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A Review on Optimization and Investigation of Transformer Bushing for Impact Resistivity

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ABSTRACT: Transformer bushings and air-end insulators are essential components in high-voltage electrical power systems, providing both electrical insulation and mechanical support for conductors passing through grounded equipment. Conventional bushings are generally manufactured using porcelain ceramic materials due to their high dielectric strength and good mechanical properties. However, porcelain insulators possess inherent limitations such as high weight and brittle fracture behavior, which make them susceptible to mechanical failure under impact loading, environmental stress, and operational disturbances. These failures can lead to equipment damage, power outages, and increased maintenance costs in substations. This study focuses on the analysis and optimization of transformer bushings to improve their impact resistance and structural reliability. The mechanical behavior of conventional porcelain bushings is investigated under different loading conditions including internal pressure, bending load, and impact forces. A mathematical analysis is performed to evaluate the stress distribution and structural response of the bushing structure. Furthermore, the potential replacement of porcelain material with polymer-based composite materials such as glass fiber reinforced polymers is explored to enhance impact resistance while reducing overall weight. Finite Element Analysis (FEA) is proposed to simulate stress, deformation, and failure behavior under various operating conditions. The results of this study are expected to contribute to the development of lightweight, durable, and impact-resistant transformer bushings suitable for modern high-voltage power systems..

KEYWORDS: Transformer Bushing, Porcelain Insulator, Polymer Composite Materials, Impact Resistance, Finite Element Analysis (FEA), Glass Fiber Reinforced Polymer (GFRP), High Voltage Insulation, Mechanical Stress Analysis, Material Optimization, Electrical Power Systems.

I. INTRODUCTION

High-voltage power transmission systems require reliable insulation components to ensure safe and uninterrupted electrical energy transfer. Among these components, transformer bushings and air-end insulators play a vital role in maintaining electrical isolation between energized conductors and grounded equipment. A transformer bushing is an insulated device that allows electrical conductors to pass safely through grounded barriers such as transformer tanks or circuit breaker housings while preventing electrical leakage and maintaining structural support. These bushings are widely used in substations, transmission lines, and other high-voltage electrical installations. Traditionally, transformer bushings and high-voltage insulators are manufactured using porcelain ceramics due to their excellent dielectric strength, high compressive strength, and good resistance to environmental conditions. Porcelain materials provide stable insulation performance under varying electrical and thermal conditions, making them suitable for high-voltage applications. In addition, porcelain insulators offer good resistance to corrosion and chemical degradation, which contributes to their long service life in outdoor environments.

Despite these advantages, porcelain materials also possess certain limitations that affect the reliability and durability of transformer bushings. One of the primary disadvantages of porcelain is its brittle nature. Ceramic materials tend to fracture suddenly when subjected to excessive mechanical stress, impact loading, or structural deformation. In practical applications, transformer bushings may experience different types of mechanical loads, including cantilever loads, bending forces, internal pressure caused by insulating oil, and accidental impact loads during installation or maintenance. These loads can lead to the development of cracks, stress concentration, or catastrophic structural failure. Mechanical failures in transformer bushings may cause serious consequences in electrical power systems. Damage to a bushing can result in electrical insulation breakdown, equipment malfunction, or even transformer explosion in extreme cases. Such failures may interrupt power transmission, damage expensive electrical equipment, and increase

maintenance costs. Therefore, improving the mechanical strength and impact resistance of transformer bushings has become an important research topic in power system engineering and materials science.

Several studies have reported that failures in porcelain bushings are commonly associated with stress concentration at critical sections, improper installation, environmental degradation, and aging of insulation materials. In particular, bending stresses at the base of the insulator structure often lead to crack initiation and propagation. Furthermore, exposure to environmental factors such as temperature variations, moisture, pollution, and mechanical vibrations may accelerate material deterioration and reduce the overall reliability of the bushing system. In recent years, researchers have explored alternative materials and advanced design techniques to overcome the limitations of conventional porcelain insulators. Polymer-based composite materials have emerged as promising candidates for high-voltage insulation applications. These materials, especially glass fiber reinforced polymers (GFRP), provide several advantages compared to traditional ceramic materials. Composite insulators are generally lighter in weight, exhibit higher impact resistance, and demonstrate improved flexibility under mechanical loading conditions. Additionally, polymer composites offer good electrical insulation properties and resistance to environmental contamination.

Another important approach for improving transformer bushing performance involves the use of computational analysis and simulation techniques. Finite Element Analysis (FEA) has become a widely adopted tool for evaluating stress distribution, deformation behavior, and structural stability of engineering components. Using simulation software such as ANSYS, researchers can model complex bushing geometries and analyze their response under various loading conditions including internal pressure, bending forces, and impact loads. These numerical simulations help engineers optimize material selection, structural design, and safety parameters without the need for extensive experimental testing. Material optimization is also an important factor in enhancing the performance of transformer bushings. By replacing conventional porcelain materials with advanced polymer composites, it is possible to reduce the overall weight of the bushing while improving its resistance to mechanical shock and impact forces. Lightweight materials can also reduce transportation and installation challenges while minimizing the risk of accidental damage during handling. The objective of this research work is to investigate the mechanical behavior and structural performance of transformer bushings under various loading conditions and to explore the potential benefits of material optimization. The study focuses on analyzing the stress and deformation characteristics of conventional porcelain bushings and evaluating alternative materials that can provide improved impact resistance and durability. Mathematical analysis and simulation-based approaches are considered to assess the mechanical response of the bushing structure under different operating conditions. The findings of this study are expected to contribute to the development of improved transformer bushing designs with enhanced reliability and mechanical strength. By integrating advanced materials and simulation-based design techniques, it is possible to create high-performance insulation components that can withstand harsh operating conditions in modern electrical power systems.

II. LITERATURE SURVEY

Previous studies have extensively investigated the performance and failure mechanisms of high-voltage porcelain and composite insulators used in electrical power systems. Researchers have identified that porcelain insulators provide excellent dielectric strength but are prone to brittle fracture and mechanical failure under impact or excessive stress. Recent research focuses on polymer composite materials such as Glass Fiber Reinforced Polymer (GFRP) due to their lightweight structure and improved impact resistance. Several studies have applied experimental testing and numerical methods such as Finite Element Analysis (FEA) to analyze stress distribution and deformation behavior of transformer bushings. The findings indicate that composite insulators can enhance mechanical durability while maintaining electrical insulation performance. However, further investigation is required to optimize material selection and structural design for improved reliability of transformer bushings.

No	Author & Year	Title / Journal	Method Used	Key Findings
1	Wang et al., 2023	Failure Characterization of Glass Fiber Composite Insulators	Experimental + dielectric analysis	Studied degradation of GFRP insulators and identified fiber-epoxy interface failure due to liquid penetration.
2	Zhu et al., 2024	Seismic Performance of GFRP Transformer Bushings	Shaking table test + simulation	Demonstrated that composite bushings maintain structural stability under earthquake loading.
3	Zhang et al., 2024	Moisture Absorption in GFRP Composite Insulators	Experimental testing	Moisture significantly affects durability and long-term insulation performance.
4	Agüero-Barrantes & Hain, 2024	Structural Performance of Porcelain Insulators	Experimental testing	Aging and installation conditions influence mechanical strength and failure modes.
5	Zhong et al., 2025	Insulating Properties of Glass Fiber Reinforced Polymers	Material analysis	GFRP provides high strength-to-weight ratio and excellent electrical insulation properties.
6	Fang et al., 2023	Electrical Insulation Characteristics of Porcelain and Composite Insulators	Comparative study	Composite insulators offer improved mechanical flexibility compared with porcelain.
7	Ghosh et al., 2018	Degradation of Polymeric High-Voltage Insulators	Experimental study	Polymeric insulators show good electrical performance but require monitoring against aging.
8	Holmberg et al., 2015	Dry Transformer Bushings with Composite Insulators	Design review	Composite insulation improves reliability and reduces brittle fracture risk.
9	Kumosa et al., 2005	Failure Analysis of Composite Insulators	Failure modeling	Identified brittle fracture and stress corrosion as major failure mechanisms.
10	Carpenter et al., 2000	Brittle Fracture of Composite Insulator Rods	Experimental testing	Stress corrosion in glass fibers can cause catastrophic failures.
11	Ely et al., 2001	Stress Corrosion Properties of Pultruded Glass Fiber Composites	Laboratory testing	Composite rods show strong tensile performance but can degrade under chemical exposure.
12	Mao et al., 2026	Electrical Failure Mechanism of High Voltage Bushings	Risk assessment	Mechanical and electrical stresses contribute to bushing failures.
13	He et al., 2022	Seismic Performance of GIS Bushings	Experimental analysis	Porcelain and composite bushings show different vibration characteristics.
14	Wang et al., 2023	Lightning Flashover Characteristics of Composite Insulators	Simulation + testing	Composite insulators demonstrate improved flashover performance.
15	Zhang et al., 2025	Thermal Behavior of Composite Insulators	Thermal analysis	Temperature rise influences degradation and failure probability.
16	Liu et al., 2023	Surface Modification of Silicone Rubber Insulators	Material engineering	Nano-coating improves surface hydrophobicity and insulation performance.
17	González et al., 2017	Structural Fiber Reinforced Composite Materials	Review study	Fiber-reinforced composites show superior strength and durability.
18	Wang et al., 2020	Non-Destructive Testing of Composite Structures	Review paper	Advanced NDT methods are useful for detecting composite material defects.
19	Subramaniyan et al., 2024	Thermal Transport in Fiber Reinforced Polymer Composites	Experimental + simulation	Fiber morphology significantly affects mechanical and thermal performance.
20	Luo et al., 2014	Electromagnetic Behavior of Polymer Composite Materials	Experimental study	Reinforced polymer composites demonstrate unique electrical properties.

III. MATHEMATICAL PROCEDURE

3.1 COMPONENT SELECTION AND AESTHETICS:

3.1.1 STUDY OF INSULATOR:

The Bushing is selected of 245 KV transformer. The bushing is made of Porcelain Ceramics. The features and specifications of Bushing is discussed in this chapter. The Below figure 3.1, shows the Prototype of Bushing Prepared in Creo Model. The dimensions of Porcelain are described in official draft as shown in figure 3.2 and 3.3.



Figure 3.1: LHS-Actual Assembly of Bushing, RHS- Creo Model of Bushing

Table 3.1: Specifications of Condenser Bushing Section

No.	Parameter	Notation	Value
1.	Capacity	KV	245
2.	Maximum Cantilever Load	Cmax	1100 KgF
3.	Minimum Cantilever Load	Cmin	5500 KgF
4.	Total Creep age	-	4350mm
5.	Working Temperature	T	-50 to 105o
6.	Roundness of Tongs	-	6 mm
7.	Specific Internal Pressure	P	6 MPa
8.	Basic Pressure Range	-	0.8 MPa to 1.6 Mpa.

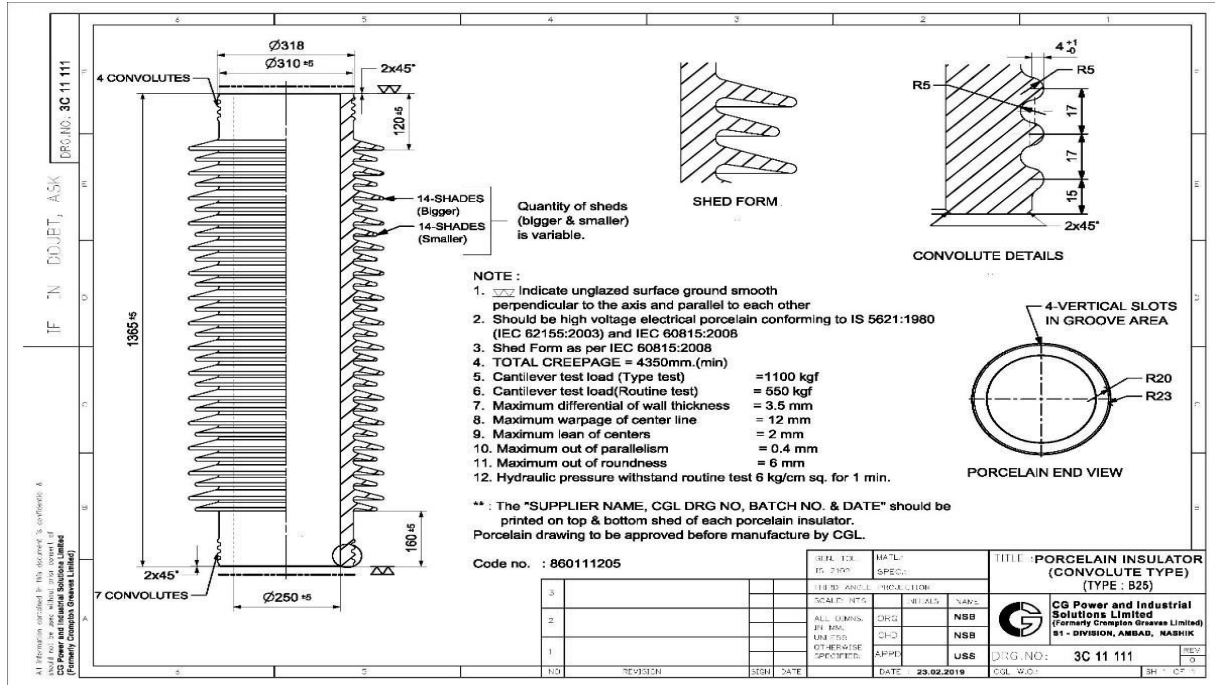


Figure 3.2: Details of Bushing Outer Cross Section.

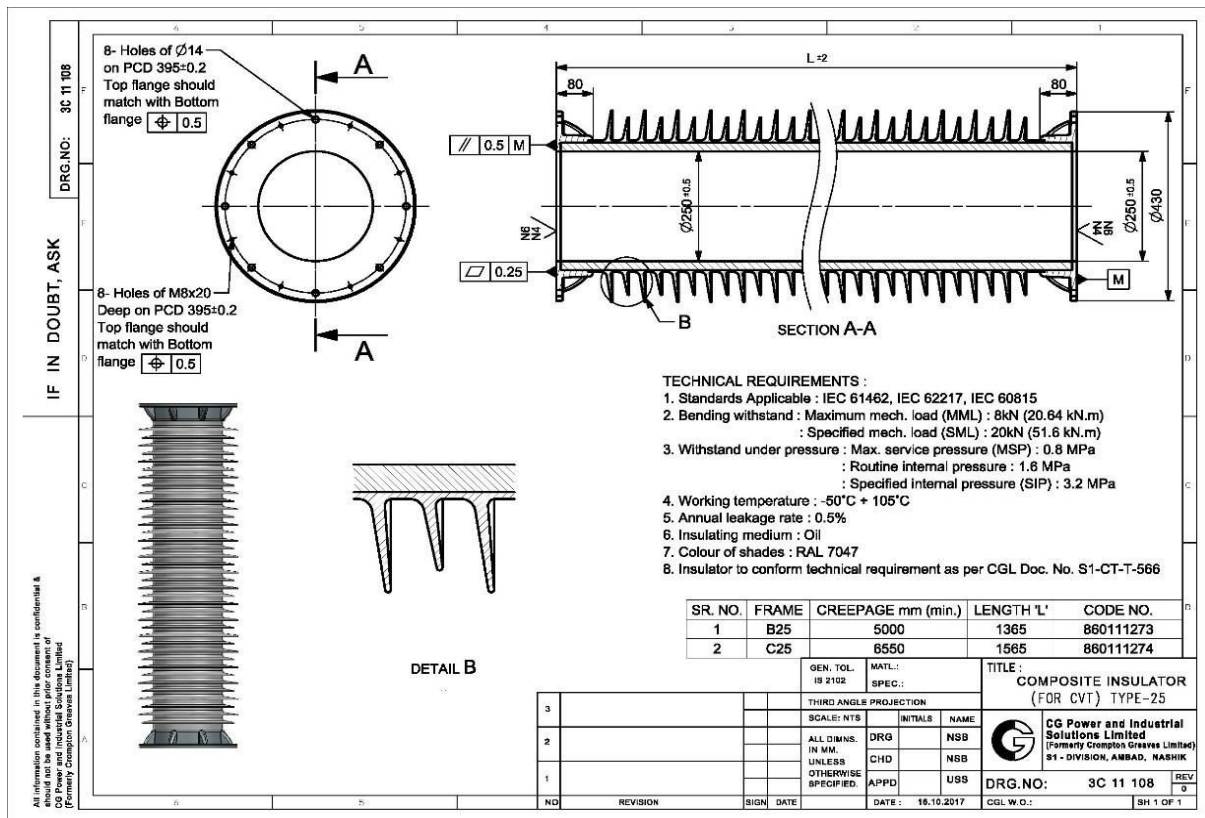


Figure 3.3: Details of Bushing Inner Cross Section.

IV. CONCLUSION

Transformer bushings are critical components in high-voltage power transmission systems, providing both electrical insulation and mechanical support for conductors passing through grounded equipment. Conventional porcelain bushings are widely used because of their high dielectric strength and mechanical stability. However, porcelain materials exhibit brittle behavior and high weight, which makes them susceptible to mechanical damage, cracking, and impact failure under severe operating conditions. These limitations can lead to equipment malfunction and increased maintenance costs in electrical substations. This study reviewed the structural performance and failure mechanisms of transformer bushings and highlighted the importance of material optimization for improving reliability. Various loading conditions such as internal pressure, cantilever load, bending stress, and impact forces were analyzed to understand the mechanical behavior of the bushing structure. The review also emphasized the advantages of polymer composite materials, particularly glass fiber reinforced polymers, which offer improved impact resistance, reduced weight, and enhanced durability compared to traditional porcelain materials.

Furthermore, simulation techniques such as Finite Element Analysis (FEA) can play a significant role in evaluating stress distribution, deformation, and failure behavior of transformer bushings under different operating conditions. By integrating advanced materials with computational analysis, it is possible to design optimized transformer bushings with improved structural performance and longer service life. Overall, the adoption of composite materials and simulation-based design approaches can significantly enhance the mechanical strength and reliability of transformer bushings in modern electrical power systems. Future research can focus on experimental validation and advanced material development to further improve the performance of high-voltage insulation components.

REFERENCES

- [1] P. Agüero-Barrantes and A. Hain, "Structural Performance of Porcelain Insulators in Overhead Railway Power Systems," *Infrastructures*, vol. 9, no. 8, pp. 1–18, 2024.
- [2] F. A. Jamaludin and C. S. Chao, "Effect Analysis of Pollutant Distribution on the Flashover Performance of Porcelain and Composite Insulators Using Finite Element Method," *Science & Technology Asia*, vol. 29, no. 1, pp. 82–90, 2024.
- [3] A. Holmberg and M. Lundborg, "Dry Transformer Bushings with Composite Insulators for Increased Reliability," ABB Technical Report, 2014.
- [4] T. Ren, "Review of Aging Characteristics of High-Voltage Composite Insulators," *Renewable and Sustainable Energy Reviews*, 2025.
- [5] A. O. Ezzat et al., "High-Performance Epoxy Composite Electrical Insulator for High Voltage Applications," *Results in Engineering*, 2024.
- [6] A. Siddique and L. Akram, "Development of Novel Epoxy-Based Transformer Bushing Insulator for High Breakdown Voltage," in *Proc. Int. Conf. Emerging Trends in Electrical Control and Telecommunication Engineering*, 2024.
- [7] M. Ghassemi, "Accelerated Insulation Aging Due to Fast Repetitive Voltages: Challenges and Future Research Needs," *IEEE Electrical Insulation Magazine*, 2020.
- [8] S. Jyothi and R. Ramu, "Temperature Distribution in Resin-Impregnated Paper Transformer Bushings," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 26, no. 3, pp. 760-768, 2019.
- [9] A. K. Pal, "Studies on HTV Silicone Rubber as Dielectric Material for Composite Insulators," *IET Science, Measurement & Technology*, vol. 15, no. 4, pp. 368-375, 2021.
- [10] IEEE Power Engineering Society, **IEEE Standard for Power Apparatus Bushings**, IEEE Std C57.19.00-2004.
- [11] M. Kumosa, "Failure Mechanisms of Composite Insulators in Power Transmission Systems," *IEEE Transactions on Power Delivery*, vol. 21, no. 2, pp. 817-825, 2016.
- [12] S. Sanyal et al., "Deterioration of Porcelain Insulators in Overhead Transmission Lines," *IEEE Electrical Insulation Magazine*, vol. 32, no. 5, pp. 20-28, 2018.
- [13] P. Wang et al., "Stress Analysis of Porcelain Post Insulators Using Finite Element Method," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 25, no. 4, pp. 1430-1438, 2018.
- [14] M. Ramesh et al., "Electric Field Analysis of Composite Insulators with Internal Defects," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 23, no. 2, pp. 891-898, 2017.
- [15] T. J. Holmquist et al., "Impact Strength of Ceramic Materials under High Velocity Loading," *Journal of Applied Mechanics*, vol. 72, no. 3, pp. 379-388, 2005.



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