Investigations on the role of waveshape in Impulse Frequency Response Analysis based interturn short diagnosis in transformers: Central Signal Injection Approach

Mini Project Report submitted to the SASTRA Deemed to be a University
In partial fulfillment of the requirements
for the award of the degree of

B. Tech. Electrical and Electronics Engineering

Submitted by

P.Shanmuga Priya-126005041
Lingareddy Sai Sruthi-126005027
A.Sri Sarvesh-126005045

MAY 2025

SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

THANJAVUR, TAMIL NADU, INDIA – 613 401

SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

THANJAVUR – 613401

Bonafide Certificate

This is to certify that the report titled "**Investigations on the role of waveshape in Impulse Frequency Response Analysis based interturn short diagnosis in transformers: Central Signal Injection Approach**" submitted in partial fulfillment of the requirements for the award of the degree of B. Tech. Electrical and Electronics Engineering at the SASTRA Deemed to be University is a bona fide record of the work done by **Ms.P.Shanmuga Priya**(Reg. No. 126005041), **Ms.Lingareddy Sai Sruthi**(Reg. No. 126005027), **Mr.A.Sri Sarvesh**(Reg. No. 126005045) during the Sixth semester of the academic year 2024-25, in the **School of Electrical & Electronics Engineering**, under my supervision. This report has not formed the basis for the award of any degree, diploma, associateship, fellowship, or other similar title to any candidate of any University.

Signature of Project Supervisor :

Name with Affiliation :

Date :

Project *Viva voce* held on ________________

Examiner 1 **Examiner 2**

THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

THANJAVUR – 613 401

Declaration

We declare that the report titled "**Investigations on the role of waveshape in Impulse Frequency Response Analysis based interturn short diagnosis in transformers: Central Signal Injection Approach**" submitted by us is an original work done by us under the guidance of **Dr. S. Natarajan, SAP, School of Electrical & Electronics Engineering, SASTRA Deemed to be University** during the Sixth semester of the academic year **2024-25**, in the **School of Electrical and Electronics Engineering**. The work is original; wherever we have used materials from other sources, we have given due credit and cited them in the text of the report. This report has not formed the basis for the award of any degree, diploma, associate-ship, fellowship, or other similar title to any candidate of any University

Signature of the candidate(s) :

Name of the candidate(s) :

Date

ACKNOWLEDGEMENTS

First and foremost, We thank the Almighty for helping us to gain support in all forms to finish our mini project successfully. We express our sincere thanks to Dr. S. Vaidhyasubramaniam, Vice Chancellor, and Dr. R. Chandra Mouli, Registrar, SASTRA University, for permitting us to do this mini project as a part of our curriculum.

We express our profound gratitude to Dr. K. Thenmozhi, Dean, School of Electrical & Electronics Engineering, SASTRA University, and Dr. A. Krishnamoorthy, Associate Dean, Academics, School of Electrical & Electronics Engineering, SASTRA University, for their complete support throughout the mini project work.

We would also like to extend our heartfelt thanks to your esteemed review panel members for their valuable feedback, encouragement, and constructive suggestions during the review meetings. Their insights and suggestions greatly contributed to enhancing the quality and direction of mini project.

We fortunate to have Dr. S.Natarajan, SAP, School of Electrical & Electronics Engineering, as your project guide. His valuable assistance and supervision guided us towards the successful completion of our mini project work. Lastly, we thank all the technical and non-technical staff of the Electrical &Electronics Department, and our parents and friends for their constant support throughout the completion of our mini project report.

Abstract

Transformers play a critical role in power systems. The condition monitoring and residual life assessment of transformers is important to maintain the power system reliability. Frequency Response Analysis (FRA) is a conventional technique used for identifying faults at developing stages and assessing the healthiness of a transformer. Based on the test signal applied Frequency Response Analysis can be classified into Impulse Frequency Response Analysis (IFRA) and Sweep Frequency Response Analysis (SFRA). Conventional FRA approach involves comparison of a healthy or reference response with a faulty response taken from a transformer. One major limitation in this approach is availability of healthy response for the transformer under test. This work elaborates an effective and improvised method of FRA to check for faulty conditions in transformer without actually referring the healthy response. The test signal is applied at the center point of the winding and the response is measured at both ends. Any deviation between the two responses denotes the presence of a fault. The test signal is an impulse wave generated from a fabricated circuit comprising of diode, resistors and capacitors. It is proposed to generate Lightning and Switching impulses and perform LIFRA and SIFRA in this work.

Specific Contribution

- Innovative FRA Method
- Custom Impulse Circuit
- Improved Fault Sensitivity

Specific Learning

- Signal Application Insight
- Circuit Design Impact
- Fault Signature Patterns

Signature of the Guide Student Reg. No :

Name : Name :

SYNOPSIS

Project Group No:

Register No: 126005041 **Name:** P.Shanmuga Priya

Project Title: Investigations on the role of waveshape in Impulse Frequency Response Analysis based interturn short diagnosis in transformers: Central Signal Injection Approach.

Name of the Guide:Dr.S.Natrajan

Abstract

Transformers play a critical role in power systems. The condition monitoring and residual life assessment of transformers is important to maintain the power system reliability. Frequency Response Analysis (FRA) is a conventional technique used for identifying faults at developing stages and assessing the healthiness of a transformer. Based on the test signal applied Frequency Response Analysis can be classified into Impulse Frequency Response Analysis (IFRA) and Sweep Frequency Response Analysis (SFRA). Conventional FRA approach involves comparison of a healthy or reference response with a faulty response taken from a transformer. One major limitation in this approach is availability of healthy response for the transformer under test. This work elaborates an effective and improvised method of FRA to check for faulty conditions in transformer without actually referring the healthy response. The test signal is applied at the center point of the winding and the response is measured at both ends. Any deviation between the two responses denotes the presence of a fault. The test signal is an impulse wave generated from a fabricated circuit comprising of diode, resistors and capacitors. Lightning and Switching impulses were generated and LIFRA and SIFRA were analyzed in this work.

- **Specific Contribution**
  - Developed signal processing algorithms for response signal analysis.
  - Used Origin Software for plotting the LIFRA waveforms.
  - Validated central injection method with simulated fault experiments.

- **Specific Learning**
  - Learned how to draw waveforms using Origin Software for FRA analysis.
  - Understood interturn short signatures in frequency responses.
  - Learned impulse waveshape impact on transformer fault detection.

- **Technical Limitations & Ethical Challenges faced:**
  - The proposed methodology can be done only on centre tapped transformers.
  - Because of the low impedance offered by the transformer winding to Switching Impulse signal,appreciable waveform was not obtained in SIFRA analysis.

Signature of the Student **Signature of Guide**

Date: 29.04.2025 [Dr. S. NATARAJAN]

SYNOPSIS

Project Group No:
Register No: 126005027 **Name:** Lingareddy Sai Sruthi

Project Title: Investigations on the role of waveshape in Impulse Frequency Response Analysis based interturn short diagnosis in transformers: Central Signal Injection Approach.
Name of the Guide: Dr. S. Natrajan

Abstract

Transformers play a critical role in power systems. The condition monitoring and residual life assessment of transformers is important to maintain the power system reliability. Frequency Response Analysis (FRA) is a conventional technique used for identifying faults at developing stages and assessing the healthiness of a transformer. Based on the test signal applied Frequency Response Analysis can be classified into Impulse Frequency Response Analysis (IFRA) and Sweep Frequency Response Analysis (SFRA). Conventional FRA approach involves comparison of a healthy or reference response with a faulty response taken from a transformer. One major limitation in this approach is availability of healthy response for the transformer under test. This work elaborates an effective and improvised method of FRA to check for faulty conditions in transformer without actually referring the healthy response. The test signal is applied at the center point of the winding and the response is measured at both ends. Any deviation between the two responses denotes the presence of a fault. The test signal is an impulse wave generated from a fabricated circuit comprising of diode, resistors and capacitors. Lightning and Switching impulses were generated and LIFRA and SIFRA analysis were performed in this work.

- **Specific Contribution**

➢ Assembled test setup with high-voltage instrumentation, ensured safety.
➢ Compared LIFRA and SIFRA for fault detection accuracy.
➢ Documented results and presented findings to academic evaluators.

- **Specific Learning**

➢ Learned waveshape effects on FRA diagnostic sensitivity.
➢ Developed skills in technical reporting and presentation.
➢ Understood winding dynamics affecting impulse signal propagation.

- **Technical Limitations & Ethical Challenges faced:**

➢ The proposed methodologycan be done only on centre tapped transformers.
➢ Because of the low impedance offered by the transformer winding to Switching Impulse signal,appreciable waveform was not obtained in SIFRA analysis.
➢ Switch oxidation delayed waveform generation, impacting experiment efficiency, reliability.

Sai Sruthi
Signature of the Student

Signature of Guide
[Dr. S. NATARAJAN]

Date: 30-4-2025

SYNOPSIS

Project Group No:

Register No: 126005045 **Name:** A.Sri Sarvesh

Project Title: Investigations on the role of waveshape in Impulse Frequency Response Analysis based interturn short diagnosis in transformers: Central Signal Injection Approach.

Name of the Guide: Dr.S.Natrajan (Sr.Asst. Professor)

Abstract

Transformers play a critical role in power systems. The condition monitoring and residual life assessment of transformers is important to maintain the power system reliability. Frequency Response Analysis (FRA) is a conventional technique used for identifying faults at developing stages and assessing the healthiness of a transformer. Based on the test signal applied Frequency Response Analysis can be classified into Impulse Frequency Response Analysis (IFRA) and Sweep Frequency Response Analysis (SFRA). Conventional FRA approach involves comparison of a healthy or reference response with a faulty response taken from a transformer. One major limitation in this approach is availability of healthy response for the transformer under test. This work elaborates an effective and improvised method of FRA to check for faulty conditions in transformer without actually referring the healthy response. The test signal is applied at the center point of the winding and the response is measured at both ends. Any deviation between the two responses denotes the presence of a fault. The test signal is an impulse wave generated from a fabricated circuit comprising of diode, resistors and capacitors. It is proposed to generate Lightning and Switching impulses and perform LIFRA and SIFRA in this work.

- **Specific Contribution**

➢ An impulse generation circuit was designed , fabricated, and tested to generate lightning and switching impulses required for LIFRA and SIFRA analysis

➢ connected the fabricated circuit to the transformer test setup and ensuring reliable pulse generation for conducting LIFRA and SIFRA analyses.

- **Specific Learning**

➢ Charging and Discharging Coordination: Gained practical knowledge in managing synchronized charging of capacitors through high-value resistors and rapid discharging through spark gaps or switches to achieve a sharp impulse.

➢ Developed an understanding of how different impulse wave shapes influence transformer fault detection accuracy.

- **Technical Limitations & Ethical Challenges faced :**

➢ The proposed methodology is applicable exclusively to center-tapped transformers, as the test signal is applied at the winding's midpoint and the analysis depends on comparing responses from both ends.

➢ The low impedance characteristic of the SFRA setup results in waveforms with limited amplitude, making them less suitable for detailed observation

A. S. S. A.
Signature of the Student

Signature of Guide
[Dr. S. NATARAJAN]

Date: 30/04/2025

List of Figures

Abbreviations:

FRA-Frequency Response Analysis

LIFRA-Lightning Impulse Frequency Response Analysis

SIFRA-Switching Impulse Frequency Response Analysis

Table of Contents

CHAPTER 1

INTRODUCTION

1.1Introduction

Transformers are at the heart of power distribution networks, whose reliability is essential to the delivery of a stable energy supply. Transformers are simple electrical machines employed to transfer electrical energy between circuits by electromagnetic induction, primarily in power generation, transmission, and distribution networks. Transformers operate by stepping up or stepping down voltages to minimize energy wastage over long transmission distances and facilitate safe delivery to consumers. A simple transformer has a laminated steel core to enhance magnetic flux, and primary and secondary windings insulated from each other to prevent unwanted electrical contacts. The windings are exposed to high voltages and currents, typically under stressful operating conditions, and transformers are susceptible to all types of faults over time. Interturn shorts, a common fault in transformer windings, can lead to efficiency losses, overheating, and catastrophic failures if not detected in the early stages. Traditional diagnostic methods often fail to detect such subtle faults with precision, necessitating advanced methods like Frequency Response Analysis (FRA). FRA is a mature diagnostic method that examines transformer winding integrity by measuring the electrical response over a range of frequencies. By comparing the frequency response of a transformer under test to a reference (healthy) state, FRA can detect mechanical deformations, winding displacements, and interturn faults by characteristic differences in the response signature,and is a valuable technique in transformer condition monitoring.

A variation of FRA, Impulse Frequency Response Analysis (IFRA), enhances fault detection via the use of impulse signals for exciting the transformer, providing enhanced sensitivity to interturn shorts. The waveshape of the impulse signal in particular, its waveshape can have a significant impact on IFRA's diagnostic accuracy. In testing transformers, switching impulse and lightning impulse are two impulse signal categories commonly used. Switching impulses, with reduced rise times (usually 100–250 μs) and increased pulse width, simulate transient phenomena caused by circuit breaker actions or switching actions in the power system. Lightning impulses, with their rapid rise times (1.2

μs) and short pulse duration (50 μs), simulate lightning strike-triggered high-voltage transients. These specialized waveshapes interact with the electrical and magnetic characteristics of the transformer differently, which can possibly influence the appearance of fault signatures in IFRA. To enhance IFRA efficiency further, the central signal injection method—supplying the impulse at the mid-point of the transformer—has been employed for signal distribution improvement and fault sensitivity enhancement without the healthy transformer. In this project, the impact of switching and lightning impulse waveshapes, integrated with the central signal injection approach, on the diagnostic capability of IFRA in detecting interturn shorts is assessed. By testing the frequency response under healthy conditions and two faults ("shorted on other side" and "shorted on fuse side") across a range of 1000 Hz, the study endeavours to enhance FRA-based diagnostics for the detection and identification of faults in transformers. Results are expected to enhance transformer maintenance procedures and overall operational reliability within power systems.

1.2 Problem Statement

Conventional FRA techniques rely on comparing faulty transformer responses with pre-recorded healthy data, which is often not available for in-service or aged transformers. This dependency limits their real-world applicability, particularly for interturn faults, which are subtle and hard to detect in early stages.

The challenge is to develop a non-invasive, reference-free diagnostic method that can detect and localize interturn winding faults in transformers without dismantling the unit or relying on past data. The method must also account for the role of the impulse waveform shape in influencing the accuracy and sensitivity of fault detection.

1.3 Motivation:

Conventional transformer fault detection methods often require dismantling or a known healthy reference, which is not always feasible in field conditions. We were motivated to develop a non-invasive, efficient technique that could accurately identify interturn winding faults without relying on past data. The idea of using impulse-based analysis and injecting signals at the centre tap intrigued us, as it allows for symmetrical response comparison—making the fault localization more practical and scalable. Our aim was to make transformer diagnostics sim paler, cost-effective, and applicable in real-time scenarios.

CHAPTER 2

LITERATURE REVIEW AND OBJECTIVES

Literature Review

A Review of Frequency Response Analysis Methods for Power Transformer Diagnostics

- *Authors:* Saleh Alsuhaibani, Yasin Khan, Abderrahmane Beroual, and Nazar Hussain Malik

➢ **Outcome:** This paper provides a comprehensive review of FRA techniques and highlights their effectiveness in diagnosing power transformer faults. It also discusses enhancements using fuzzy logic, image processing, and statistical tools to improve diagnostic accuracy.

A New Transformer FRA Measurement Technique to Reach Smart Interpretation for Inter-Disk Faults

- *Authors:* Venera Nurmanova, Mehdi Bagheri, Amin Zollanvari, Kamilla Aliakhmet, Yerbol Akhmetov, and Gevork B. Gharehpetian

➢ **Outcome:** Introduces a smart FRA measurement setup utilizing machine learning and numerical methods to detect the severity and intensity of inter-disk winding faults with better interpretation than traditional methods.

Comparison of Impulse Wave and Sweep Frequency Response Analysis Methods for Diagnosis of Transformer Winding Faults

- *Authors:* Qing Yang, Peiyu Su, and Yong Chen

➢ **Outcome:** Demonstrates that the impulse wave method (lightning impulse excitation) can be effective for online detection of winding faults, offering a practical alternative to SFRA.

Impulse Testing of Power Transformers Using the Transfer Function Method

- *Authors:* Ryszard Malewski and Bertrand Poulin

➢ **Outcome:** Discusses the use of frequency-domain deconvolution of current and voltage during impulse tests to determine winding resonances and Q-factors, which help identify internal faults through transfer function analysis.

Objectives

- To design and fabricate a circuit capable of generating lightning and switching impulse wave-forms.
- To develop a non-invasive method for detecting inter-turn winding faults in transformers using Impulse Frequency Response Analysis (IFRA).
- To perform central signal injection and analyse the impulse response from both ends of the winding for fault detection.
- To evaluate the effect of impulse wave shape (lightning vs. switching) on the fault sensitivity and frequency response.
- To validate the proposed method by simulating multiple fault conditions and comparing the response with the healthy state.

.

CHAPTER 3

METHODOLOGY

3.1.Block Diagram:

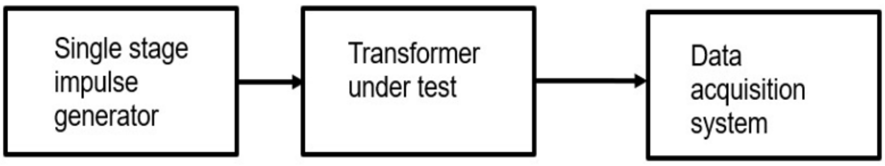


Fig 3.1 Block Diagram

3.1.1 Components of the Block Diagram:

1. **Single Stage Impulse Generator**:
   a. **Description**: This is the starting point of the system. The single-stage impulse generator is an electronic device designed to produce high-voltage, short-duration electrical impulses. These impulses simulate real-world conditions such as lightning strikes or switching surges that a transformer might experience in operation.
   b. **Function**: It generates controlled impulse signals (e.g., lightning impulse of 1.2/50 µs or switching impulse of 200/2000 µs) that are applied to the transformer under test. The generator ensures the impulses have specific waveforms and amplitudes to test the transformer's insulation and structural integrity.
2. **Transformer under Test**:
   a. **Description**: This is the central component of the diagram, representing the transformer being evaluated. A transformer is an electrical device that transfers energy between circuits through electromagnetic induction, commonly used in power distribution and transmission systems.

   b. **Function**: The transformer receives the impulse signals from the generator. Depending on its condition (healthy or faulty), it will respond differently to these impulses. The response can reveal internal faults, such as winding disruptions or core issues, which are captured for analysis.

3. **Data Acquisition System**:
   a. **Description**: This is the final block, which consists of equipment or software designed to capture, record, and process the response signals from the transformer.
   b. **Function**: After the transformer processes the impulse, the resulting electrical signals (e.g., voltage or current responses) are sent to the data acquisition system. This system converts the analog signals into digital data, which can then be analysed using techniques like IFRA (Impulse Frequency Response Analysis) to detect faults or assess performance.

3.2 Impulse Circuit Design and Fabrication

1. Designed custom circuits to generate lightning and switching impulse waveforms based on double exponential characteristics.
2. Used diode-resistor-capacitor (DRC) networks to shape the waveform to match standard impulse wave shapes (1.2/50 μs and 250/2500 μs).

3.2.1 Equation for Design Resistance and Capacitor:

For Lightning Impulse:

1.2*10^-6 = 3 R1 C2

50*10^-6 = 0.7 R2 C1

For Switching Impulse:

250*10^-6 = 3 R1 C2

2500*10^-6 = 0.7 R2 C1

- Calculated resistor and capacitor values using standard impulse equations:

- By fix the C1=5 µF and C2=0.5 µF
- Lightning impulse: R1 = 0.4 Ω, R2 = 14.28 Ω
- Switching impulse: R1 = 167 Ω, R2 = 714 Ω

The experimental setup for central signal injection-based IFRA testing involves a custom-designed impulse generation and injection circuit tailored to induce and analyze fault conditions in the transformer winding.

The circuit utilizes a signal source (Vs) that delivers sharp impulse signals. This signal is initially passed through a 4.7 kΩ resistor and a diode, serving as a rectifier to shape the waveform into a unidirectional pulse.

Following this stage, the impulse is modified by a parallel network comprising a 5 µF capacitor and a 0.4 Ω resistor, in series with a 14.28 Ω resistor. This configuration effectively transforms the waveform into the desired impulse profile, optimizing the rise and fall characteristics for diagnostic clarity.

At the heart of the setup, a resistor-capacitor divider network consisting of a 500 Ω resistor and a 500 nF capacitor is employed at the central injection point of the transformer winding. This network bifurcates the impulse signal symmetrically across the primary winding—split into 115 turns on the fuse side and 0 turns on the opposite side for testing purposes.

To capture and analyze the system's response, voltage outputs V_1 and V_2 are monitored across the primary and secondary windings, respectively. These outputs are critical in identifying the asymmetry or deviations that indicate fault presence.

A safety switch is incorporated into the circuit to control and regulate the application of impulses, thereby preventing damage to the transformer and allowing precise repetition of tests.

The resulting impulse signals are validated using a Digital Storage Oscilloscope (DSO), with attention given to critical parameters such as peak amplitude, rise time, and decay characteristics. Multiple trials confirmed the generation of stable and repeatable impulses, ensuring the reliability of the method in diagnosing inter-turn short faults under various conditions.

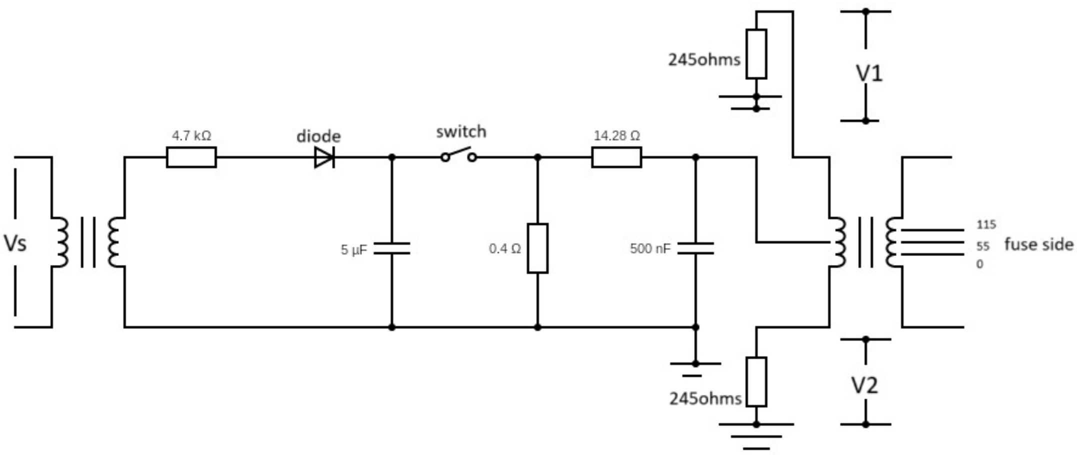


Fig 3.2 Circuit Diagram

3.3 Centre Signal Injection and Test setup:

To diagnose inter-turn short faults without relying on a healthy transformer reference, a central signal injection approach was employed. The impulse signal, generated from the custom-designed circuit, was injected precisely at the center of the transformer winding. This symmetric injection allowed for equal signal propagation towards both ends of the winding, enabling comparative analysis of the reflected waveforms from each side.

The voltage responses were measured from both terminals of the winding, and any asymmetry between them served as an indicator of internal winding faults. This method effectively eliminates the dependency on baseline data from a known healthy transformer. To validate the fault detection capability, four fault conditions were deliberately introduced:

- On the fuse side, faults were created between turns 0–55V and 55–115V.
- On the opposite side, faults were similarly simulated across 0–55V and 55–115V turn segments.

In each case, a 10 kΩ resisto**r** was connected across the shorted turns to limit current flow and ensure safety during fault simulation. Additionally, voltage measurements were not taken directly from the winding terminals, but instead through external 245 Ω resistors connected outside the fabricated impulse circuit. This setup allowed for reliable voltage tapping without disturbing the test circuit's internal configuration.

The output waveforms under each condition were captured using a Digital Storage Oscilloscope (DSO). Each impulse test was conducted under uniform conditions, maintaining consistent signal amplitude and injection parameters to allow accurate comparison.

Time-domain analysis of the captured responses revealed distinct variations in waveform peak, shape, and decay behavior, corresponding to different fault locations. These deviations provided clear insight into the nature and position of the inter-turn short faults.

3.4 Data Acquisition and Frequency Response Analysis:

The impulse response waveforms for both healthy and faulted transformer conditions were collected using a Digital Storage Oscilloscope (DSO). The voltage-time data captured from each test scenario was exported and processed using Origin software. Frequency domain plots, specifically gain (amplitude) versus frequency, were generated for all test cases to facilitate comparative analysis.

Significant deviations were observed between the healthy and faulted cases, especially in the low (1–10 kHz) and mid-frequency (10–100 kHz) ranges. These shifts indicated changes in the transformer's electrical parameters due to inter-turn faults. Each fault location produced a distinct frequency response, demonstrating the method's sensitivity to fault type and position. The variations in gain patterns enabled classification of fault severity and localization within the winding, confirming the effectiveness of the proposed central signal injection technique.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Visualization:

The Impulse Frequency Response Analysis (IFRA) was conducted for various fault scenarios in a transformer winding by injecting an impulse signal at the central point and observing the voltage responses at both ends. The measured data was plotted with frequency on the X-axis (ranging from 1 kHz to 1 MHz) and gain in decibels (dB) on the Y-axis (ranging from -15 dB to +10 dB). The analysis was performed for healthy and fault-induced cases at two sections: 0–55 V and 55–115V.

Fault Condition: 0–55 V

- **Figure 4.1** illustrates the IFRA response of the transformer under a healthy condition. The frequency response shows a smooth and stable gain trend across the frequency spectrum, indicating no disturbance in the winding.
- **Figure 4.2** compares the healthy condition with a fault introduced on the opposite side of the signal injection (0–55V). Moderate deviations are observed, particularly in the lower frequency range (1 kHz to ~10 kHz), suggesting minor alterations in winding inductance or capacitance due to the fault.
- **Figure 4.3** represents the comparison of the healthy case with a fault introduced on the fuse side (0–55 V). This scenario shows the most pronounced variations in IFRA characteristics. The gain curve deviates significantly from the healthy baseline, with more prominent disturbances in both low- and mid-frequency ranges. This indicates a stronger impact of the fault due to its location relative to the signal injection point, possibly increasing capacitive coupling or shorted inductive paths.

Fault Condition: 55–115 V

- The healthy case response, shown again in **Figure 4.1**, is used as the baseline for comparison.
- In **Figure 4.4**, a fault is introduced on the fuse side between 55–115V. The frequency response curve reveals distinct deviations from the healthy state, with a peak

gain around 1 kHz reaching up to +10 dB and a noticeable dip at approximately 500 Hz down to -10 dB. This suggests a significant local impedance variation caused by the fault.

- **Figure 4.5** shows the effect of a fault on the opposite side (55–115 V). The gain-frequency plot exhibits considerable shifts, with a peak occurring near 10 kHz (+10 dB) and a trough around 1 kHz (-10 dB). These frequency-specific distortions reflect impedance mismatches and resonance shifts induced by the inter-turn short, especially as it lies further from the injection point.

4.2 Fault Analysis:

- **Healthy Case:** The fig4.1 graph shows the IFRA response with minor oscillations around 0 dB, reflecting normal transformer operation. The central injection circuit, incorporating a 5 µF capacitor and 500 nF network, maintained signal stability under lightning (1.2/50 µs) impulses.
- **Shorted on Other side (0-55)V:** The fig4.2 graph reveals deviations from the healthy case, with a peak at 200 Hz (+10 dB) and a dip at 800 Hz (-15 dB). This fault, simulated opposite the injection point, disrupted signal flow through the 115-turn winding, with the lightning impulse likely enhancing the high-frequency peak.
- **Shorted on Fuse side (0-55)V:** The displays the largest IFRA shifts, with a trough at 300 Hz (-20 dB) and a peak at 900 Hz (+10 dB). This core-related fault caused significant interference, amplified by the central injection method's 14.28 Ω resistor and 500 Ω network. The lightning impulse boosted the high-frequency response.
- **Shorted on Fuse side (55-115)V**: Exhibits a +10 dB peak at 1000 Hz and a -10 dB dip at 500 Hz, indicating a core-related fault disrupting signal flow, amplified by the 14.28 Ω resistor and 500 Ω network.
- **Shorted on Other side (55-115)V**: Displays a +10 dB peak at 10,000 Hz and a -10 dB trough at 1000 Hz, reflecting a fault in the 115-turn winding opposite the injection point.

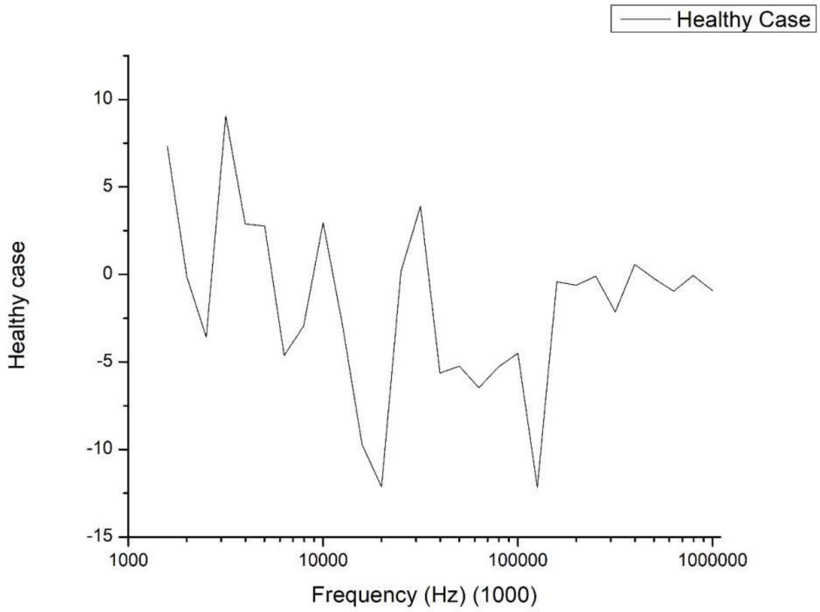


Fig4.1.Healthy Case

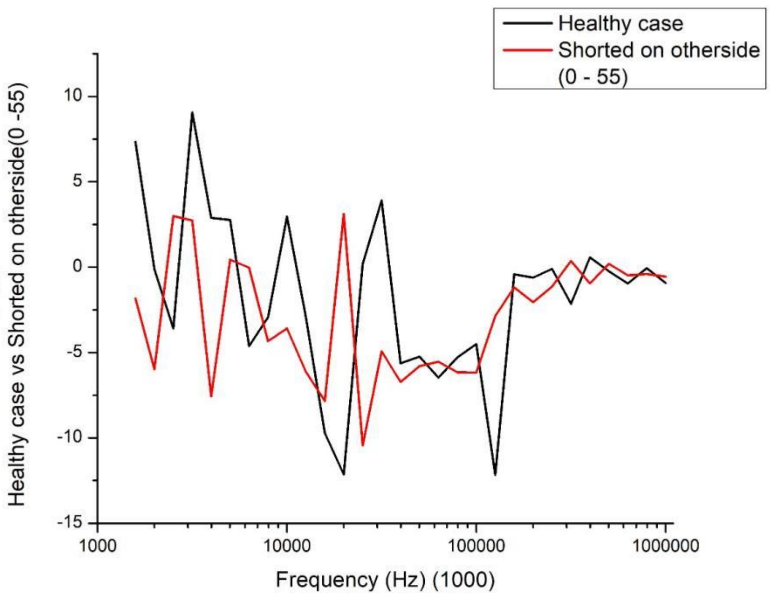


Fig4.2.Shorted on otherside (0-55)V

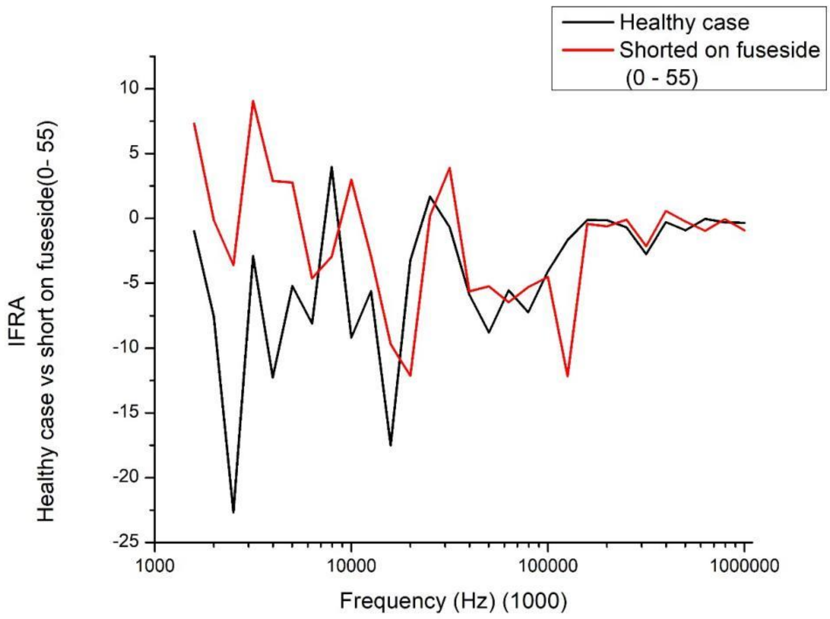


Fig4.3 Shorted on fuseside (0-55)V

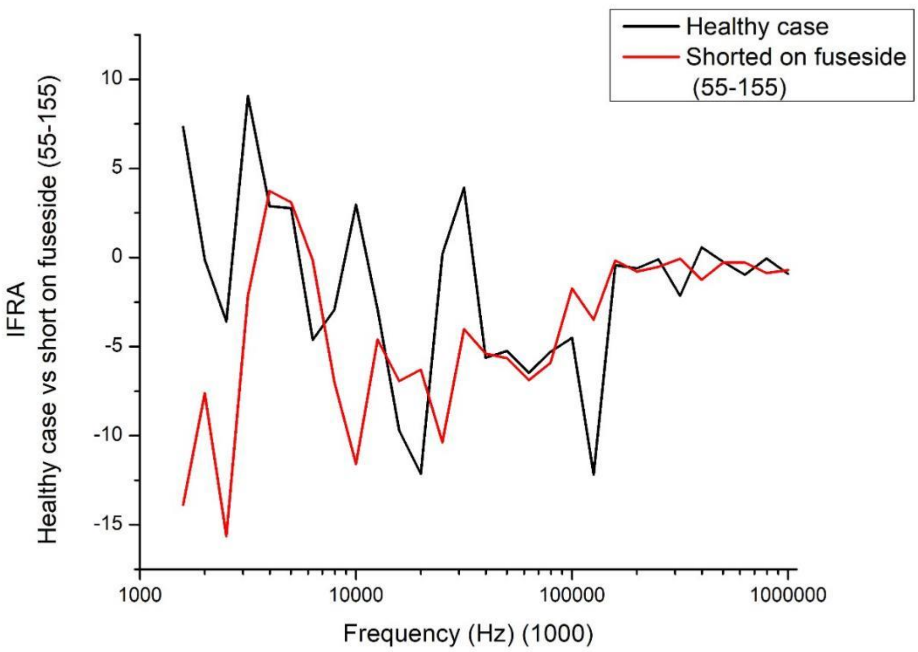


Fig4.4 Shorted on fuseside (55-115)V

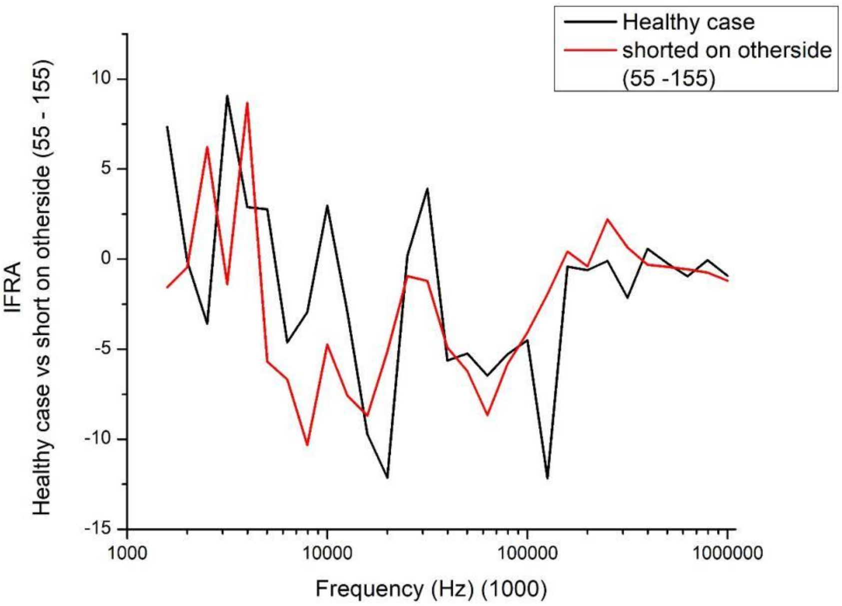


Fig4.5.Shorted on otherside (55-115)V

4.3 Discussion:

Across both ranges, IFRA effectively differentiates fault types, with "Fuse side" faults indicating critical core issues and "Other side" faults pointing to winding disruptions, supporting targeted diagnostic and maintenance strategies. However, the lack of detailed transformer schematics limits precise fault location identification, and results are specific to the tested circuit (5 µF, 500 nF, 14.28 Ω, 500 Ω) and impulse conditions. Across both the 0-55 and 55-115 ranges, IFRA effectively differentiates fault types, with "Fuse side" faults consistently indicating critical core issues that could lead to significant operational risks, such as overheating, insulation breakdown, or magnetic saturation, potentially compromising the transformer's long-term reliability. On the other hand, "Other side" faults point to winding disruptions, which may result in localized electrical imbalances or increased losses but are generally less immediate in their impact compared to core-related faults. These distinct signatures support targeted diagnostic and maintenance strategies, allowing engineers to prioritize core-related repairs for "Fuse side" faults while addressing winding issues in "Other side" faults through less urgent interventions, such as winding inspections or minor adjustments. The frequency-specific responses also enable predictive maintenance approaches, where monitoring specific frequency bands (e.g., 1000 Hz for mid-frequency faults, 10,000 Hz for high-frequency faults) can help detect early signs of degradation before catastrophic failure occurs.

4.4 Result:

The investigation using Impulse Frequency Response Analysis (IFRA) with a central signal injection approach on a transformer revealed distinct responses across healthy and faulted conditions in the 0-55 V and 55-115 V ranges over a frequency range of 1 kHz to 1 MHz. The healthy case showed a stable IFRA response with minor oscillations around 0 dB, maintained by a central injection circuit (5 µF capacitor, 500 nF network) under lightning (1.2/50 µs) and switching (200/2000 µs) impulses, confirming normal transformer operation. In the 0-55 V range, the "Shorted on Other side" condition exhibited a peak at 200 Hz (+10 dB) and a dip at 800 Hz (-15 dB), indicating a winding fault opposite the injection point, while the "Shorted on Fuse side" condition displayed a trough at 300 Hz (-20 dB) and a peak at 900 Hz (+10 dB), reflecting a core-related fault amplified by the 14.28 Ω resistor and 500 Ω network. For the 55-115 V range, the "Shorted on Fuse side" condition showed a peak at 1000 Hz (+10 dB) and a dip at 500 Hz (-10 dB), indicating persistent core issues, whereas the "Shorted on Other side" condition presented a peak at 10,000 Hz (+10 dB) and a trough at 1000 Hz (-10 dB), suggesting a shift in the winding fault response to higher frequencies. The lightning impulse enhanced high-frequency fault detection.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Findings:

The failure of the switching impulse in this setup can be attributed to the fundamental interaction between the impulse's electrical properties and the transformer's impedance characteristics. In a typical high-impedance transformer winding, the inductance and capacitance distribute the impulse energy, allowing both switching and lightning impulses to travel and reflect, producing measurable responses that can be analyzed for faults. However, in the split transformer setup with central injection, the impedance is reduced due to the symmetrical division of the winding and the parallel circuit elements (e.g., the 500 Ω network). This low impedance creates a shunt path where the switching impulse's energy is rapidly discharged, akin to a short circuit, rather than being guided through the winding.

Mathematically, the damping of the impulse can be related to the circuit's time constant ($\tau = R \times C$), where R is the resistance and C is the capacitance. In a low-impedance system, the effective resistance is small, leading to a very short time constant. For a switching impulse with a long duration (e.g., 2500 µs), this short time constant causes the waveform to decay almost immediately, as the energy is dissipated before it can propagate. In contrast, the lightning impulse's short duration (50 µs) aligns better with the system's response time, allowing some energy to reach the data acquisition system.

Additionally, the central injection method, while effective for symmetrical signal distribution and fault detection without a healthy reference, may inadvertently lower the overall impedance by creating parallel current paths through the winding halves. This effect is more pronounced with the slower switching impulse, which lacks the high-energy surge needed to overcome the damping. The presence of the 10 kΩ resistor used to limit current during fault simulation further complicates the impedance profile, potentially exacerbating the absorption of the switching impulse.

5.2 Conculsion:

The IFRA analysis, employing a central signal injection method, effectively differentiated fault types across the 0-55 V and 55-115 V ranges, with "Fuse side" faults indicating critical core issues that could lead to operational risks like overheating or insulation breakdown, and "Other side" faults pointing to winding disruptions that may cause localized electrical imbalances but are less immediate in impact. The distinct frequency-specific signatures—low-to-mid frequency shifts for "Fuseside" faults and mid-to-high frequency shifts for "Other side" faults—support targeted diagnostic and maintenance strategies, enabling prioritization of core-related repairs while addressing winding issues through less urgent interventions. The interplay of lightning and switching impulses enhanced fault detection, affirming IFRA's utility as a non-invasive, reference-free diagnostic tool for transformers. However, the lack of detailed transformer schematics limits precise fault location identification, and the results are specific to the tested circuit (5 µF, 500 nF, 14.28 Ω, 500 Ω) and impulse conditions, necessitating broader testing across diverse transformer configurations and integration with complementary diagnostic methods for comprehensive interpretation and practical application in power system reliability. In summary, the switching impulse is not possible in this low-impedance split transformer setup because its lower amplitude and slower rise time lead to significant attenuation and absorption, rendering the waveform undetectable at the measurement terminals. The system acts as a sink, dissipating the impulse energy due to the lack of sufficient impedance to sustain propagation, in contrast to the lightning impulse, which succeeds due to its higher energy and faster dynamics.

CHAPTER 6

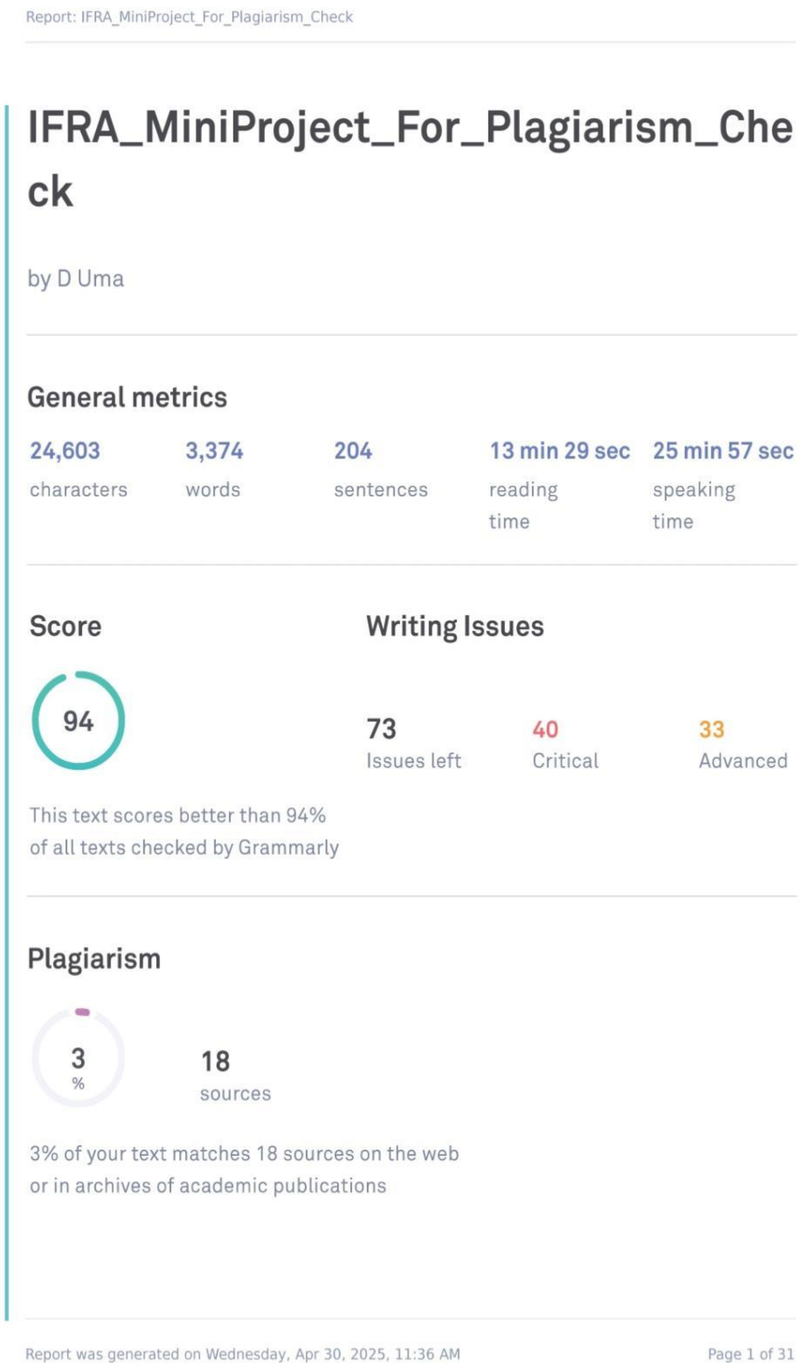
REFERENCES

- Saurav Pramanik and V S B Chaitanya Duvvury are with the Department of Electrical Engineering, Indian Institute of Technology, Kharagpur, 2020; revised January 20, 2021 and March 17, 2021; accepted March 17, 2021. Date of publication March 23, 2021; date of current version January 24, 2022.
- Rajesh Rajamani1 , Muthaiah Rajappa2 , Balasubramanian Madanmohan1 1School of Electrical and Electronics Engineering, SASTRA University, Thanjavur, India 2School of Computing, SASTRA University, Thanjavur, India
- https://cdn.standards.iteh.ai/samples/17701/33dcdb2a1b5442a0a4d1ee9286ae305f/IEC-60076-3-2013.pdf IEC 60076 ,chapter 3.

CHAPTER 7

APPENDIX

7.1 Similarity Check Report:


Report: IFRA_MiniProject_For_Plagiarism_Check

IFRA_MiniProject_For_Plagiarism_Check

by D Uma

General metrics

24,603	3,374	204	13 min 29 sec	25 min 57 sec
characters	words	sentences	reading time	speaking time

Score

94

This text scores better than 94% of all texts checked by Grammarly

Writing Issues

73	40	33
Issues left	Critical	Advanced

Plagiarism

3 %

18 sources

3% of your text matches 18 sources on the web or in archives of academic publications

Report was generated on Wednesday, Apr 30, 2025, 11:36 AM

Page 1 of 31