A Study on the Effectiveness of Transformer Condition Monitoring Systems

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1. Research Background

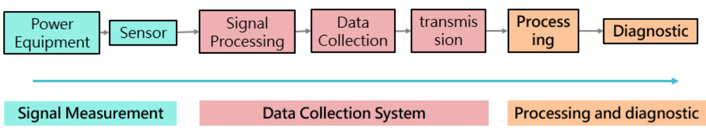
Power transformers are the core components responsible for voltage conversion and transmission in substations, playing a vital role in the power supply system. With the rise of energy transition and changes in grid operating environments, transformers are facing increasingly complex loads and external influences. Therefore, enhancing reliability and operational safety has become a key issue.

To address this issue, various advanced transformer condition monitoring systems have been developed. These systems provide real-time monitoring of internal operating conditions, offering crucial data and diagnostics to help field personnel assess the health of their equipment. When abnormalities occur, the system can issue early warnings, allowing operations and maintenance teams to respond promptly and perform preventive maintenance to avoid unexpected failures.

This study aims to explore the application and effectiveness of transformer condition monitoring technologies. The research begins by reviewing relevant theories and international standards to establish a comprehensive framework for monitoring. Subsequently, case studies and benefit evaluations of different types of monitoring equipment are conducted to assess their practical value in transformer management. Condition Monitoring System is installed and monitored over time, with collected data compared to historical records to evaluate performance trends and validate the role of monitoring systems in fault prevention and life extension.

2. Research Findings

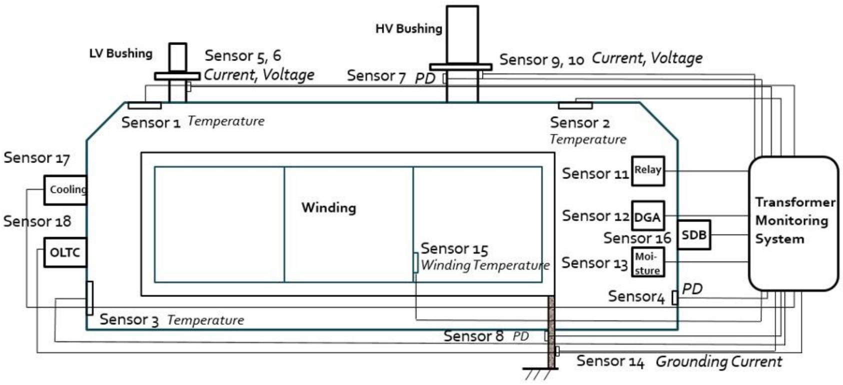
Online monitoring systems provide real-time awareness of transformer operation and are primarily used for detecting progressive faults, such as insulation aging or moisture ingress. By continuously collecting critical data with sensors and integrating data analysis with a visual interface, these systems support health assessments and fault identification (as shown in Figure 1). Although sudden and unexpected failures cannot be completely avoided, online monitoring significantly improves reliability and maintenance efficiency, serving as an important tool for preventive maintenance.



Source: Made by the author

Figure 1. Basic Principle of Online Monitoring System

Modern intelligent transformer monitoring systems (Figure 2) incorporate data processing units installed near the transformer to collect sensor data, such as temperature, current, gas-in-oil, partial discharge, and bushing conditions, in real time, then upload and analyze the data. These systems feature automated anomaly detection and predictive analysis, providing real-time alerts and maintenance recommendations. Key advantages include digital measurement, networked control, graphical user interfaces, function integration, and bidirectional interaction—offering superior functionality and responsiveness compared to traditional systems.



Source: Made by the author

Figure 2. Intelligent Transformer Monitoring System Overview (Summarized by this study)

As the power system faces increasing demands from the energy transition and environmental challenges, transformers must maintain stable operation and accurately predict faults. This study focuses on the application of transformer condition monitoring by deploying intelligent monitoring equipment (see Figures 3 and 4) to enhance reliability and preventive maintenance. The monitored items include OLTCs (On-Load Tap Changers) and bushing monitoring systems — each addressing key concerns such as dehumidification performance, switching mechanism vibration, and insulation deterioration.

By collecting and analyzing long-term data on parameters such as temperature, humidity, leakage current, and partial discharge, potential faults can be detected early, reducing unexpected failures and maintenance costs. This transition from traditional time-based maintenance (TBM) to condition-based maintenance (CBM) improves resource allocation and extends equipment life. The study also compares various product features and specifications across manufacturers, compiling compliance with standards and measurement capabilities to support future equipment selection decisions.

With the integration of artificial intelligence and IoT technologies, smart monitoring will further enhance the resilience and efficiency of the power supply system, laying a foundation for stable power delivery.

Source: Taken by TPRI

Figure 3. Sensor Wiring and Conduit Installation

Source: Taken by TPRI

Figure 4. OLTC Monitoring Sensor and Cable Layout

3. Conclusion

To assess the practical benefits of transformer online monitoring systems, this project selected an actual transformer for long-term data collection and analysis. Since its activation in 2023, the system has continuously recorded key parameters, including bushing leakage current, power factor, capacitance, and OLTC vibration waveforms, to track operational status and detect potential anomalies.

In summary, the installed equipment has successfully demonstrated the feasibility and potential of online monitoring. Future efforts may involve validating its long-term value in conjunction with scheduled transformer maintenance cycles, while continuously enhancing data analysis and system integration capabilities to improve equipment reliability and maintenance efficiency.