

Application of Fluoride Detection in Early Diagnosis of SF₆ Equipment

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1. Introduction

Sulfur hexafluoride (SF₆) is widely used as an insulating and arc-extinguishing gas in high-voltage power equipment because of its outstanding dielectric strength and chemical stability. Under normal operating conditions, SF₆ gas can self-recover after discharge or high-energy events. However, when H₂O or O₂ are present in the chamber, SF₆ may undergo partial decomposition, generating sulfur dioxide (SO₂) as well as various fluorine-containing byproducts. By analyzing the composition of these decomposition gases, the type of equipment malfunction resulting from discharge or overheating can be identified. In addition, these reactive byproducts also lead to material degradation, accelerated corrosion, ultimately leading to failures of critical components. Therefore, monitoring decomposition products provides a valuable pathway for identifying abnormal events such as partial discharge or overheating at an early stage.

Currently, Taiwan Power Company's maintenance standards adopt SO₂ concentration in SF₆ as a key diagnostic indicator for evaluating the health condition of SF₆-insulated power equipment. To provide sufficiently early warning, Taiwan Power Research Institute (TPRI) has developed an advanced detection method that focuses on water-soluble fluorides in SF₆. By targeting fluorides, this approach enables earlier diagnosis of abnormal conditions in gas-insulated transformers (GIT). The combined monitoring of SO₂ and fluorides leads to a more accurate, comprehensive, and forward-looking assessment of equipment reliability.

2. Development and Application of the Detection Technology

During a routine inspection in 2024, a 161 kV transformer #A was found to have SO₂ concentrations of 6~11 ppmv and was therefore classified as abnormal. To further verify its condition, we extended the investigation to other 161 kV transformers and collaborated with an overseas laboratory for analysis of fluoride ions in SF₆. Results revealed not only abnormalities in transformer #A, but also high fluoride levels in transformers #B and #C. According to diagnostic standards defined in the Journal of Electrical Cooperative Research of Japan (Vol. 54, No. 5), transformer #B exceeded the "Abnormal" threshold (>1 ppmw), while #C reached the "Caution" level (>0.1 ppmw).

Although outsourcing to overseas laboratories provided valuable verification, the process required nearly two months before results were available, delaying maintenance decisions. To overcome this limitation and improve timeliness in equipment management, TPRI developed an in-house analytical method for detecting water-soluble fluorides in SF₆.

Under discharge or overheating, SF₆ decomposes into various reactive fluorides such as SOF₄ and SOF₂. In the presence of moisture, these compounds generate hydrofluoric acid (HF). Using alkaline solution as an absorbent to capture fluorides and HF from SF₆, SF₆ decomposition products were converted into stable fluoride ions in solution. The collected solution is subsequently analyzed using ion chromatography (IC), which allows precise quantification of fluoride levels.

Compared with conventional gas sampling using steel cylinders, which are prone to instability and losses of low-concentration byproducts, the liquid-absorbent sampling technique offers multiple advantages. It provides more stable samples with longer shelf life, reduces logistical constraints in transportation, and achieves a detection limit as low as 0.01 ppmw with strong reproducibility. Validation tests on samples from transformers #B and #C demonstrated excellent consistency with overseas laboratory results, confirming the accuracy and reliability of the in-house method.

Following the detection of anomalies in transformers #A, #B, and #C, on-site internal inspections were conducted. Findings included deposits of black powder, sulfuration of OLTC (On-load tap changers) silver-plated

contacts, and corrosion of insulating boards (Figure 1). These conditions reflected varying levels of overheating in the transformer cores. Notably, the severity of deterioration showed a strong correlation with both SO₂ and fluoride concentrations. More importantly, fluoride detection revealed abnormalities earlier than SO₂ monitoring, enabling the company to initiate timely maintenance strategies before a significant malfunction occurred.

The inspection results confirmed that this method provides effective, non-intrusive monitoring without requiring equipment shutdown or disassembly, making it a practical and efficient tool for early diagnosis of SF₆-insulated power equipment.



Source: Data compiled in this study

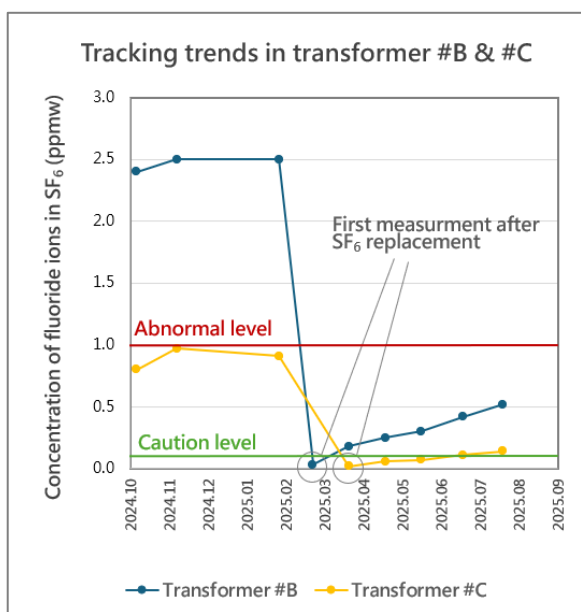
Figure 1. Comparison of on-site internal inspection findings and laboratory results

To further improve efficiency, our laboratory has automated the sample injection process. This automation enables 24-hour batch analysis, substantially boosting processing capacity and preparedness for routine inspections. A survey of 22 transformers in northern Taiwan has already been completed, demonstrating the

feasibility of this method for large-scale monitoring of SF₆-insulated equipment.

Additionally, for abnormal transformers, monthly monitoring was performed after SF₆ gas replacement. The results (Figure 2) showed that fluoride concentrations in transformers #B and #C initially dropped sharply after

replacement but gradually increased from the first month onward. This trend, closely resembling patterns seen in dissolved gas analysis of transformer oil, suggests two possible sources: (1) residual decomposition gases adsorbed in the insulating paper being slowly released into the new SF₆, and (2) persistent overheating of the transformer core continuing to decompose SF₆. This phenomenon highlights the sensitivity of the fluoride detection method to dynamic changes in gas composition and provides valuable insights into the real-time condition of equipment. By enabling continuous tracking, the method equips the company with a reliable tool for monitoring GIT abnormalities.



Source: Data compiled in this study

Figure 2. Tracking water-soluble fluoride ion trends in transformers #B and #C

3. Conclusion and Outlook

This water-soluble fluoride detection technology has proven to be an effective and critical diagnostic indicator for SF₆-insulated equipment. When combined with SO₂ monitoring, it provides both earlier detection and a more comprehensive assessment of abnormal events and their severity. The strong correlation between laboratory results and field inspection findings demonstrates the reliability of this method. Furthermore, its non-intrusive characteristic significantly improves maintenance efficiency, reducing downtime while maintaining safety standards.

Looking forward, we aim to continue accumulating operational data from a broader range of equipment and integrating these data into predictive maintenance models. By combining trend analysis with diagnosis models, we expect to establish a more robust health monitoring platform. This method can also potentially be expanded to other types of SF₆-insulated equipment, offering broader applications across the power industry. Ultimately, this advancement will enhance the long-term stability, efficiency, and safety of the power grid, while providing utilities with a forward-looking approach to equipment lifecycle management.