A Comprehensive Review of ML Techniques for Power Transformer Fault Diagnosis and Predictive Maintenance

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Abstract

Power transformers play a vital role in modern power systems, and any unexpected failure can lead to serious consequences, including power outages, financial losses, and loss of public trust. To avoid such disruptions, several condition monitoring techniques have been developed over the years. Traditional methods such as Dissolved Gas Analysis (DGA), Frequency Response Analysis (FRA), and Partial Discharge (PD) testing are widely used in industry. However, these approaches often rely heavily on expert interpretation, are mostly con ducted offline, and follow fixed diagnostic rules that may not perform consistently in complex or noisy real-world conditions.

In recent years, machine learning (ML) and artificial intelligence (AI) have gained significant attention as more intelligent and reliable alternatives for trans former fault diagnosis. This paper provides a comprehensive review of both conventional diagnostic techniques and modern data-driven methods. It discusses popular ML approaches, including Support Vector Machines (SVM), Artificial Neural Networks (ANN), ensemble learning models, hybrid fuzzy systems, and automated ML frameworks. The review also highlights commonly used datasets, feature extraction techniques, optimization strategies, and evaluation metrics found in existing studies.

At the same time, the paper critically examines the limitations of current research, such as dependence on synthetic data, limited real-world validation, high computational complexity, and lack of adaptability for field deployment. Based on these observations, future research directions are suggested, focusing on developing adaptive, scalable, and optimization-driven diagnostic frameworks that support online monitoring and predictive maintenance of power transformers.

Keywords

Power Transformer Fault Diagnosis, DGA, ML, AI, Predictive Maintenance, AutoML, Smart Grid Monitoring.