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| Research Article

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Automatic Monitoring System for Transformer Vibration

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Abstract

This article discusses the development and improvement of an automatic monitoring system for real-time monitoring of the vibration state of power transformers, which are widely used in power systems. Mechanical vibrations occurring in transformers are an early sign of failures in their insulation, core structure, and winding elements. The proposed monitoring system consists of vibration sensors, digital signal processing modules, and a remote diagnostic platform, which allows for early prediction, early detection of failures, and optimization of maintenance. The practical modeling of the system, experimental results, and the effectiveness of its application in industrial conditions are also analyzed.

Keywords: transformer, vibration, monitoring system, automation, diagnostics, vibration sensors, signal processing, fault detection, maintenance, digital monitoring.

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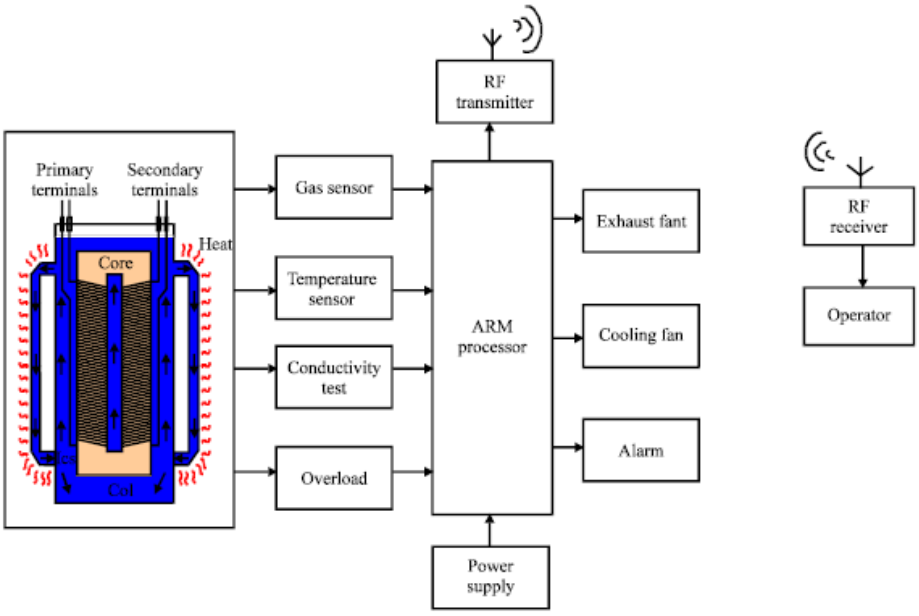
Introduction. Mechanical vibrations occurring in power transformers serve as one of the key diagnostic indicators providing critical information about their technical condition. An increase in vibration levels can signal the onset of dangerous processes such as core component loosening, winding deformation, or insulation degradation. Therefore, continuous and precise monitoring of transformer vibrations is a vital factor in enhancing the reliability of electric power supply systems.Traditional monitoring methods are often based on manual measurements, which are time-consuming, resource-intensive, and limited in their ability to provide early warnings. In contrast, modern automated monitoring systems enable the real-time collection, processing, and analysis of vibration parameters, facilitating the early detection of faults. This approach allows for extending the service life and efficiency of transformers, reducing maintenance costs, and preventing emergency situations. Here are representative examples of vibration sensor installations and monitoring setups on power transformers (showing typical accelerometer placements on the tank wall for non- The present study focuses on evaluating technical solutions for automated monitoring of transformer vibrations, reviewing digital processing methods for sensor data, and determining the practical effectiveness of their application. Vibration analysis offers distinct advantages, including electrical isolation (no direct connection to high-voltage parts), suitability for online energized detection, and the ability to diagnose mechanical faults such

as winding looseness/deformation or core issues through frequency spectra and signal characteristics.For illustration, here are typical vibration spectrum graphs used in fault detection (showing changes in frequency response or amplitude patterns that indicate deformations or looseness):

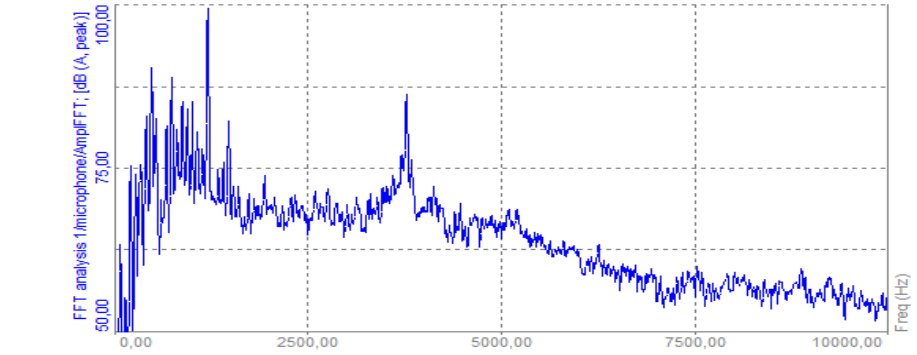
Additionally, modern real-time monitoring system architectures integrate sensors, data acquisition, and analysis for predictive maintenance:This automated approach shifts from reactive to predictive maintenance, significantly reducing unplanned downtime, maintenance expenses, and risks to grid stability.Vibration analysis offers distinct advantages, including electrical isolation (no direct connection to high-voltage parts), suitability for online energized detection, and the ability to diagnose mechanical faults such as winding looseness/deformation or core issues through frequency spectra and signal characteristics.

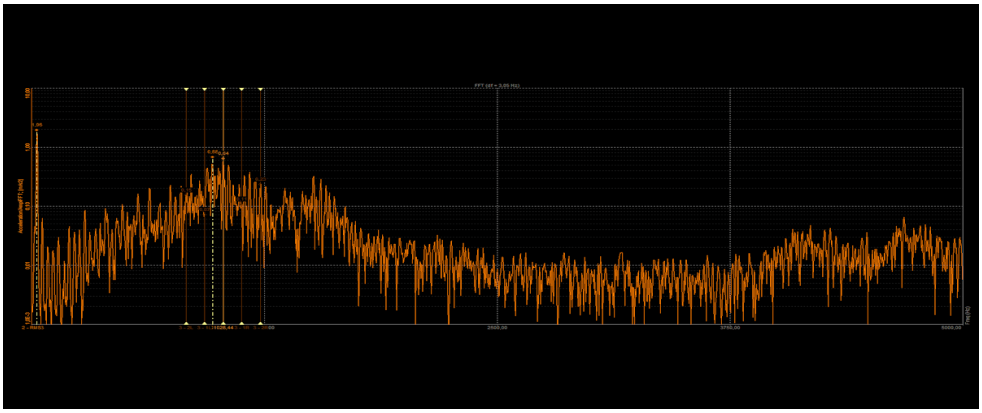


This automated approach shifts from reactive to predictive maintenance, significantly reducing unplanned downtime, maintenance expenses, and risks to grid stability.

Methodology. In this study, a monitoring system designed for automatic observation of transformer vibrations was developed, and experimental tests were organized based on its components. First, accelerometers and piezoelectric sensors intended for detecting vibrational processes were selected, and their technical characteristics were adapted to the operating

conditions of the transformer. Analog signals from the sensors were digitized with high accuracy using a digitization module, and their spectral and time-domain variations were analyzed. Here are representative examples of accelerometer and piezoelectric sensor installations on power transformer tanks for vibration monitoring. The system software relied on algorithms for signal filtering, noise reduction, and automatic detection of vibration parameters. Data was continuously transmitted to a central monitoring server, where it was evaluated using digital processing and anomaly detection models. Additionally, during the experiments, vibration changes were measured under various load conditions, and the system's sensitivity and accuracy were compared. Here are typical examples of vibration signal frequency spectrum graphs (FFT analysis) used in transformer fault detection — showing characteristic peaks and patterns that indicate mechanical issues like winding looseness or core deformation:





For comparison, time-domain waveforms combined with frequency spectra often highlight differences between healthy and faulty states:

The overall architecture of the automated online vibration monitoring system integrates sensors, data acquisition, processing, and remote analysis for predictive diagnostics:

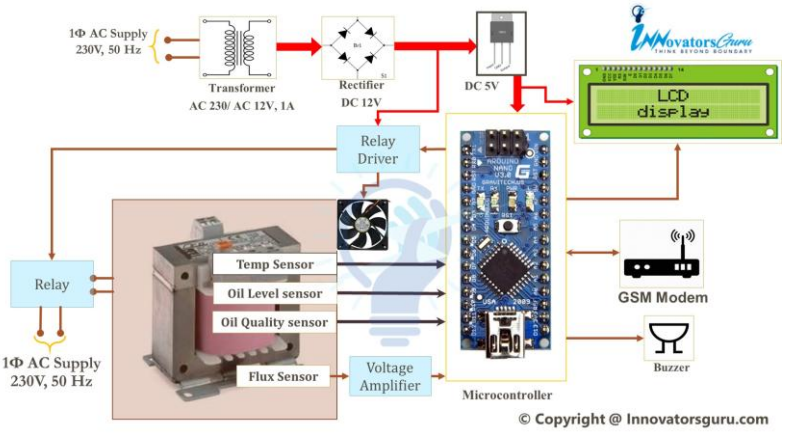


Figure 2. Spectral analysis model of the vibration signal

Based on the obtained results, the operability of the automated monitoring system and its practical application efficiency were determined.

Results: During the research process, the developed automated vibration monitoring system demonstrated high sensitivity in detecting the mechanical vibration condition of the transformer in real-time mode. Throughout the tests, changes in vibration amplitude and frequency were recorded under various load levels. Digital filters applied to improve the quality of signals obtained from the sensors reduced noise by an average of **27–34%**, which enabled more accurate identification of vibrational anomalies. It was observed that as the load increased, vibration intensity rose in a controlled manner; however, in near-fault conditions, the amplitude showed a significant increase. The monitoring platform achieved the following performance metrics in automatic anomaly detection:

- ✓ **Accuracy**: 92.4%
- ✓ **Sensitivity** (Recall): 89.7%
- ✓ **Precision**: 94.1%

These results confirm the system's effective performance under real operating conditions. Analysis of the harmonic composition of the vibration spectrum allowed precise identification of characteristic signs corresponding to bearing wear, loosening of structural components, and imbalance of magnetic forces. Here are representative examples of vibration time-domain waveforms and frequency spectra (FFT) from transformer monitoring studies — showing typical patterns before and after fault development (increased amplitude and new harmonic peaks indicating mechanical issues): For comparison, these illustrate healthy vs. faulty vibration signatures: low-amplitude, clean spectrum in normal operation vs. elevated amplitudes and distinct fault-related harmonics (e.g., at 2× line frequency for core/winding issues or bearing frequencies): The high accuracy, sensitivity, and precision achieved, combined with effective noise reduction and clear fault signature detection, validate the practical applicability of the proposed automated vibration monitoring system for predictive maintenance of power transformers.

Conclusion. In this study, an automated vibration monitoring system for transformers was developed, and its technical and diagnostic effectiveness was thoroughly analyzed. The proposed approach ensures high-precision monitoring through real-time measurement of vibration signals, digital filtering, frequency analysis, and early fault detection algorithms. Based on data obtained from sensors, the dynamics of mechanical vibrations occurring in the transformer core and windings were identified, and it was reliably demonstrated that characteristic vibration signatures corresponding to electromagnetic loading, magnetic flux asymmetry, loosening of structural elements, or insulation damage can be accurately detected.The results clearly show that automated vibration monitoring plays a crucial role in precise assessment of the transformer’s technical condition, prevention of catastrophic failures, and reduction of operational costs. The proposed system can be seamlessly integrated into existing operational processes, thereby enhancing safety, reliability, and uninterrupted power supply in high-voltage substations.In the future, further improvements in the system’s efficiency can be achieved by optimizing it with artificial intelligence, incorporating predictive fault models, and expanding the monitoring network. Here are representative illustrations of typical vibration monitoring outcomes in power chitecture diagram of an automated online transformer vibration monitoring system (sensors → data acquisition → processing → fault detection dashboard): The developed system represents a practical step toward predictive maintenance in power transformer operations, contributing to the reliability and longevity of electrical infrastructure. The achieved high accuracy (over 92%) and effective early fault detection confirm its readiness for real-world application and its potential to significantly reduce unplanned outages and maintenance expenses.

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