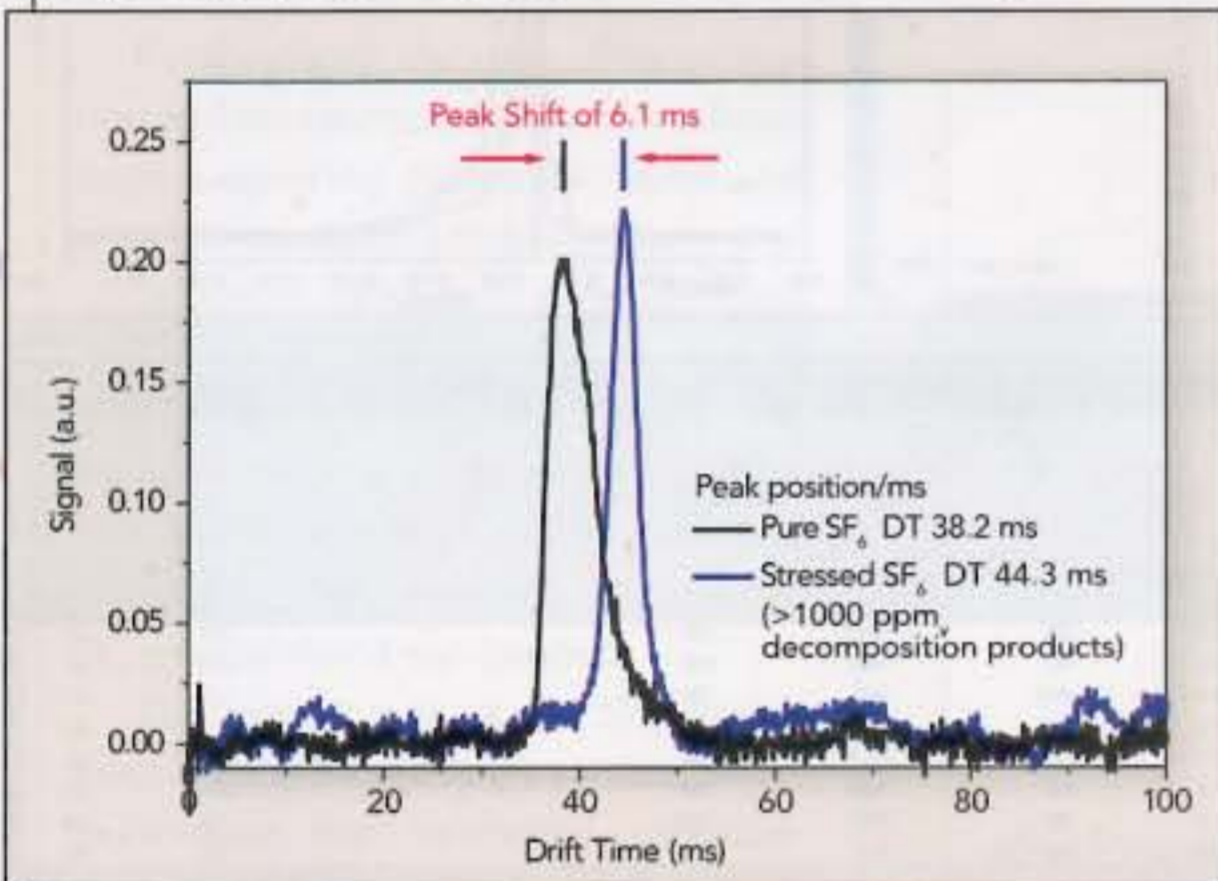


Fig. 3. The peak shift representing the total amount of decomposition products.



Fig. 4. Screen of the SF₆ analyzer and LED on the front panel indicating contamination. In this case, the decomposition products concentration exceeds the limit for contamination.

faults due to flashovers on insulating surfaces are shown in Fig. 2.


G.A.S. Gesellschaft für analytische Sensorsysteme mbH (GAS) and DILO Armaturen und Anlagen GmbH (DILO) have developed a multifunctional inspection device for GIS and SF₆ circuit breakers called the SF₆ Percentage Analyzing Device. The unit combines three different sensors to evaluate SF₆ quality by measuring decomposition products, moisture and the percentage of SF₆. The analyzer enables transmission and distribution utilities to undertake a quick and precise check of the gas-quality information required to maintain the SF₆ equipment.

The SF₆ analyzer is designed for unskilled utility staff to conduct on-site and on-line quality control. It provides infor-

mation on SF₆ quality via a single connection to the equipment. Three quantities are measured with results displayed in real time:

- *Moisture.* The moisture sensor is based on the absorption of water molecules in a special polymer/ceramic material. The sensor is temperature compensated, and values of dew point and moisture in parts per million (ppm) are displayed at ambient pressure in real time.

- *Percentage of SF₆.* The measuring principle is based on the evaluation of different velocities of sound in gases. The velocity of sound in air is about 330 m/s (1083 ft/s), while it is




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INNOVATORS IN COMPOSITES

only about 130 m/s (427 ft/s) in pure SF₆ atmosphere. The velocity of sound measured by the measuring cell is temperature compensated and converted into SF₆ volume content in the micro-processor.

● **Decomposition products.** An Ion Mobility Spectrometer (IMS) is based on the drift of ions at ambient pressure under the influence of an electric field. According to their mobility, impurities can be detected by comparing the drift time of ions in pure SF₆ with the drift time of the compartment gas. The different velocities are used as a characterization of the gas condition as it differs according to the quantity of contaminants (Fig. 3).

A comparison of the IMS measurement results with the published results of parallel-operated infrared spectrometer measurements is used as the basis for determining the correlation between the concentrations of decomposition products and peak shift. To aid and support utility maintenance staff in making qualified decisions, the analyzer interprets the measured results with the words "OK" and "Contamination" appearing on the screen and also by green and red light indications on the front panel, respectively (Fig. 4). An indication of contamination is correlated to the recommended maximum tolerable impurity level included in the SF₆ Recycling Guide (Table 1) published by CIGRÉ.

The limits for the SF₆ value interpretation can be adjusted in the settings of the equipment, a useful feature with respect to reuse of the inspected SF₆. Furthermore, the analyzing device is able to store up to 150 measurements through internal flash memory. With the evaluation software GASpector, SF₆ data can be downloaded and archived on an external computer. For alternative documentation, a report can be printed (Fig. 5, top). Also, trending of measurements over a long period can easily be achieved and a change in the SF₆ quality can be visualized (Fig. 5, bottom). The analyzer and software is considered an important tool to adopt for decisions on the maintenance strategy (that is, time- or event-based strategy versus condition-based maintenance [CBM]).

ANALYZER RESULTS

The Tenaga National Board in Malaysia (TNB) has a large

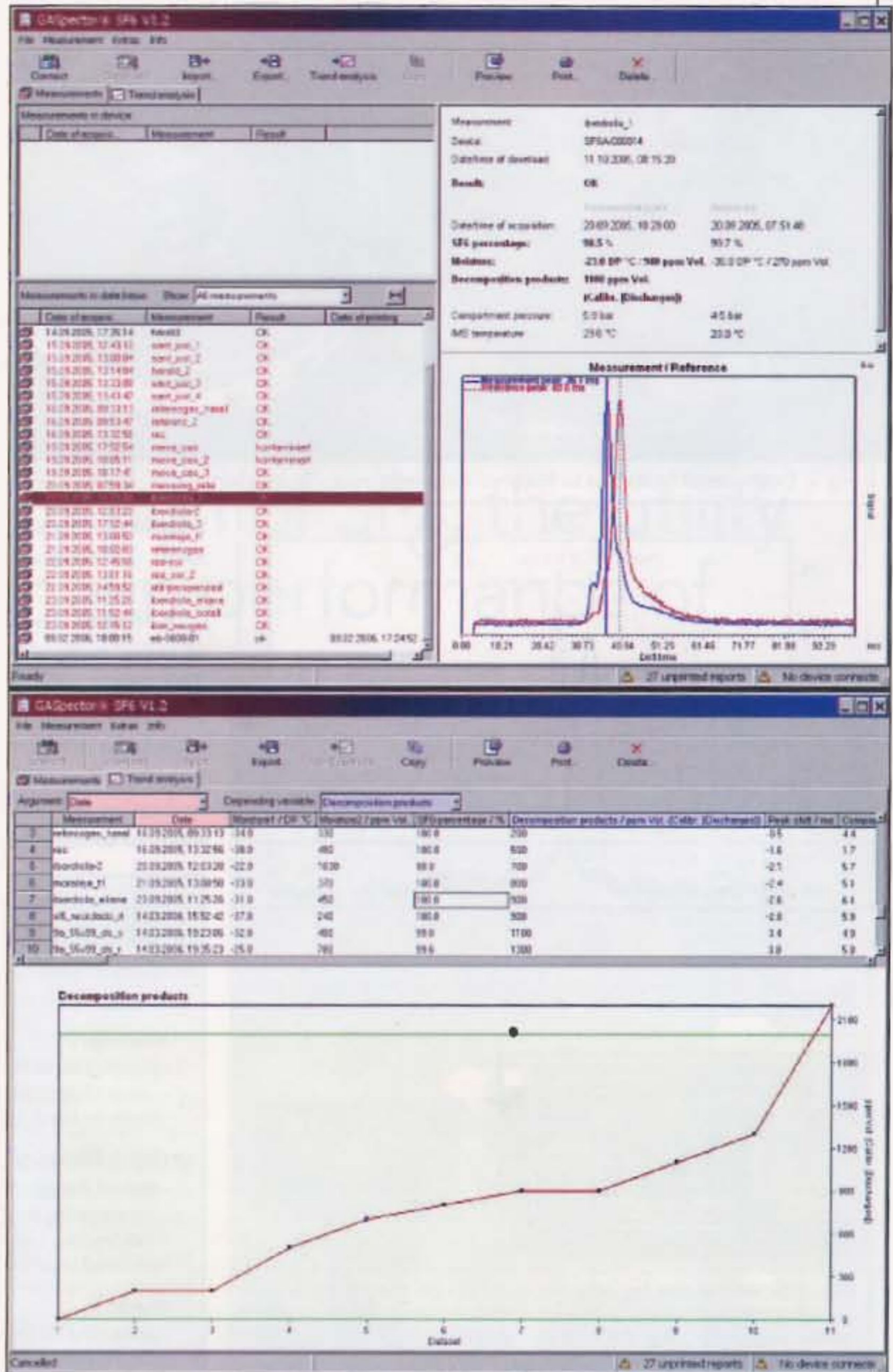


Fig. 5. Measuring report (top) and trend analysis (bottom) using the GASpector SF₆ software.

population of GIS units in operation and its staff has been using the analyzer for the past three years. Regularly inspected gas chambers have successfully detected poor SF₆ quality failing to meet the specified standards in terms of the gas quality, moisture content or the presence of excessive decomposition products. The analyzer has proven to be an excellent diagnostic tool for the evaluation of SF₆ quality in terms of the technical performance and maintenance of SF₆-insulated equipment. The analyzer is easy to use and identifies which equipment is exhibiting characteristics likely to result in major faults. Adoption of a CBM strategy has assisted TNB in analyzing the causes of abnormalities in critical compart-

ments, but more importantly, by reducing plant failures, system reliability has been improved.

Hitachi Engineering & Service Co. Ltd. (HESC) in Japan now uses the SF₆ Percentage Analyzing Device and has changed from a time-based maintenance (TBM) to CBM strategy. HESC and its customers appreciate the quality of the SF₆ measurements, which are produced in from one short sampling. This reduces time given to on-site measurements for the CBM strategy and provides data required to produce historical records and analyze trends.

Furthermore, the operation navigation and measurement correction functions measuring gas temperature and inlet pressure are automatic features of the analyzer, helping to prevent errors and misoperation during use. HESC appreciates these functions of the analyzer, which the company uses regularly when installing and maintaining GIS, GCB, gas transformer and other SF₆ gas-insulated equipment.

The importance of the SF₆-quality assurance is increasingly evident when examining the in-service measurements on an SF₆ circuit breaker. Figure 6 shows the gas analytical results of a circuit breaker at a Korean GIS where strong partial discharge activity had been observed. Table 2 shows the results for three circuit breakers in different substations owned and operated by an Asian GIS utility.

For the first circuit breaker (CB1), the decomposition products exceeded the recommended limit of 2000 ppm_v given by CIGRÉ's SF₆ Recycling Guide, and the measured moisture content of -18°C (-0.4°F) dew point was also below the critical limit of the -5°C (23°F) dew point recommended by CIGRÉ. The SF₆ percentage of 97% is the maximum tolerable impurity level. Two weeks following this inspection, a major flashover occurred with fatal consequences.

Table 2 also shows the results for CB2, which was being commissioned, and the SF₆ quality of a service car used for filling, evacuation, filtering and refilling. The SF₆ quality for CB2 was out of tolerance (>2000 ppm_v of decomposition products) and the moisture content, a dew point of -17°C (1.4°F), was below the preferred standard level. Problems linked to the sta-

bility of the electrical insulation stability and flashover activity were experienced during the commissioning of CB2.

The gas quality of the service car showed similarly high values of decomposition products and a high concentration of moisture, a -10°C (14°F) dew point. This substandard SF₆ quality in these different units was linked to the commission-

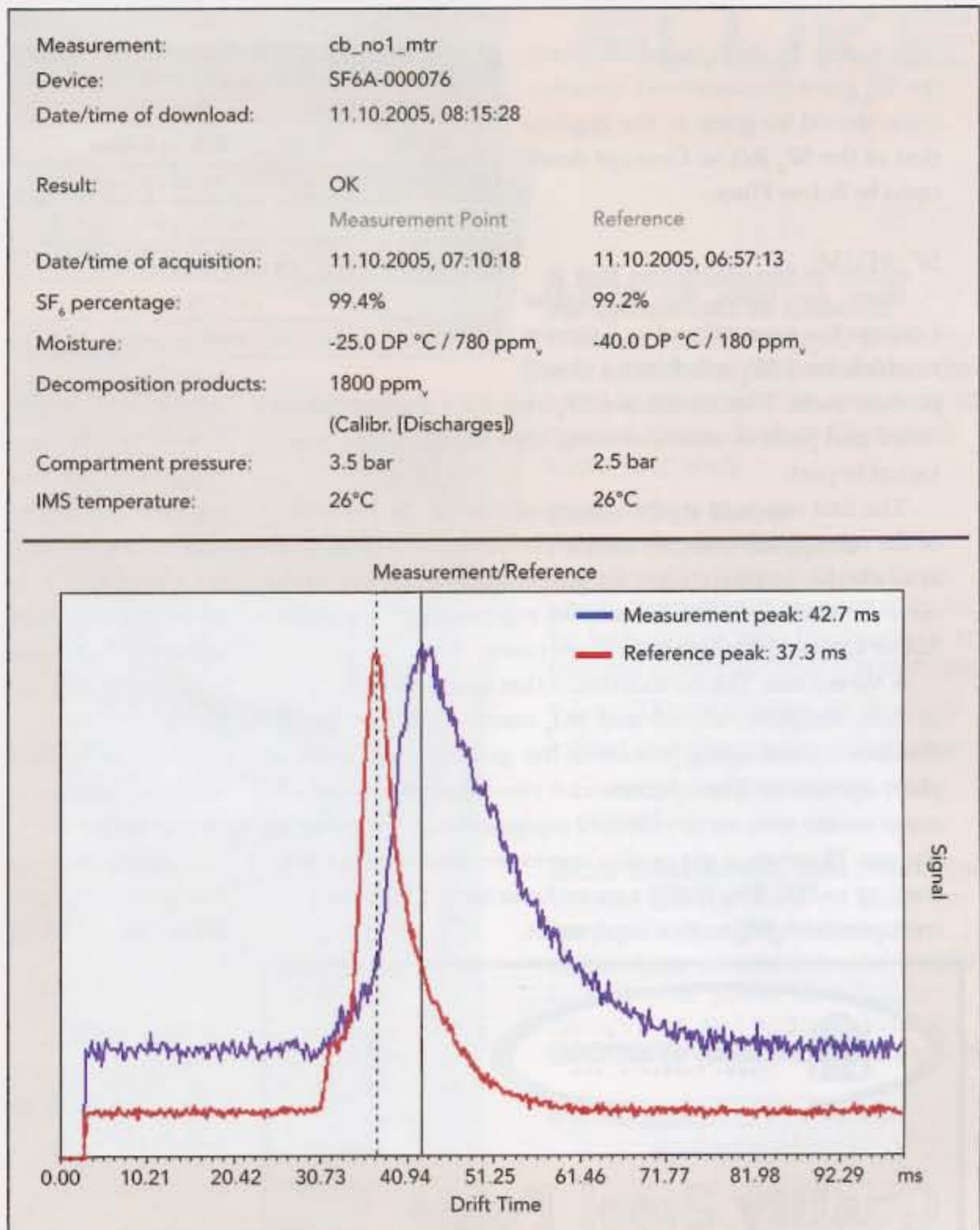


Fig. 6. Measurement report on the SF₆ quality in a Korean GIS circuit breaker.

Table 1. Values of CIGRÉ's SF₆ Recycling Guide

Contaminant	Maximum tolerable impurity levels in equipment	Proposed maximum tolerable impurity levels for reuse
Nonreactive gases: Air and CF ₄	3%	3%
Reactive gases or vapors: SF ₄ , WF ₆ , SOF ₄ , SO ₂ F ₂ , SOF ₂ , SO ₂ and HF	2000 ppm _v	50 ppm _v or, equivalently, 12 ppm _v SO ₂ + SOF ₂
Moisture (dew point)	-5°C (23°F) at ambient pressure	-15°C (5°F) at ambient pressure

Table 2. Acquired Results at an Asian GIS Circuit Breaker Site

Compartment	Decomposition products	Moisture (dew point)	SF ₆
CB1	2100 ppm _v	-18°C	97%
CB2	2300 ppm _v	-7°C	97%
Service Car	2130 ppm _v	-10°C	97%

ing process. In these instances where the SF₆ gas is contaminated, consideration should be given to the application of the SF₆ ReUse Concept developed by Solvay Fluor.

SF₆ REUSE

Since the 1990s, the SF₆ ReUse Concept has been offered as a service in which used SF₆ is fed into a closed product cycle. This minimizes SF₆ emissions during maintenance and plant decommissioning, thus minimizing any ecological impact.

The first step is to analyze the condition of the gas quality of the substation's compartments. The decision is then made as to whether to clean/filter the gas on-site with service equipment or whether it is necessary to regenerate the gas. The ReUse Concept distinguishes three cases:

- *Normal case.* The contaminants that normally occur, such as dust, moisture, air, oil and SO₂ compounds are formed due to a normal aging process of the gas and are a result of plant operation. The operator can eliminate these contaminants on-site with service devices equipped with the cleaning systems. However, a gas quality corresponding to new gas according to IEC 376/60376 cannot be achieved by on-site gas treatment with SF₆ service equipment.

Contamination	SF ₆ Reuse Specification
Air (N ₂ , O ₂)	< 30% by volume
CF ₄	< 5% by volume
H ₂ O	< 1000 ppm _v
HF	< 1000 ppm _v
Oil	< 0.1% by weight
Companion substances	< 5% by weight

- *Special case.* When the used SF₆ gas fails to comply with the electrical standards or to CIGRÉ's recommendations, it is sent for regeneration to new gas according to IEC 376/60376.

- *Exceptional case.* If the used SF₆ fails to comply with the SF₆ reuse specification, the gas is incinerated in an accredited incineration plant.

For the SF₆ regeneration the delivered material must fulfill the so-called SF₆ reuse specification (Table 3). The used SF₆ that satisfies this specification is processed and the new regenerated SF₆ conforms in all aspects with the quality requirements of IEC 376/60376 for new gas.

Decomposition products in SF₆, caused by discharges, react with moisture and air forming toxic and highly corrosive by-products, adversely affecting the surfaces of epoxy resin insulators. This reduces the electrical surface strength that can lead to the loss of pressure, correlated to electrical volume strength.

To avoid faults caused by the degradation of the insulating material, utilities should regularly monitor the quality of SF₆ to prevent faults. Inspection is particularly important during the commissioning of SF₆ equipment to eliminate faults before circuit energization. A change from event- or time-based maintenance to CBM reduces costs and is environmentally friendly. TDW

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