Analysis of Tan Delta Test Results for a 20 kV Incoming Cable of a 30 MVA Transformer at Keramasan Substation

Muhammad Fikri, Pristisal Wibowo, Siti Anisah

Abstract

The 20 kV incoming cable connected to a power transformer is a critical asset for maintaining the continuity of power delivery. This study evaluates the insulation condition of the 20 kV incoming cable of a 30 MVA transformer at Keramasan Substation using tan delta test data. The data were obtained through offline testing with a B2 VLF unit at 0.1 Hz and test-voltage levels of 0.5 U0, 1.0 U0, and 1.5 U0. The analysis considers three indicators: the mean tan delta at U0, measurement stability, and the voltage-dependent increase in tan delta. The tan delta values at U0 for phases A, B, and C were 3.39×10^{-3}, 3.93×10^{-3}, and 2.75×10^{-3}, respectively. All phases remained within the acceptable category. However, phase B recorded a delta tan delta of 4.84×10^{-3}, the value closest to the 5.0×10^{-3} threshold. The cable remains suitable for service, but phase B should be prioritized for retesting, termination inspection, and partial discharge confirmation. These findings support the application of phase-specific, condition-based maintenance intervals.

Keywords: *20 kV cable; tan delta; XLPE insulation; VLF testing; insulation condition assessment*

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Introduction

Distribution-network reliability depends not only on transformer capacity and protection systems but also on the condition of the cables that connect major equipment on the medium-voltage side. At Keramasan Substation, the 20 kV incoming cable of the 30 MVA transformer connects the power transformer to the distribution system. Degradation of the cable insulation can therefore affect the cable itself and disrupt supply continuity in the connected service area.

Cross-linked polyethylene (XLPE) cable insulation may undergo changes in its characteristics because of service age, moisture, electrical stress, temperature, and the condition of joints or terminations. These changes may increase dielectric losses and reduce the insulation's ability to withstand voltage. Because degradation often progresses gradually, diagnostic testing is required to detect early indications before they develop into operational failure.

Tan delta testing is widely used to evaluate the condition of medium-voltage cable insulation. The method assesses dielectric-loss behavior from the ratio of resistive current to capacitive current in the insulation. It provides information about insulation condition without damaging the test object. In field applications, tan delta testing is often combined with very-low-frequency (VLF) excitation because it requires less test power and is practical for highly capacitive cables [2], [5], [6].

Previous studies have shown that the tan delta magnitude, its increase with applied voltage, and data stability during measurement can indicate insulation condition [7], [8], [11]. Nevertheless, interpretation must consider the specific test object because each cable has a different operating history, length, termination configuration, environment, and loading pattern. Therefore, this study not only reports the measured values but also compares them with standard criteria and converts the findings into maintenance recommendations.

This study analyzes the insulation condition of the 20 kV incoming cable of a 30 MVA transformer at Keramasan Substation using tan delta test results obtained at three voltage levels. Its practical contribution lies in using actual maintenance data to identify the phase requiring closer monitoring and to establish a baseline for subsequent testing.

Literature Review

2.1 Medium-Voltage Cables and XLPE Insulation

Medium-voltage cables transmit electrical energy at distribution-voltage levels. IEC 60502-2 classifies cables with rated voltages from 6 kV to 30 kV as medium-voltage cables [1]. XLPE is widely used in 20 kV distribution systems because of its favorable mechanical strength and thermal resistance. Nevertheless, XLPE can degrade under prolonged thermal, electrical, mechanical, and environmental stresses [9].

Insulation degradation is not always immediately visible. Under certain conditions, moisture and microscopic defects may create localized conductive paths that increase dielectric losses. This increase provides the basis for diagnostic testing. Periodic insulation assessment is therefore necessary so that maintenance decisions are based on the actual condition of the cable rather than on asset age alone.

2.2 Tan Delta Testing Concept

Tan delta, or the dissipation factor, represents dielectric losses in an insulation system. Ideally, insulation behaves as a capacitor and the capacitive current is dominant. Real insulation, however, always has a resistive component associated with losses. A larger resistive component produces a higher tan delta value and indicates a greater likelihood of insulation deterioration [10]. The fundamental relationship is given in (1).

$$\tan \delta = I_r / I_c = 1 / (\omega RC) \qquad (1)$$

where I_r is the resistive current, I□ is the capacitive current, ω is the angular frequency, R is the equivalent resistance, and C is the equivalent capacitance of the insulation.

2.3 Calculation Basis for Test Results

To ensure systematic and traceable evaluation, the tan delta data at each voltage level were processed using the mean value, standard deviation, and delta tan delta. The mean value represents the central tendency of the measurements at a given voltage level, as expressed in (2).

$$\tan \delta mean = (\Sigma \tan \delta_i) / n \quad (2)$$

Measurement stability was evaluated using the standard deviation. This parameter indicates whether the readings at a given voltage level remain consistent or fluctuate during the test. The standard-deviation equation is shown in (3).

$$\sigma = \sqrt{[\Sigma(\tan \delta_i - \tan \delta mean)Z / (n - 1)]} \quad (3)$$

Delta tan delta represents the change in insulation response as the applied voltage increases. In this study, it was calculated as the difference between tan delta at 1.5 U0 and 0.5 U0, as shown in (4).

$$\Delta\tan \delta = \tan \delta(1.5\ U0) - \tan \delta(0.5\ U0) \quad (4)$$

2.4 VLF Testing and Assessment Criteria

VLF testing was selected because it can be applied to medium-voltage cables with lower test-power requirements than power-frequency AC testing. IEEE Std 400.2-2013 defines VLF within the range of 0.01 Hz to 1 Hz. Tan delta testing at 0.1 Hz can be evaluated using the mean tan delta at U0, time stability, and differential tan delta or tip-up [2]. The assessment criteria used in this study are summarized in Table 1. General field-testing practices for shielded cable systems also refer to IEEE Std 400-2012 [12].

Table 1. Assessment criteria for 0.1 Hz VLF tan delta testing of PE/XLPE insulation

Condition	**Stability at U0 ($\times 10^{-3}$)**	**Δtan δ ($\times 10^{-3}$)**	**Mean tan δ at U0 ($\times 10^{-3}$)**
No Action Required	< 0.1	< 5	< 4
Further Study Advised	0.1-0.5	5-80	4-50
Action Required	> 0.5	> 80	> 50

Table 1 provides the comparison limits used to determine whether the cable may remain in normal service, requires further study, or requires corrective action. The test results were also interpreted in conjunction with PLN maintenance guidelines so that the recommendations remain relevant to asset-operation requirements [3].

2.5 Related Studies

Several related studies have applied measurement-based, simulation-based, and limit-comparison approaches. Anisah et al. evaluated overcurrent-relay performance on a 60 MVA power transformer using MATLAB simulation [13]. Wibowo and Aryza examined distribution-network quality under unbalanced loading [14]. Putri et al. investigated a passive LC filter for reducing current harmonics [15]. Tharo et al. analyzed the effect of unbalanced loading on electrical-equipment life [16], whereas Rahmaniar et al. examined transient stability on a 150 kV transmission line [17]. These studies provide methodological references because they emphasize technical data, calculations, and operating standards in power-system decision-making.

Research Methodology

This study used tan delta test data obtained on 9 February 2026 during the biennial maintenance of the 70/20 kV, 30 MVA Transformer Bay No. 2 at Keramasan Substation. A descriptive quantitative approach was applied because the numerical test results were analyzed and compared with the assessment limits specified in the adopted standards.

The test object was the approximately 30 m long XLPE-insulated 20 kV incoming cable of 30 MVA Transformer No. 2. Testing was performed with the cable de-energized. Both cable ends were disconnected from the connected switchgear to isolate the response of the cable insulation. The references used were IEEE Std 400.2-2013 for VLF testing, IEC 60502-2 for medium-voltage cable classification, PLN Director's Decree No. 520 for maintenance guidance, SPLN D3.042-1:2025 for cable specifications, and IEEE Std 400-2012 for general field testing of shielded cable systems [1]-[4], [12].

The procedure began with inspection of the B2 VLF test set, installation of protective grounding, connection of the high-voltage output to the cable under test, and connection of the sensing ground to the copper screen. After selecting the XLPE cable configuration with an operating phase-to-ground voltage of 11.5 kV, tan delta measurements were performed at 0.5 U0, 1.0 U0, and 1.5 U0. Each voltage level was measured over 10 cycles to provide data for calculating the mean, stability, and delta tan delta.

The analysis consisted of three stages. First, the tan delta value at U0 was compared with the mean tan delta limit. Second, measurement stability was compared with the standard-deviation limit. Third, delta tan delta was calculated from the difference between the values at 1.5 U0 and 0.5 U0 and compared with the tip-up limit. These three parameters were then used to determine the condition category and follow-up recommendation for each phase.

Table 2. Test object and equipment

Parameter	**Description**
Test location	Keramasan Substation, 30 MVA Transformer Bay No. 2
Test object	20 kV NA2XSY cable, single-core, 400 mmZ, XLPE
Cable length	Approximately 30 m
Cable manufacturer	VOKSEL
Voltage rating	12/20 kV
Conductor	Aluminum
Main test equipment	B2 VLF 0.1 Hz tan delta test set
Supporting equipment	Voltage stabilizer and tool kit

The research process was structured sequentially, beginning with the literature review and ending with the formulation of maintenance recommendations. The start and end points in the flowchart define the boundaries of the study. Figure 1 presents the complete workflow.

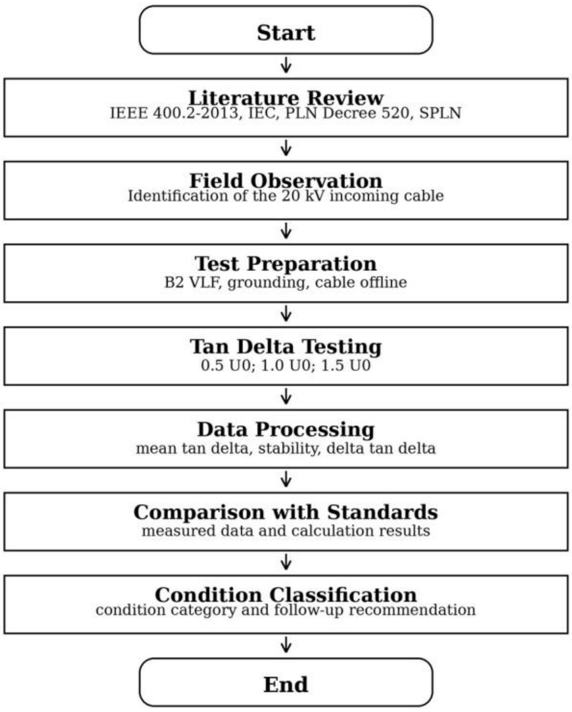

Figure 1. Research flowchart for tan delta testing and analysis of a 20 kV cable

Results and Discussion

Table 3. Summary of 20 kV cable tan delta measurements

Phase	0.5 U0 ($\times 10^{-3}$)	1.0 U0 ($\times 10^{-3}$)	1.5 U0 ($\times 10^{-3}$)	Stability ($\times 10^{-3}$)	Δtan δ ($\times 10^{-3}$)
A	3.15	3.39	3.72	0.07	0.57
B	2.99	3.93	7.83	0.07	4.84
C	2.42	2.75	3.05	0.07	0.63

Table 3 shows that the tan delta values at the operating voltage of 1.0 U0 were 3.39×10^{-3}, 3.93×10^{-3}, and 2.75×10^{-3} for phases A, B, and C, respectively. All three values were below the 4.0×10^{-3} limit and were therefore categorized as acceptable. Phase B, however, had the highest value and was the closest to the threshold, indicating that it requires greater attention than phases A and C.

Delta tan delta was calculated using (4). Phase A produced $3.72 - 3.15 = 0.57 \times 10^{-3}$, phase B produced $7.83 - 2.99 = 4.84 \times 10^{-3}$, and phase C produced $3.05 - 2.42 = 0.63 \times 10^{-3}$. The increase in phase B was substantially greater than those of phases A and C as the voltage rose from 0.5 U0 to 1.5 U0.

Table 4. Insulation-condition assessment and recommended follow-up actions

Phase	Mean tan δ at U0 ($\times 10^{-3}$)	Stability ($\times 10^{-3}$)	Δtan δ ($\times 10^{-3}$)	Interpretation	Follow-up
A	3.39	0.07	0.57	Acceptable	Normal operation; retest in 2-3 years

Phase	Mean tan δ at U0 (×10⁻³)	Stability (×10⁻³)	Δtan δ (×10⁻³)	Interpretation	Follow-up
B	3.93	0.07	4.84	Acceptable, near the limit	Close monitoring; retest in 6-12 months; inspect terminations; perform PD testing
C	2.75	0.07	0.63	Acceptable	Normal operation; retest in 2-3 years

Table 4 indicates that all parameters still satisfy the acceptable criteria. However, the mean tan delta at U0 and the delta tan delta of phase B are the values closest to their respective limits. This condition does not justify removing the cable from service, but it provides a technical basis for closer monitoring of phase B.

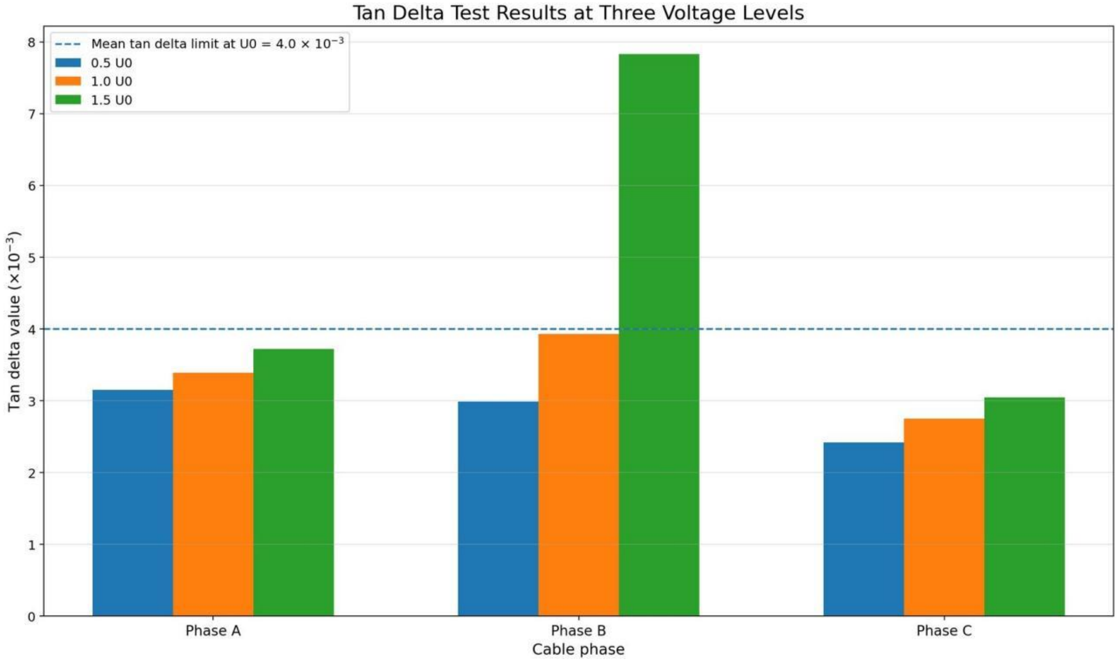

Figure 2. Tan delta test results for phases A, B, and C

Figure 2 illustrates the tan delta trend for each phase. Phases A and C show relatively gradual increases from 0.5 U0 to 1.5 U0. In contrast, phase B shows a pronounced increase at 1.5 U0. This nonlinear pattern is consistent with the findings of Hernandez-Mejia et al., who reported that insulation in the early stages of degradation may exhibit a larger increase in tan delta as the test voltage rises [7], [8].

The stability value for all phases was 0.07×10^{-3}, which is below the 0.1×10^{-3} limit. The measurements for each phase were therefore stable, with no substantial fluctuations observed during testing. This stability supports the conclusion that the overall insulation condition remains acceptable, although phase B still requires attention because its tip-up characteristic is close to the limit.

The different response of phase B may be associated with early-stage water treeing, localized contamination, termination condition, or joint-related effects. Ghaderi et al. demonstrated that cable joints and terminations can influence tan delta measurements, particularly when material condition and temperature vary [10]. Accordingly, the recommended response for phase B is not immediate cable replacement, but retesting, termination inspection, and confirmation through partial discharge testing.

Based on Table 4, maintenance decisions can be differentiated by phase. Phases A and C can serve as baseline data for the next periodic assessment. Phase B remains within the acceptable range but should receive priority in condition monitoring because its tip-up value is close to the threshold. This approach is consistent with multiparameter assessment for diagnosing the ageing condition of medium-voltage cables [11].

Conclusion

The tan delta test results for the 20 kV incoming cable of the 30 MVA transformer at Keramasan Substation show that all phases remain within the acceptable category. The tan delta values at U0 for phases A, B, and C were 3.39×10^{-3}, 3.93×10^{-3}, and 2.75×10^{-3}, respectively, all below the 4.0×10^{-3} threshold. Measurement stability was also satisfactory because all phases recorded 0.07×10^{-3}. For delta tan delta, phases A and C were well below the limit, whereas phase B reached 4.84×10^{-3} and was closest to the 5.0×10^{-3} threshold. Phase B is therefore the main priority for subsequent monitoring.

The practical implication is that the cable can remain in service, but the maintenance strategy should be differentiated by phase. Phases A and C may be used as normal-operation baselines with periodic retesting. Phase B should undergo closer monitoring, retesting within 6-12 months, termination inspection, and partial discharge testing to verify the absence of localized defects in the insulation system. Future studies should incorporate multi-period trend data and partial discharge results to strengthen the cable-condition diagnosis.

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