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Formation and Removal of Silver Sulphide on Oltc Contacts: Field Investigations, Practical Approaches and Maintenance Perspective

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FORMATION AND REMOVAL OF SILVER SULPHIDE ON OLTC CONTACTS: FIELD INVESTIGATIONS, PRACTICAL APPROACHES AND MAINTENANCE PERSPECTIVE

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***Abstract*—These instructions give you guidelines for preparing full text papers for the International Colloquium Transformer Research and Asset Management. Use this document as a template if you are using Microsoft *Word* 6.0 or later. Otherwise, use this document as an instruction set. Define all symbols used.**
***Index Terms*—Three to six keywords, separated by commas.**

I. INTRODUCTION

On-load tap changers (OLTCs) are critical components in power transformers that enable voltage regulation under load conditions. The selector switch contacts in these tap changers are typically silver-plated to ensure reliable electrical conductivity and minimise contact resistance [1]. However, the formation of silver sulphide (Ag_2S) on these contacts has emerged as a significant reliability concern, leading to increased maintenance costs and potential transformer failures.

Silver sulphide formation occurs when corrosive sulphur compounds in transformer insulating oil react with the silver plating on selector contacts. This process creates semi-conductive films and particles that degrade both contact performance and oil dielectric properties [2]. Recent field investigations have revealed that OLTC design factors, particularly the extent of silver coating usage, significantly influence the susceptibility to corrosion [9]. The phenomenon has gained increased attention following several high-profile OLTC failures linked to silver sulphide corrosion, particularly after oil reclamation processes that inadvertently introduced or concentrated corrosive sulphur species within the oil.

This paper provides a comprehensive examination of silver sulphide formation mechanisms, presents effective cleaning methodologies, establishes best practices for preventive maintenance, and incorporates recent findings on design-related factors that influence corrosion susceptibility. The analysis is based on recent research findings, field experience, and industry standards to offer practical guidance for addressing this critical maintenance challenge.

II. CHEMICAL MECHNISMS OF SILVER SULPDIFE FORMATION

A. Reaction Chemistry

The formation of silver sulphide on OLTC contacts is primarily driven by the reaction between silver (Ag) and corrosive sulphur species present in transformer oil. The fundamental reactions include:

With elemental sulphur (S_8):
$16Ag + S_8 \rightarrow 8Ag_2S$
With dibenzyl disulfide (DBDS):
$4Ag + C14H14S2 \rightarrow 2Ag2S + C14H14$

Dibenzyl disulfide (DBDS) represents one of the most problematic corrosive sulphur compounds, with field investigations showing concentrations as high as 140 ppm correlating with severe silver sulphide formation [9].

These reactions are thermodynamically favourable and proceed readily even at elevated selector switch contact temperatures typical in transformer environments generally caused by emergency operating conditions or intermediate faults within the selector switch [3]. Research has shown that concentrations as low as a few

mg/kg of elemental sulphur in oil can initiate significant corrosion on the relatively small surface area of selector contacts [4].

B. Sources of Corrosive Sulphur

Corrosive sulphur in transformer oil can originate from several sources:

- Oil Reclamation Processes: Adsorbent reactivation during oil reclamation can leave residual elemental sulphur, making this a primary source of contamination [5].
- DBDS Formation: Dibenzyl disulfide can form through degradation of certain oil additives or contamination during manufacturing and processing [9].
- Degradation Products: Certain organo-sulphur compounds can decompose or concentrate during oil processing, producing reactive sulphur species.
- External Contamination: Atmospheric sulphur compounds, including hydrogen sulphide (H_2S), can enter the transformer system and contribute to corrosion [6].
- Material Degradation: Degradation of sulphur-containing materials within the transformer can release corrosive species into the oil.

C. Formation Kinetics and Design Influence

Studies on elemental sulphur (S_8) removal indicate that S_8 interactions with silver are chemically activated through chemisorption processes. The high reactivity of S_8 toward silver under typical service conditions explains the rapid deposit formation observed after oil reclamation that leaves residual sulphur [5]. The reaction is species-specific, with silver showing much higher reactivity than copper surfaces under identical conditions.

Field investigations have revealed that the extent of silver coating in OLTC design significantly influences corrosion severity. Case studies show that OLTCs with silver coating on all fixed contacts and current collector rings experience widespread silver sulphide formation, while designs using copper collector contacts without silver coating show minimal corrosion even in the presence of DBDS [9].

III. DESIGN FACTORS INFLUENCING SILVER SULFIDE FORMATION

Recent field investigations have identified key design factors that influence silver sulphide formation susceptibility [9].

A. Collector and Fixed Contact Material Selection

Silver-Coated Contacts: The presence of silver-coated contacts in tap selectors represents the primary vulnerability factor. Elemental sulphur (S_8) shows extremely high reactivity toward silver, leading to rapid silver sulphide formation [9]. Material Alternatives: Improved designs utilise copper contacts without silver coating for collector rings and fixed contacts, significantly reducing corrosion susceptibility while maintaining adequate electrical performance [9].

B. Support Structure Design

Material Selection: The choice of support structure materials affects overall corrosion resistance. Fiberglass supports with modified designs (rounded edges versus sharp edges) can be part of improved designs to eliminate sulphur corrosion issues [9]. Surface Considerations: Sharp edges and complex geometries can promote deposit accumulation and surface tracking, making simplified designs preferable [9].

IV. EFFECTS ON TRANSFORMER PERFORMANCE AND NON-INVASIVE DETECTION

A. Electrical Performance Degradation

Silver sulphide formation significantly impacts OLTC performance through multiple mechanisms:

- Contact Resistance Increase: Ag_2S deposits create a semi-conductive layer that increases contact resistance, leading to higher I^2R losses and potential overheating [7]. Field measurements have shown resistance variations up to 1.7% between different tap positions in affected transformers [8].
- Dielectric Strength Reduction: When Ag_2S particles disperse in the oil, they increase oil conductivity and reduce breakdown voltage, creating conditions for dielectric failure [2]. Silver sulphide particles can become pathways for electrical current, leading to flashovers and severe damage [8].

- Field Distortion and Surface Tracking: Finite element analysis has shown that Ag_2S deposits and suspended particles distort local electric fields, reducing voltage margins between adjacent contacts and increasing flashover risk [2]. Additionally, silver sulphide formation can cause surface tracking on solid insulation support surfaces [9].

B. Non-Invasive Diagnostic Techniques

Recent advances in non-invasive condition assessment provide powerful tools for early detection of silver sulphide problems:

a) DC Winding Resistance Measurement

This non-invasive test applies controlled DC current to transformer windings and measures resulting voltage to calculate resistance [8]. Key benefits include:

- Early Detection: Provides insights into contact condition without opening the transformer
- Temperature Correction: Requires careful temperature correction for accurate interpretation
- Trend Analysis: Enables tracking of resistance changes over time
- Case Study Evidence: Field measurements showing 1.7% resistance variation correlated with silver sulphide accumulation [8]

b) Dissolved Gas Analysis (DGA)

DGA provides critical information about thermal and electrical faults related to silver sulphide formation [8]:

- Key Gases: Hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO), and carbon dioxide (CO_2)
- Duval Triangle Analysis: Categorizes gas concentrations to identify fault types (T1: <300°C, T2: 300-700°C, T3: >700°C)
- Warning Signs: Appearance of acetylene can serve as an early warning of severe contact problems [9]
- Thermal Indication: DGA can reveal thermal problems across transformer phases with varying severity levels [8]

c) Integrated Diagnostic Approach

Combining multiple diagnostic techniques provides comprehensive assessment capabilities:

- Correlation Analysis: DC (static and dynamic) winding resistance measurements combined with DGA results and oil analysis for corrosive sulphur provides accurate assessment of selector switch contact status [8]
- Proactive Monitoring: Integration of diagnostic methods allows early identification of potential issues, enhancing reliability and extending transformer lifespan [8]
- Design Consideration: Understanding OLTC design features (silver coating extent, contact materials) enhances diagnostic interpretation [9]

V. CLEANING METHODS AND PROCESDURES

A. Mechanical Cleaning Considerations

Mechanical cleaning methods should be used judiciously due to the risk of damaging silver plating: Gentle Abrasion using fine abrasives or polishing compounds (varying grit level starting at 400 and finishing at 800) may be necessary for heavy deposits but must be followed by thorough cleaning to remove residues.

B. Recommended Integrated Cleaning Procedure

Based on synthesis of current research and documented field practices:

1. System Isolation: De-energize and isolate the transformer and OLTC following established safety protocols.
2. Comprehensive Baseline Assessment:
   - Oil sampling and analysis for DBDS, elemental sulphur, and standard oil properties
   - DC winding resistance measurement across all tap positions
   - DGA analysis with Duval Triangle interpretation
3. Visual Documentation: Open OLTC under controlled clean conditions and document deposit extent and location with particular attention to design-specific vulnerable areas.
4. Contact Cleaning: mechanical cleaning of contaminated contacts using appropriate abrasive paper.
5. Comprehensive Verification:
   - Re-measure contact resistance across all positions
   - Verify oil properties meet specifications
   - Perform operational tests before returning to service
   - Establish ongoing monitoring protocol

VI. CASE STUDY

The transformer 220/66/22kV 140MVA was manufactured in 2005. The tap changer was a in-tank style with the selector switch within the main tank oil. The tap changer is rated for 500A. The transformer mineral oil has corrosive sulphur, and the oil was not passivated. The measured DBDS level within the transformer is 176ppm and no elemental sulphur was detected. The transformer had a bag for the oil preservation system but was faulty hence oil interface was contacting oxygen. It was also known that the selector switch collector ring contacts were silver plated from the pre vapour phase inspection photos with the transformer factory.

As part of the transformer routine maintenance plan DC winding resistance was undertaken. The DC winding resistance result (after temperature correction) indicates an increase of resistance across all three phases tapping ranges. The B phase winding had the highest increase of resistance of up to 1.87%, refer to figure 4-6.

By reviewing and evaluating the historical transformer temperatures, loading data and ambient it was found that the recorded top oil temperature was not reliable as it indicated temperatures much lower than the ambient temperature over long periods of time. The ambient temperature records were verified with local metrology data indicating correct accuracy. The ambient temperature records on site indicated maximum of 55 deg C with several heat waves of 40 deg C weather lasting for a week. This is why we estimated oil temperatures would be 55-70 deg C top oil based on the ambient temperature and loading. With the addition of the selector switch contact gradient to the oil of 5K for the given loading would then give the selector switch contact temperature in the range of 60-75 deg C.

Historical DGA results was reviewed. The historical results revealed a T1, T2 and T3 fault code. The most recent result indicated a liner increase in both ethane and methane, although the levels where not extreme 37ppm and 140ppm respectively, suggesting problem indicating “hot metal” in transformer. Figure 1 illustrates the historical DGA results against Duval Tricangle.

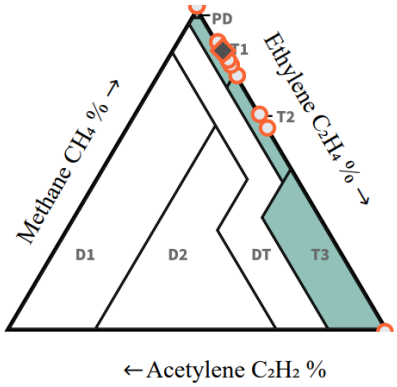


Figure 1 DGA Duval triangle historical results

Considering the transformer had silver plated selector switch contacts, increase DC winding, combined with high level of DBDS, the defective oil preservation system, no passivator within the oil and historical DGA results it was decided to inspect the selector switch to understand its condition.

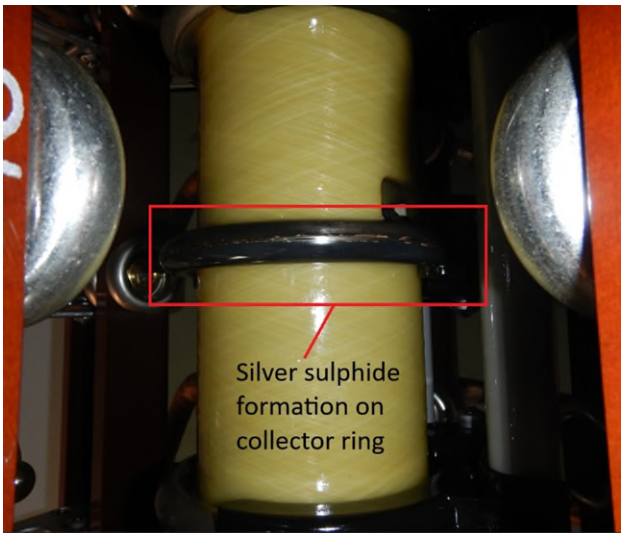


Figure 2 Selector switch contact with silver sulphide

An inspection of the selector switch found that the collector ring on all three phases had silver sulphide deposits on the silver-plated ring, refer to figure 2. There were also deposits of silver sulphide found toward the bottom of the main tank underneath the selector switch. The selector switch contacts that had silver sulphide was mechanically cleaned using abrasive paper starting with 400 grit gradually increasing the grit to 800 of the abrasive paper. Figure 3 shows the cleaned selector switch contacts. The selector switch contacts were then flashed with clean oil with a container to catch the oil. The silver sulphide at the base of the tank was also cleaned up with a wet and dry vacuum. The OLTC was test operated mechanically and electrically to visually confirm the operation of the selector switch moving contact against the fixed contact. The oil preservation system was replaced and the transformer was passivated. The transformer was then placed under vacuum and then filled via a hot oil filtration system. Once the transformer was filled with oil and the oil preservation system was set, oil samples was taken to confirm the condition of the oil was suitable for it to be in-service. The oil results were successful. The transformer had DC winding resistance test redone to confirm the condition. The result improved and correlated with the SAT DC winding test results. Figure 4-6 has the SAT, precleaning and post cleaning DC winding resistance results plotted. The transformer was put back into service with a regular DGA monitoring.

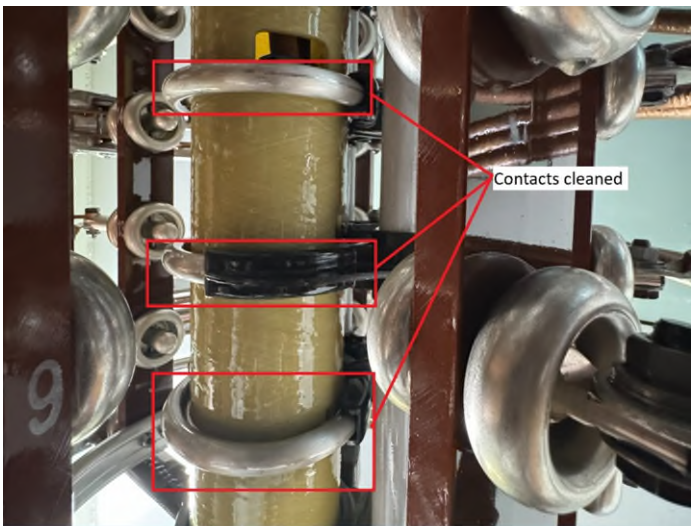


Figure 3 Selector switch contacts cleaned

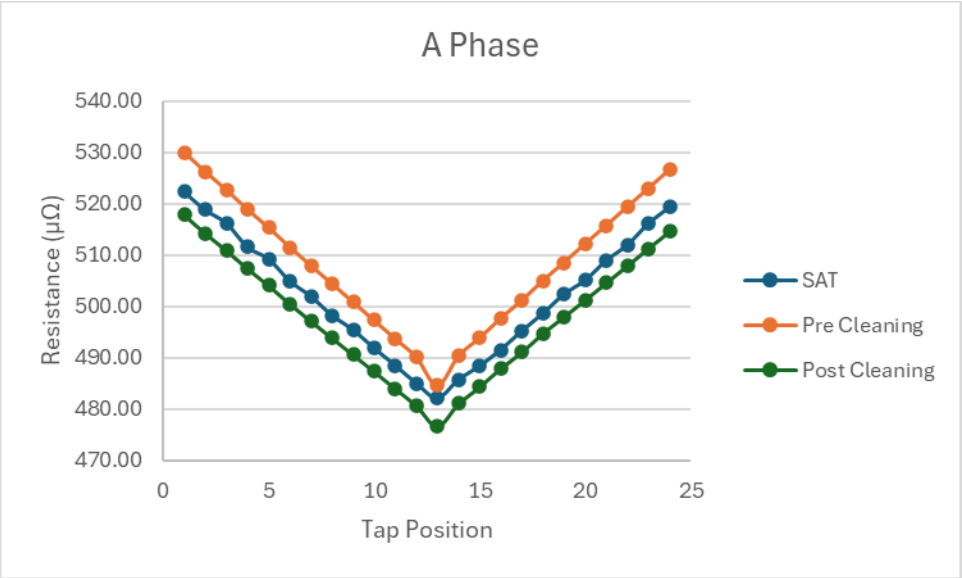


Figure 4 A Phase DC winding resistance results

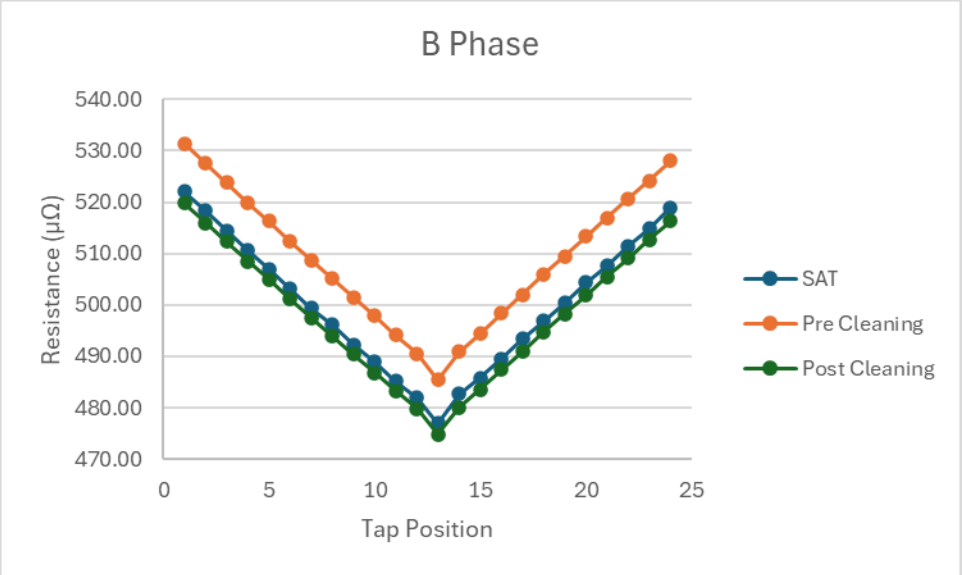


Figure 5 B Phase DC winding resistance results

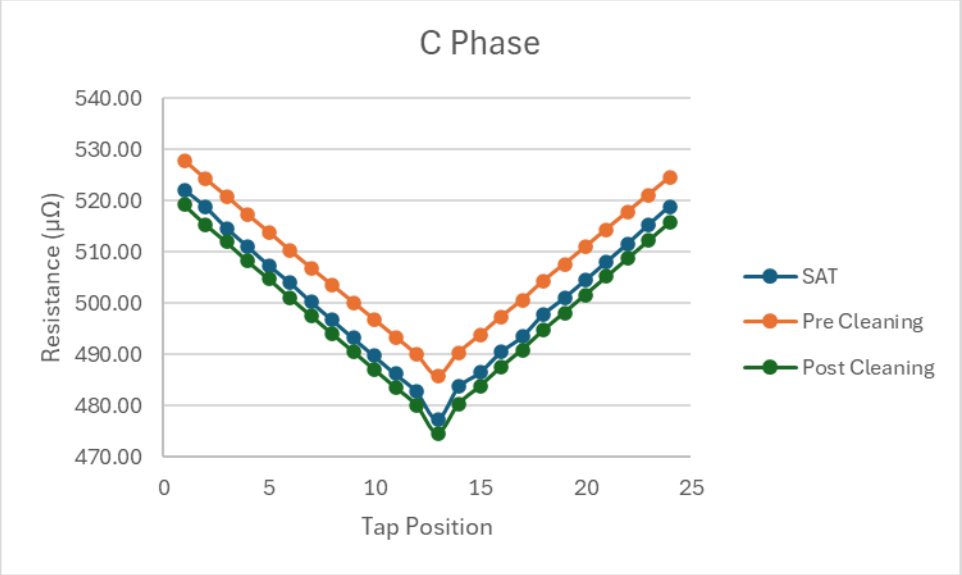


Figure 6 C Phase DC winding resistance results

VII. CONCLUSTION

Silver sulphide formation on OLTC selector switch contacts represents a significant maintenance challenge requiring a comprehensive approach that combines understanding of chemical mechanisms, design factors, effective cleaning procedures, and robust preventive maintenance strategies. Key conclusions include:

- Design Criticality: OLTC design factors, particularly the extent of silver coating usage, represent the most significant factor influencing corrosion susceptibility. Designs with copper contacts without silver coating show dramatically reduced vulnerability.
- Chemical Complexity: Both elemental sulphur and DBDS contribute to silver sulphide formation, with DBDS representing a particularly persistent and problematic compound requiring specialized attention.
- Non-Invasive Diagnostics: Integration of DC winding resistance measurements, DGA analysis, and oil testing provides powerful tools for early detection and monitoring without requiring invasive inspection.
- Remediation Effectiveness: Successful remediation requires both contact cleaning and oil treatment, with effectiveness depending on contamination severity and OLTC design factors.
- Prevention Strategies: The most effective prevention involves design considerations during procurement, combined with proactive monitoring tailored to design vulnerability.
- Standards Evolution: Existing standards provide frameworks for testing and assessment, but continued development is needed to address DBDS-specific issues and design-related factors.

The economic and reliability impacts of silver sulphide corrosion make this a critical area for continued research and development. Utilities should implement comprehensive programs that consider design factors, utilize non-invasive diagnostics, and maintain appropriate monitoring intensity based on OLTC vulnerability. Future OLTC specifications should prioritize corrosion-resistant designs while maintaining electrical and mechanical performance requirements.

Successful management of this challenge requires close collaboration between utility engineers, maintenance professionals, equipment manufacturers, and researchers to ensure safe, effective, and economical solutions that account for both technical and design factors.

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