Identification of Composite Insulator Failures in Service: A Utility Experience

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Abstract: ***High-voltage insulators are critical to the reliability of power transmission systems. This study explores the degradation issues of composite insulators and presents the implementation of Reliability-Centered Maintenance (RCM) at DEWA. Using advanced inspection tools such as UV and IR cameras, hydrophobicity tests, and laboratory analyses, the research identifies defects and outlines preventive strategies. The findings underscore the value of adopting RCM for early detection, enhancing reliability, and optimizing the economic lifespan of insulators.***

Keywords: Composite Insulators, Reliability-Centred Maintenance, UV Inspection, IR Thermal Inspection, Hydrophobicity

1. Introduction

In a world increasingly reliant on uninterrupted power, insulators play a crucial role in transmission systems as providing critical insulation between conductors and towers. Within DEWA's overhead line network, silicon rubber composite insulators are employed due to their numerous advantages including their lightweight nature, ease of handling and cost-effective installation. Moreover, these insulators possess a distinctive hydrophobic property that effectively prevents the formation of water droplets on their surface, thereby enhancing their performance and durability during service.

To maintain high reliability and a long operational lifespan, insulators must have the ability to tolerate both mechanical and electrical stresses. Although these insulators have gone through a series of type and factory acceptance tests to ensure compliance with design specifications, their performance can still be affected by other factors encountered during installation and service. These factors include quality of workmanship, environmental conditions such as weather and pollution levels, and the manufacturing process. Failure to withstand these factors can lead to an electrical breakdown, such as a flashover or puncture, disrupting power delivery networks and causing financial losses and increased restoration costs for affected lines. Implementing preventive inspection methods based on Reliability-Centred Maintenance (RCM) optimises the lifespan of network insulators. These methods minimise the occurrence of flaws, thereby enhancing efficiency and reliability of power transmission.

2. Process of Defect Identification

DEWA has adopted condition monitoring practices based on RCM to enhance the management of its high-voltage transmission line components, with a particular emphasis on insulators. RCM involves identifying the critical functions of each component, assessing potential failure modes and determining the most effective maintenance strategies to ensure reliable operation. For transmission line insulators, this means systematically evaluating their performance and condition to prevent failures that could lead to service interruptions or safety hazards.

2.1 UV Corona Camera Utilisation

In 2013, DEWA introduced advanced, non-invasive inspection equipment to support this RCM approach. One such tool is the Ultra-Violet (UV) Corona Camera, as shown in Figure 1. This camera is specifically designed to monitor the condition of composite insulators by capturing real-time video and images that reveal corona discharge, sparking and arcing along the transmission lines. These detailed visuals allow DEWA inspectors to pinpoint the exact locations of issues on the insulators, providing crucial data for diagnosing potential problems and planning targeted maintenance interventions.

Figure 1: UV Site Inspection & UV Camera

These inspections are conducted according to an annual RCM plan. Upon identifying abnormalities such as high corona discharge, their severity is categorised based on guidelines outlined from EPRI Technical Update Report Coro-Cam Users Advanced Site Inspection Guide [1]. Depending on the severity level identified, the following two procedures are implemented for further assessment of the affected insulator condition:

2.2 Visual and Close-Up Inspection Techniques

Visual inspection is performed either by capturing close-up photos using a high-resolution Digital Single-Lens Reflex (DSLR) camera for detailed analysis or by physically examining the insulator if the circuit is under outage conditions, or both.

2.3 IR Camera Utilisation

An Infrared Thermal (IR) camera may be used for a follow-up inspection to detect and verify any hotspots. IR cameras use Infrared technology to detect, display and record thermal patterns on surfaces, pinpointing potential hotspots that could lead to significant failures if not promptly addressed.

The following figure illustrates the process flow for the implementation of the described condition monitoring process.

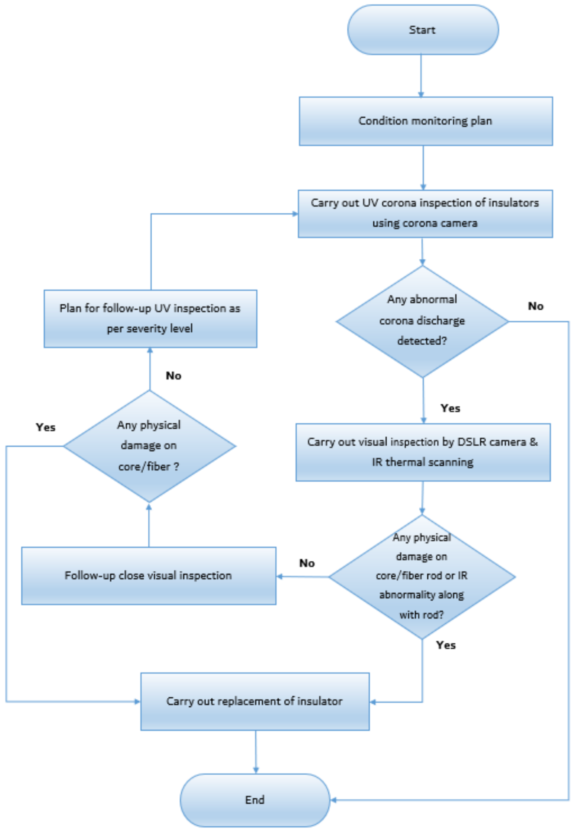

Figure 2: Condition Monitoring Process Flow

3. RCM In Practice: A Case of Site Abnormality

3.1 Corona Discharge Abnormality

Corona discharge is a luminous phenomenon resulting from the ionisation of the air surrounding a conductor when subjected to a voltage gradient that exceeds a critical value. This ionisation causes the air to become de-ionised, releasing excess energy as photons in the UV and visible light ranges, as well as producing audible and radio noise. Ultraviolet scanning is employed to detect these UV emissions, which signify the presence of corona discharge on overhead transmission line components. The formation of corona discharge, caused by partial breakdown of the air due to a high electric field, can lead to significant failures in transmission line systems.

The primary objective of implementing UV corona inspection for overhead line networks is to ensure trouble-free and reliable performance through the early detection of unusual corona activities. This approach aligns with international standards and technologies for transmission line maintenance. As said earlier, DEWA uses the CoroCAM 6 for UV scanning to detect these emissions. Inspections are conducted by UV-certified inspectors; in case of any abnormalities detected during the scan, similar to the one shown in Figure 3, the findings are promptly reported to the relevant engineer. The severity of detected abnormalities is classified according to the EPRI Technical Update Report (CoroCAM Users Advanced Site Inspection Guide, Issue 1.0 – September 2013), as detailed in Table 1 below.

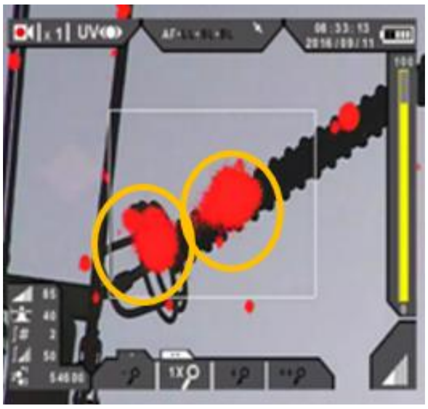

Figure 3: Defective Insulator with High Corona Discharge

Figure 3 depicts a photograph captured by the UV Corona Camera highlighting significant corona discharge activity (indicated in red). According to the EPRI guide, which is integrated into DEWA's quality procedures for overhead lines, this level of abnormality is categorised as "C". Referring to Table 1, this category requires action to replace or repair the metallic fittings of the insulator at the next available opportunity.

Table 1: UV criteria for severity level as per EPRI guide, visual verification & IR follow-up guide

UV Rating	UV Severity/Abnormility	Visual Verification		IR Follow-up	Action
		DSLR Inspection	Close-up inspection		
A Normal	Normal (none or benign) discharge activity	x	x	x	No Action Required
B Intermediate	Intense (concentrated) discharge activity with no visual damage on polymer component of insulator captured by DSLR camera	✓	✓	x	UV monitoring every 6 (six) months to address any damage.
C Serious	Intense (concentrated) discharge activity with minor damaged or degraded polymer component on insulator rod or shed	✓	✓	✓	UV monitoring every 3 (three) months. If a close-up inspection reveals any significant damage or an infrared abnormality along the rod, the insulator needs to be replaced.
D Critical	Intense (concentrated) discharge activity with major damage on polymer component of insulator rod or multiple damaged sheds	✓	✓	✓	Remove from service within 15 working days to avoid sudden mechanical failure.

3.2 IR Scanning Results

Following the identification, a subsequent inspection was conducted using an IR camera to ascertain the presence of hotspots at the same location of the defective insulator. Figure 4 reveals that a hotspot on the defective insulator was detected in a position analogous to the UV findings, specifically at sheds numbered 1 and 5 on the conductor side.

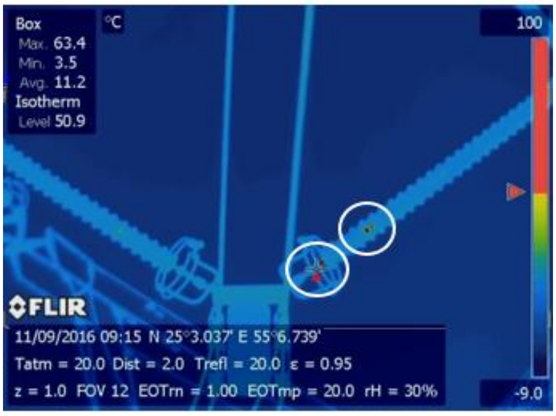

Figure 4: Defective insulator identified using IR Camera

3.3 Close-up Visual Inspection Findings

Based on the data presented in previous sections, an abnormality was identified on the insulator by both the UV & IR Cameras. Hence, it was verified through close inspection using the DSLR camera. Figure 5 illustrates damage in the form of a hole on the core rod housing of the insulator, precisely matching the exact location pinpointed by both IR and UV inspections.

Figure 5: Defective insulator identified using DSLR Camera

3.4 Hydrophobicity Test

Additionally, another testing method was conducted for this insulator, which is the hydrophobicity test that requires temporarily removing the insulator from service. This test assesses the wetting properties of the insulator surface by measuring the contact angle of water droplets or an organic liquid mixture. Figure 6 depicts a hydrophobicity test performed on-site using the spray method on the defective insulator.

Figure 6: Hydrophobicity test on the surface of insulator

The results from the hydrophobicity test were compared to the six hydrophobic classes outlined in Figure 7, where HC1 denotes the most hydrophobic and HC6 the most hydrophilic in accordance with the IEC TS 62073 Standard [3]. Upon comparing Figures 6 and 7, it was evident that water droplets did not remain on the insulator surface, indicating a loss of hydrophobic properties. This categorises the defective insulator under HC6, signifying significant degradation of the insulator.

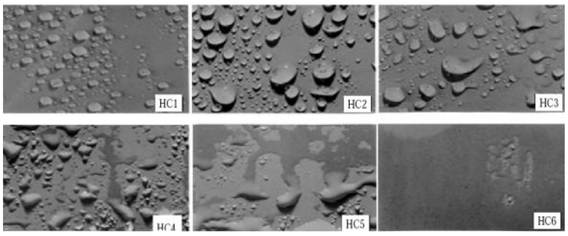

Figure 7: Characteristics of insulator surface HC1-HC6

4. Evaluation and Analysis of Defects

4.1 Laboratory Analysis

All site inspection findings of the insulators collected from the UV camera, the IR camera, the DSLR camera and the hydrophobicity test were to be carefully analysed to establish the targeted condition assessment and then to formulate the appropriate rectification recommendations, such as replacement or surface soft cleaning. Furthermore, a database of insulator defects was established to comprehensively catalog all serious and non-serious defects as detailed in Table 2. This database presents a common brand type of 400kV long rod insulators installed from 2008 to 2009, highlighting significant identified defects. According to the statistics depicted in Figure 8, 52% of these defects were classified as serious.

Table 2: 400kV Long Rod Composite Insulator Defects

Insulator	QTY	Commissioning Date	Expected lifetime (years)	Actual lifetime after defect identification (years)	No of identified Defects	No of serious defects
Brand A – batch 1	3505	2008	25	12	568	266
Brand A – batch 2	3564	2009	25	11	173	119
TOTAL	7069				741	385

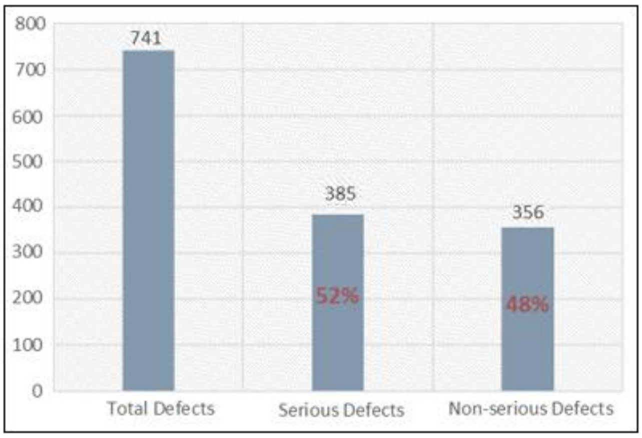

Figure 8: 400kV insulator defect statistics

4.2 Laboratory analysis

To comprehensively understand and analyse the abnormalities observed on composite insulators, especially if these have become a commonly occurring phenomenon on a certain make or due to other common factors such as insulator generation or design, insulator samples can be sent to a laboratory for more in-depth analysis of the defects. Based on an actual case, samples of failed composite insulators were sent to a third-party laboratory for comprehensive in-depth testing and investigation aimed at determining the root cause of the premature degradation of the defective insulators. This investigation was conducted in co-ordination with the Original Equipment Manufacturer (OEM). The following investigation and tests were requested of a third-party specialist by DEWA:

- Hydrophobicity measurements (before and after washing)
- EDX (Energy Disperse X-Ray Analysis) chemical composition
- EDX chemical analysis of contaminant
- FT-IR (Fourier-Transform Infrared Spectroscopy) analysis
- TGA (Thermogravimetric Analysis)
- DSC (Differential Scanning Calorimetry)
- Mechanical test, failing load
- Dissection of failed insulator
- Visual inspection
- Microscopy examination

4.3 Summary of Investigation and Tests Results

Visual inspection of Figures 9, 10 & 11 revealed damage to the housing of composite insulators, particularly affecting the fibre glass reinforced plastic (FRP) and sheds. The observed failures confirmed an abnormal, accelerated ageing process of the silicone rubber materials caused by severe electrical stress and erosion. Examination of the silicone rubber sheath on the FRP showed increased hardness, cracking, embrittlement, chalking, formation of holes and reduced mechanical properties.

Figure 9: Traces of electrical erosion

Figure 10: Ageing of middle and ground side sheds

Figure 11: Silicon rubber FRP damages

The third-party specialist conducted various adopted test procedures and concluded that the premature ageing of the insulators resulted from susceptibility to UV corona discharge, contamination, daily thermal cycles and high electrical stress.

5. Conclusion & Recommendation

Through the implementation of RCM-based inspections specifically tailored for silicon rubber insulators at DEWA, a significant number (more than 5%) of insulators with premature defects were identified before they reached the end of their economic life. These inspections, grounded in methodologies aligned with international standards such as IEC and EPRI, as well as recommendations from leading task forces like CIGRE, proved crucial in identifying potential issues early. Without these specialised inspections, these insulators could have suffered from mechanical failures or electrical breakdowns, potentially leading to circuit forced outages, reduced system flexibility, reliability issues and energy losses.

Therefore, it is highly beneficial for power utilities to adopt RCM-based preventive maintenance practices specifically designed for silicon rubber insulators. Developing RCM expertise in this area, informed by the latest standardised inspection methods and industry best practice, will enhance the reliability of transmission networks. Utilities are encouraged to integrate these practices with their own operational experiences and insights from other utilities to optimise the performance and longevity of their insulator assets.

References

[1] EPRI Technical Update Report (Coro-Cam Users Advanced Site Inspection Guide, issue: 1.0 – September 2013)
[2] EPRI Infrared Thermography Guide, Revision 2 (NP-6973s-Rev.2)
[3] IEC TS 62073 – Guidance on the measurement of hydrophobicity of insulator surfaces