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A Review of the Correlation Between SF_6 Decomposition Products and Partial Discharge in Gas-Insulated Switchgear

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Abstract: ***Gas-insulated switchgear (GIS) relies on sulfur hexafluoride (SF_6) due to its superior dielectric and arc-quenching characteristics. However, partial discharge (PD) activity within GIS leads to SF_6 decomposition, forming gaseous by-products that serve as diagnostic indicators. This technical review synthesizes literature review linking specific PD types-such as corona, voids, moving particle, and floating electrodes-with corresponding SF_6 breakdown products like SO_2, SOF_2, SO_2F_2, and CF_4. Emphasis is placed on correlating these chemical signatures with defect types to enable early fault detection and condition-based maintenance. The paper also identifies limitations in current diagnostic frameworks and proposes future research incorporating multi-parameter analysis and machine learning models.***

Keywords: SF_6 decomposition, partial discharge, gas-insulated switchgear, fault diagnostics, predictive maintenance

1.Introduction

Demand of high dependable high voltage transmission system has been accelerating the universal use of gas insulated substations (GIS) and gas insulated switchgear (GIL). Although they are very reliable, the failures of GIS may cause catastrophic outage and expensive repairs. Experience in the field shows that long-term insulation degradation is the major precursor of GIS failures, and it is mainly due to the activity of partial discharge. Marking partial discharge will not instantly produce a breakdown, but it will speed up insulation aging and start chemical reactions that will break down SF6 gas. The detection of PD activity and SF6 decomposition products are a chance to detect faults and perform preventive maintenance at an early stage before the catastrophic failure.

2.Definition and Characteristics of Partial discharge

2.1 Definition of Partial Discharge

The partial discharge is defined as localized electrical discharge that partially bridges the insulation between the conductors is known as partial discharge and may or may not occur around a conductor. In contrast to total breakdown, PD takes place on a limited area including gas bubbles, edges of sharp electrodes, or contaminated surfaces.

2.2 Causes of Partial Discharge in Gas insulated Switchgear

The sources of partial discharge in gas insulated systems typically are generated from;

- Metallic protrusions on conductors or enclosures
- Free-moving metallic particles introduced during manufacturing or installation
- Surface contamination (dust, moisture, or by-products)
- Insulation defects in solid spacers
- Void formation within solid insulation

Each defect geometry creates a unique electric field distribution, leading to characteristic PD behavior.

3.Types of Partial Discharge in SF_6-Insulated Systems

3.1 Corona Discharge

Takes place at acute points or depressions in non-uniform electric fields. Corona discharges are low but sustained in nature, and results in the gradual breakdown of SF6.

3.2 Surface Discharge

It develops between solid insulation and SF6 gas, which in most cases is caused by spacer contamination or abnormalities.

3.3 Internal Discharge

Internal Discharge takes place in empty spaces or holes in solid insulation. The effects of such discharges are especially destructive because of localized heating and chemical degradation.

3.4 Particle initiated discharge

Particle initiated discharge is another phenomenon occurring in the atmosphere. Induced by free metallic particles moving under the influence of electric field which intermittently and strongly triggers PD activity.

3.5 PD Cumulative effect Formula

A robust diagnostic model relates PD characteristics (pulse magnitude, repetition rate) to decomposition products.

Equation 1: PD Cumulative Effect

$$Q_{sec} = Q_{avg} \times N$$

Where:
- Q_{sec}: discharge magnitude per second (pC/s)

- Q_{avg}: average discharge per pulse (pC)
- N: pulses per second

4.Alternative Methods for Partial Discharge Identification

4.1 Electrical Detection Techniques.

- Conventional PD IEC 60270.
- Partial discharge (PRPD) pattern analysis Phase-resolved.

4.2 Electromagnetic Methods

- Ultra-high frequency sensors (UHF).
- Transient earth voltage (TEV) detection.

4.3 Acoustic Emission Methods

- Identification of PD-induced pressure waves.
- Helpful in finding points of discharge.

4.4 Methods of chemical and gas analysis.

SF6 decomposition analysis Gives evidence of PD activity indirect but cumulative. Gas analysis is also one of them, and it is especially useful to monitor the long-term conditions since the PD effects are combined over time. Decomposition of SF6 Mechanism Under Partially Discharge. The chemical stability of SF6 is preserved at normal temperature situations, but PD brings high-energy electrons which dissociate the SF6 molecules, thus creating reactive fragments of SF6 and free fluorine atoms. Secondary reactions take place in the presence of trace moisture, oxygen or organic substances resulting in production of detectable decomposition by-products. Some of the common decomposition products are: SOF2 SO2F2 SO2 HF CF4 The nature and level of such by-products is determined by discharge energy, time and nature of defects. PD and SF6 Decomposition

5.Experimental Studies

The lab experiment of PD Defects simulation was conducted as follows:

5.1 Laboratory Simulation of PD Defects Finings

It has been reported that experimental findings indicate:

- **Corona discharge** - production of SOF2 is predominant and low HF is dominant.
- **Surface discharge** - increased SO2F2 and SO2 because of the use of solid insulation materials.
- **Particle discharge** - sudden rise of numerous by-products because of high-energy intermittent discharges.
- **Internal discharge** - slower decomposition of gases, but devastating local insulation damage. These tendencies point to the fact that certain signatures of SF6 breaking down can be associated with PD processes.

6.PD Type and SF6 Decomposition Correlation

In summary, the correlation is as follows:

Table 1: PD Diagnoses significance

PD Type	Dominant Decomposition Products	Diagnostic Significance
Corona	SOF_2, trace HF	Early-stage defect
Surface	SO_2F_2, SO_2	Spacer aging/contamination
Particle	SOF_2, SO_2F_2, CF_4	High-risk defect
Internal	Low gas output, severe solid damage	Critical insulation failure

Table 2: SF6 Decomposition levels during PD conditions

PD Type	SOF_2	SO_2F_2	SO_2	CF_4	CO_2
Corona	High	Medium	Low	Very low	Very low
Surface	Medium	High	Medium	Low	Low
Internal	Medium	Medium	Medium	Low	Low
Particle	High	High	Medium	Medium	Medium

This correlation gives scientific foundation of pre-failure rectification to make the maintenance action given before it is too late to repair the damage.

7.Application to Pre-Failure Rectification on GIS

With the ongoing surveillance of the SF6 breakdown products and their comparison with established PD signature patterns:

- Defect type preliminary identification is possible without system shutdown.
- Maintenance can be condition-based rather than time-based
- Risk of catastrophic failure is significantly reduced

Gas analysis with UHF or acoustic PD detection also can be integrated with gas analysis and enhances the accuracy of the diagnosis.

8.Research and Future Work

Although numerous**.** Experimental Studies and Correlation Data studies have been made such as**:**

Study A – Lu & Liu (2015):

PD tests on SF_6 GIS simulated ground discharge. SF_6 decomposed into **SOF_2, SO_2, S_2OF_{10}**, with concentrations varying over PD duration and intensity.

Study B – Yang et al. (2017):

Experimental correlation of SF_6 decomposition under PD from free metal particles and metal protrusion. Decomposition varied significantly with pressure and defect type. SOF_2 and SO_2F_2 were dominant.

Study C – Tang et al. (2017):

Decomposition under four DC PD defect types showed CF_4, CO_2, SO_2F_2, SOF_2, and SO_2. Concentration ratios were effective for PD type recognition.

Study D – Cho et al. (2020):

Long-term surface PD experiments in SF_6 showed linear correlation between PD energy and generation of SO_2F_2, SOF_2, and SO_2.

There are still challenges such as;

- Signatures of both mixed PD conditions, mixed and underlying decomposition.
- Water and oxygen impurities.
- Extensive field test in actual current conditions.

The next round of research should be on multi-parameter diagnostic models of PD patterns, gas analysis, and machine learning to categorize the faults better.

9.Conclusion

This review provides critical insights for the development of more accurate diagnostic tools for GIS health monitoring and supports the transition from time-based to condition-based maintenance models in high-voltage systems. It highlights the strong diagnostic potential of SF_6 decomposition by-products in identifying the types and severities of partial discharge within GIS systems. By mapping specific chemical signatures to PD categories, the study establishes a foundation for early fault detection and condition-based maintenance strategies. Future research should integrate gas analysis with advanced diagnostic tools, including machine learning, to enhance prediction accuracy and system reliability.

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