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Investigating Impulse Voltage Endurance of Transformers:A Detailed Study at Nucon Switchgears

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***Abstract*—This paper presents an in-depth study of impulse voltage testing conducted on transformers at Nucon Switchgears. The research focuses on evaluating the performance and reliability of transformer insulation under high-voltage impulse conditions. The impulse testing procedure, including waveform characteristics and testing methodology, is described in detail. The study also analyzes the test results to assess the insulation's ability to withstand transient overvoltages. Key findings highlight the effectiveness of the impulse tests in predicting insulation failures and ensuring transformer durability. The paper contributes valuable insights into the practical applications of impulse voltage testing and its role in maintaining transformer reliability in real-world scenarios.**

***Keywords*—Impluse Voltage, Overvoltage, Insulation strenght,Transformer testing,Testing methodology, Transformer reliability.**

I. INTRODUCTION

In this rapidly growing world, the drive towards expansion and industrialization is transforming villages into suburbs and suburbs into urban cities at an unprecedented pace. This development, deployment, and evolution are heavily reliant on electricity.

Electricity is fundamentally divided into three main components: generators, transformers, and transmission lines. Generators produce electricity, transformers transfer electrical energy from one alternating-current circuit to one or more other circuits—either stepping up or stepping down the voltage—and transmission lines carry this electricity to various destinations.

Among these, transformers play a crucial role in the efficient distribution and utilization of electrical energy. Ensuring the health and functionality of transformers is essential for maintaining a stable and reliable electrical grid. This is achieved through regular and comprehensive testing.

This paper delves in to provide a detailed account of the impulse voltage test conducted on 25MVA, 132/33kV transformer at Nucon Switchgears, Bhiwadi, in July 2024. This was part of the factory testing that was done before deploying the transformer to MSETCL to ensure the quality, performance, and safety of transformers before they are deployed, verifying that they meet industry standards and specifications. This paper aims to describe the test procedures, analyze the resulting data, and share observations and challenges encountered during the process. This documentation will highlight the importance of such tests in ensuring transformer reliability and performance.

II. LITERATURE REVIEW

Importance of Impulse Voltage Tests:

- Impulse voltage tests simulate lightning strikes and switching surges to ensure the transformer can withstand transient over-voltages without failure.
- These tests are crucial for verifying the dielectric strength of transformers and preventing catastrophic failures in the field.
- Regular impulse voltage testing helps in early detection of potential insulation weaknesses, allowing for preventive maintenance.
- Analysis of the test results provides diagnostic insights into the health and longevity of the transformer.

Procedure:

The impulse voltage test procedure begins with the preparation of the transformer, ensuring it is properly grounded and connected to the test equipment. A standard impulse waveform, typically a 1.2/50 µs wave, is generated using a specialized impulse generator. This waveform is then applied to the high-voltage winding of the transformer. The transformer's response to this impulse is recorded using measuring devices such as oscilloscopes and digital recorders. During the test, both positive and negative polarity impulses are applied to assess the insulation strength under different stress conditions. After each impulse application, the voltage and current waveforms are analyzed to detect any signs of insulation breakdown or partial discharge. The entire procedure is conducted under controlled ambient conditions to ensure the accuracy and reliability of the results.

Measures to Be Taken Before the Test:

- Ensure the transformer is properly grounded and all connections are secure.
- Verify the calibration of testing equipment to ensure accurate measurements.
- Inspect the transformer for any visible damage or defects prior to testing.

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Test Conditions:

- The transformer should be tested under ambient temperature and humidity conditions to avoid external influences on the results.
- Both positive and negative polarity impulses should be applied to assess the transformer's performance comprehensively.

Theory behind the test.

- Basic Impulse Level (BIL)**:** BIL is the highest peak voltage that a transformer insulation can withstand without breaking down. It is a standardized measure used to assess the insulation's strength against transient overvoltages.
- Derivation of BIL: BIL is derived based on the insulation strength required to protect equipment under expected surge conditions. It is determined using statistical analysis of historical surge data, ensuring the equipment can handle extreme but rare voltage spikes.
- Analysis**:** The test results are analyzed to ensure the insulation can endure the impulse voltage without breakdown. Pass criteria are based on the peak voltage withstand capability and the insulation's behavior under impulse stress.

$$V_{BIL} = k \cdot V_{test}$$

where:

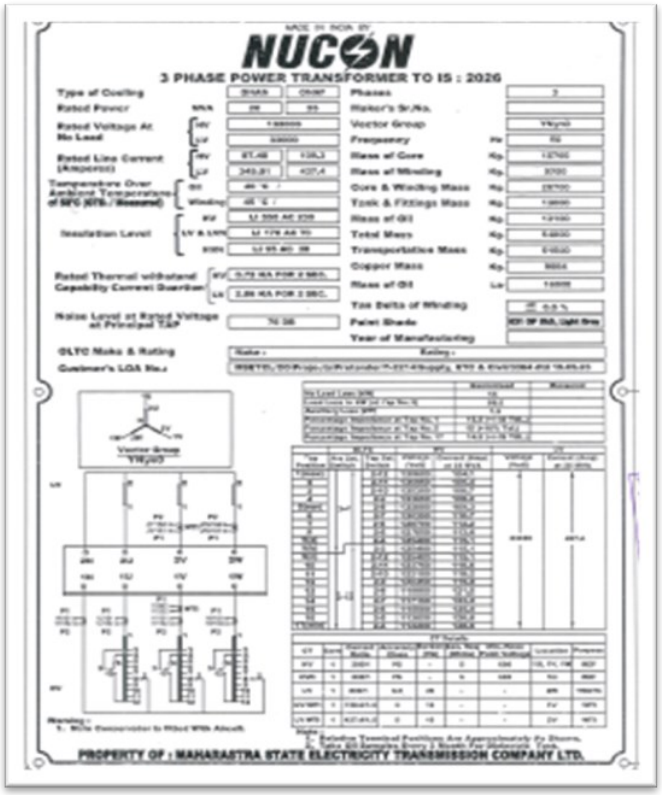
- V_{BIL} is the Basic Impulse Level in volts.
- V_{test} is the test impulse voltage applied, typically measured in volts.
- k is a factor accounting for various conditions such as insulation coordination and safety margins.

For practical purposes, BIL values are usually specified by standards and regulations, such as the IEEE or IEC standards, which provide detailed tables and guidelines. The actual calculation might involve more specific considerations depending on the transformer design and application requirements.

III TESTING SETUP AND PROCEDURE

The transformer details are as per the following.

Rating	:	20/25 MVA
Winding	:	Copper
Voltage Class	:	132/33 KV
vector group	:	YNyn0
Transformer received Dt.	:	16.07.2024
Transformer Testing Dt.	:	17.07.2024 TO 20.07.2024
Rated Current	:	109.35 Amp./ 437.40 Amp.
Frequency	:	50 Hz
Tapping Details	:	+5% to -15% at the stap 1.25% each
Cooling	:	ONAN/ONAF
Ref. Standard	:	IS-2026 & Relevant PO/Technical Specification
Bil Impulse/Power Frequency	:	550/170 kVp



Test Equipment:

- Impulse Generator: Capable of generating standard lightning impulse voltages (1.2/50 µs wave shape).
- Voltage Divider: For accurate measurement of the applied impulse voltage.
- Oscilloscope/Recording Device: To capture and record the waveform of the applied impulse.
- Measuring Transformers: For precise measurement of current and voltage.
- Earthing Arrangements: Proper earthing of the transformer and test equipment to ensure safety and accuracy.
- Test Object:

Nucon Transformer: 25 MVA, 132/33 kV transformer, prepared and connected as per standard test configurations.

- Test Environment:
  - Controlled Conditions: The test should be conducted in a controlled environment to prevent external interferences.
  - Safety Measures: Proper safety protocols and barriers to protect personnel and equipment.

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Testing Procedure

- Preparation:
  - Inspection: Inspect the transformer for any visible damages and ensure it is properly dried and oil-filled.
  - Connection: Connect the transformer to the impulse generator using appropriate connections and ensure all connections are secure.
  - Earthing: Ensure all earthing connections are properly made.
- Calibration:
  - Calibration of Equipment: Calibrate the impulse generator and measuring devices to ensure accurate readings.
  - Wave Shape Verification: Verify the 1.2/50 µs wave shape of the impulse generator by applying it to a standard load.
- Application of Impulse:
  - Polarity: Apply both positive and negative polarity impulses to each winding.
  - Number of Impulses: According to IS 2026 Part III, typically 15 full-wave and 5 chopped-wave impulses are applied.
  - Voltage Levels: Apply impulse voltages at 75%, 100%, and 115% of the Basic Insulation Level (BIL) specified for the transformer.
- Measurement:
  - Recording Waveforms: Use the oscilloscope to record the waveform of each applied impulse.
  - Data Collection: Collect data on peak voltage, rise time, tail time, and any oscillations or distortions.
- Observation:
  - Waveform Analysis: Analyze the recorded waveforms for any deviations or abnormalities.
  - Physical Inspection: Inspect the transformer for any signs of damage, such as insulation breakdown or physical deformation.
- Criteria for Acceptance:
  - Waveform Compliance: The impulse waveforms should conform to the 1.2/50 µs wave shape without significant deviations.
  - No Damage: The transformer should not exhibit any signs of damage or insulation failure.
  - No Abnormalities: There should be no abnormal oscillations or distortions in the recorded waveforms.

IV ANALYSIS OF IMPULSE TESTING WAVEFORMS

Test Results Overview

The impulse testing of the 25 MVA 132/33 kV Nucon Transformer was conducted according to the sequence and criteria outlined in IS 2026 Part III. The results of the testing are found to be satisfactory. The following is a detailed analysis of the waveforms recorded during the tests as per the Table 1.

TABLE 1: DETAILS OF WAVEFORMS APPLIED

Sr. No.	Sequence of Application	Specified Voltage kVp		Criteria as per IS:2026 Part-III
		HV Winding	LV Winding	
1	One reduced LI Wave 50 to 70% of BIL	275 to 385	85 to 119	T1 - 1.2µs ± 30% T2 - 5µs ± 20% Tc - 2 to 6 µs 3% of BIL
2	One Full LI Wave 100% of BIL	550	170	
3	One reduced Chopped Wave 50 to 70% of BIL	302.5 to 423.5	93.5 to 130.9	
4	Two Full Chopped Wave 110% of BIL	605	187	
5	Two Full LI Wave 110% of BIL	550	170	

Waveform Analysis

1. One Reduced LI Wave 50 to 70% of BIL

- Specified Voltage:
  - HV Winding: 275 to 385 kVp
  - LV Winding: 85 to 119 kVp
- Criteria:
  - T1 (Front Time): 1.2 µs ± 30%
  - T2 (Tail Time): 5 µs ± 20%
  - Tc (Chopped Time): 2 to 6 µs (3% of BIL)

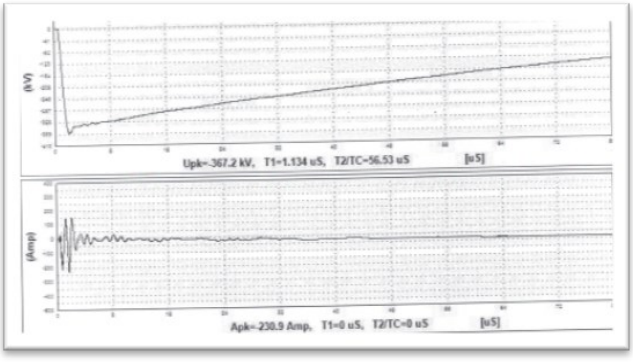

Fig.1: Reduced Lightening Impulse Wave 50 to 70% of BIL (HV)

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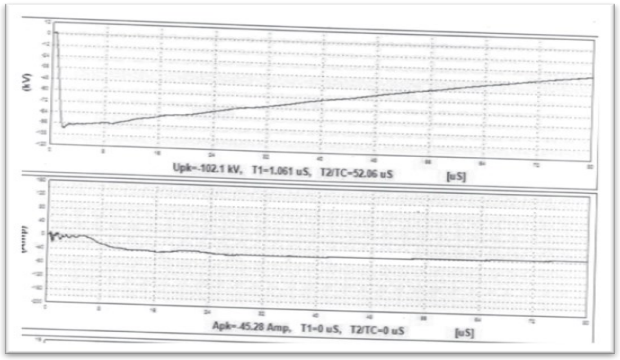

Fig.2: Reduced Lightening Impulse Wave 50 to 70% of BIL (LV)

Analysis:

- The waveform showed a smooth rise and fall within the specified front and tail times.
- No significant oscillations or distortions were observed.
- The applied voltage and the recorded waveform parameters (T1, T2, Tc) were within the acceptable limits specified.

2. One Full LI Wave 100% of BIL

- Specified Voltage:
  - HV Winding: 550 kVp
  - LV Winding: 170 kVp

- Criteria:
  - T1 (Front Time): 1.2 µs ± 30%
  - T2 (Tail Time): 5 µs ± 20%
  - Tc (Chopped Time): 2 to 6 µs (3% of BIL)

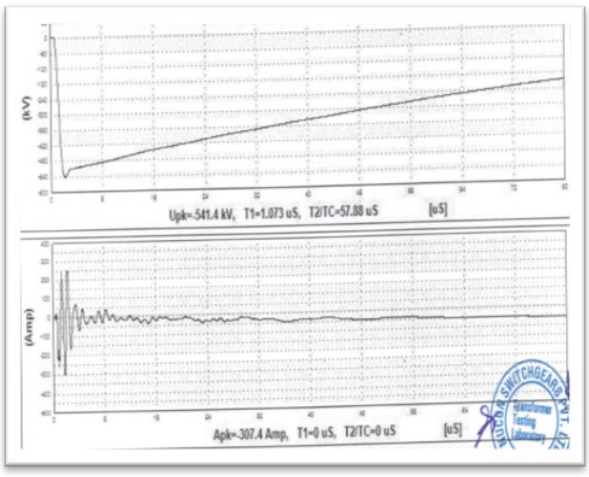

Fig.3: Full Lightening Impulse Wave 100% of BIL (HV)

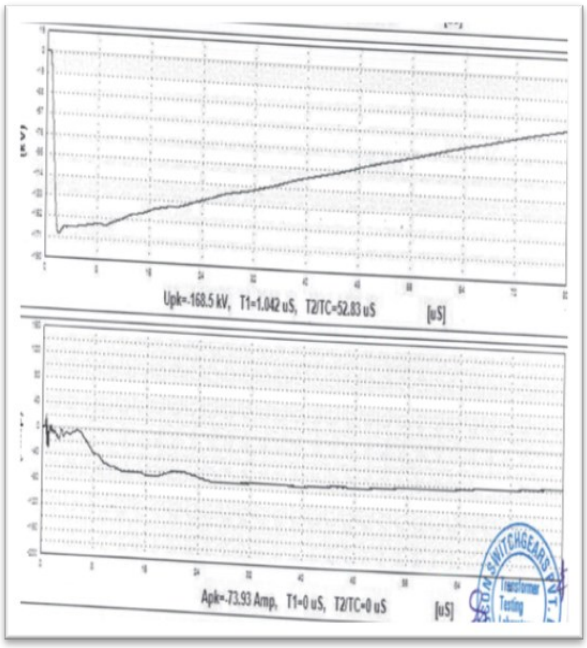

Fig.4: Full Lightening Impulse Wave 100% of BIL (LV)

- Analysis:
  - The waveform exhibited a consistent rise to the peak voltage with no anomalies.
  - The fall time adhered to the specified criteria, ensuring a clean impulse without reflections.
  - No insulation failure or physical damage was detected.

3. One Reduced Chopped Wave 50 to 70% of BIL

- Specified Voltage:
  - HV Winding: 302.5 to 423.5 kVp
  - LV Winding: 93.5 to 130.9 kVp

- Criteria:
  - T1 (Front Time): 1.2 µs ± 30%
  - T2 (Tail Time): 5 µs ± 20%
  - Tc (Chopped Time): 2 to 6 µs (3% of BIL)

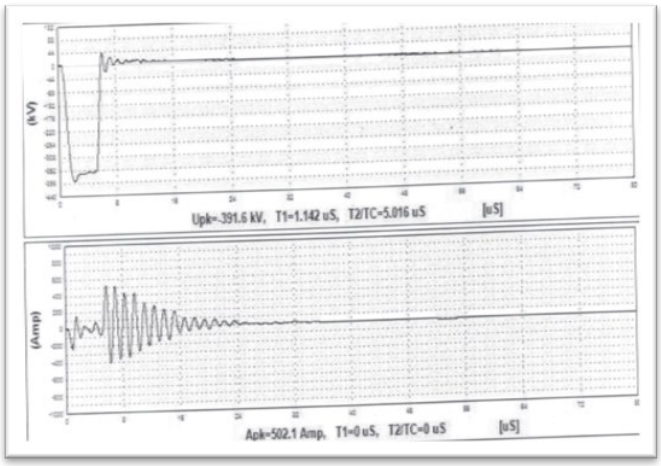

Fig.5: Reduced Chopped Impulse Wave 50 to 70% of BIL (HV)

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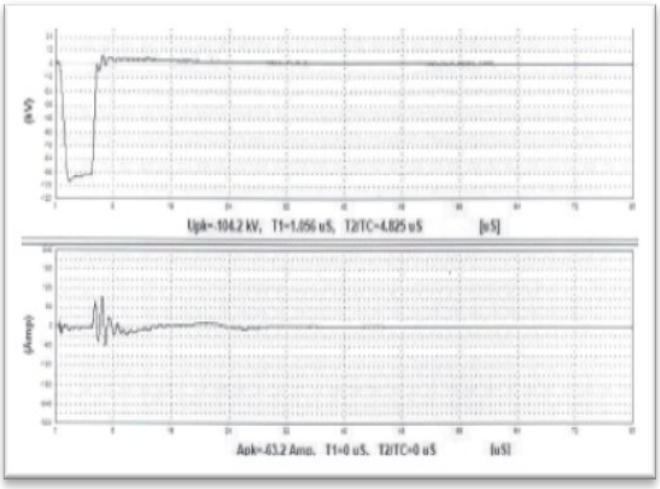

Fig.6: Reduced Chopped Impulse Wave 50 to 70% of BIL (LV)

- Analysis:
  - The chopped waveform was stable and met the rise and fall time specifications.
  - The chopping time was well within the specified range.
  - The waveform showed no signs of irregularities or excessive overshoot.

4. Two Full Chopped Wave 110% of BIL
- Specified Voltage:
  - HV Winding: 605 kVp
  - LV Winding: 187 kVp

- Criteria:
  - T1 (Front Time): 1.2 µs ± 30%
  - T2 (Tail Time): 5 µs ± 20%
  - Tc (Chopped Time): 2 to 6 µs (3% of BIL)

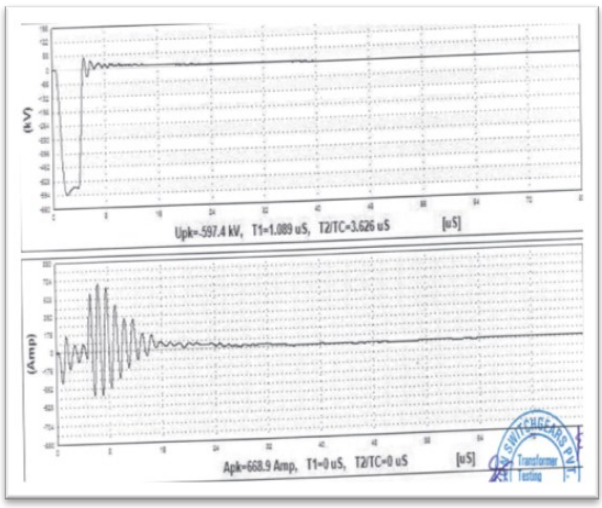

Fig.7: Full Chopped Impulse Wave 110% of BIL (HV)

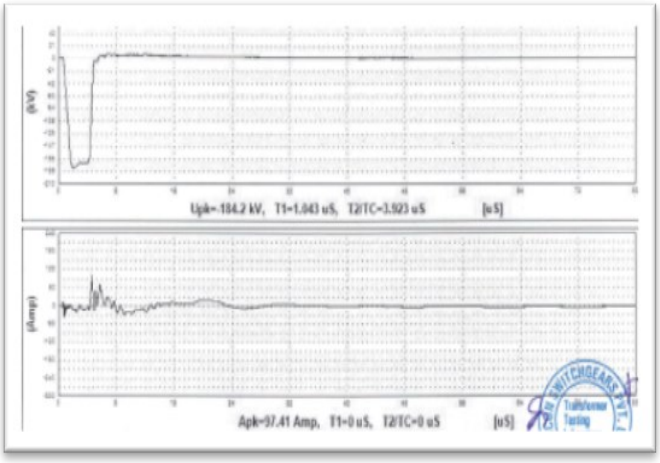

Fig.8: Full Chopped Impulse Wave 110% of BIL (LV)

- Analysis:
  - Both impulses demonstrated consistent and repeatable waveforms.
  - The chopping times and the overall waveform shape conformed to the standard requirements.
  - No physical or electrical anomalies were detected, confirming the robustness of the transformer under higher stress conditions.

5. Two Full LI Wave 110% of BIL
- Specified Voltage:
  - HV Winding: 550 kVp
  - LV Winding: 170 kVp

- Criteria:
  - T1 (Front Time): 1.2 µs ± 30%
  - T2 (Tail Time): 5 µs ± 20%
  - Tc (Chopped Time): 2 to 6 µs (3% of BIL)

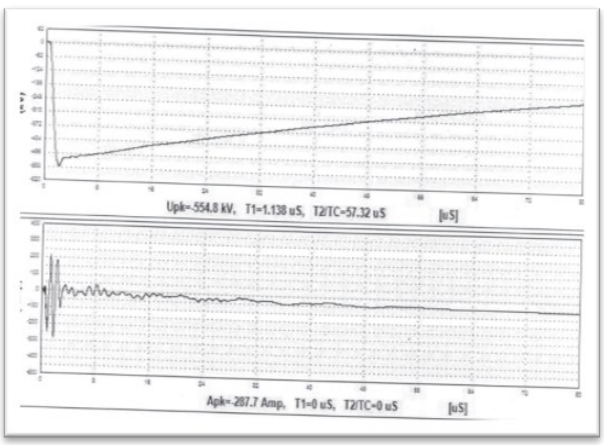

Fig.9: Full Lightening Impulse Wave 110% of BIL (HV)

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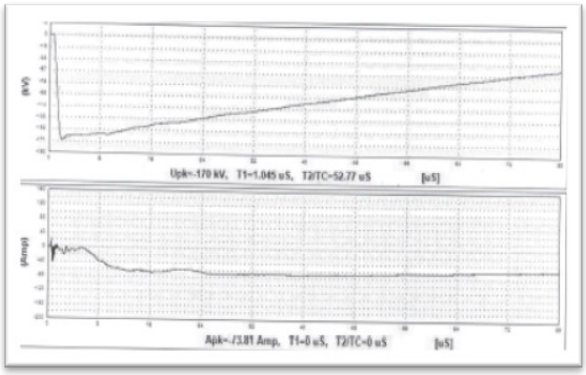

Fig.10: Full Lightening Impulse Wave 110% of BIL (LV)

- Analysis:
  - The waveforms were smooth and within the specified rise and fall times.
  - The transformer withstood the impulse without any signs of distress or failure.
  - Both impulses were consistent and adhered to the IS 2026 Part III criteria.

V. CONCLUSIONS

The impulse testing of the 25 MVA 132/33 kV Nucon Transformer at the factory was conducted successfully according to the sequence and criteria outlined in IS 2026 Part III. The analysis of the waveforms demonstrated that the transformer met all the required specifications. The waveforms for each test were within the acceptable limits for front time (T1), tail time (T2), and chopped time (Tc), with no abnormalities or damages observed.

Overall, the testing experience was positive and informative, reaffirming the transformer's reliability and robustness in withstanding impulse voltages. This successful testing process enhances confidence in the transformer's performance under operational conditions**.**

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I would like to express my sincere gratitude to MSETCL (Maharashtra State Electricity Transmission Company Limited) for providing the opportunity and support to witness this important testing. Their commitment to maintaining high standards of reliability and performance in the power transmission network is commendable.

I would also like to extend my heartfelt thanks to M/S Nucon Switchgears Pvt. Ltd. for their exceptional cooperation and provision of the 25 MVA 132/33 kV transformer for this study. Their technical expertise and high-quality manufacturing standards have been pivotal in achieving successful testing outcomes.

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