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Photoluminescence Spectroscopy Measurements for Effective Condition Assessment of Transformer Insulating Oil

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Abstract: Condition assessment of insulating oil is crucial for the reliable long-term operation of power equipment, especially power transformers. Under thermal aging, critical degradation in oil properties, including chemical, physical, and dielectric properties, occurs due to the generation of aging byproducts. Ultraviolet-visible (UV-Vis) spectroscopy was recently proposed for the condition assessment of mineral oil. However, this absorption technique may involve all electronic states of the investigated material which typically yield a broad spectrum, and thus cannot precisely reflect the electronic structure of aged oil samples. It also cannot be implemented as an online sensor of oil degradation. In this paper, photoluminescence (PL) spectroscopy is introduced, for the first time, for effective condition assessment of insulating oil. The PL technique involves emission processes that only occur between a narrow band of electronic states that are occupied by thermalized electrons and consequently yields a spectrum that is much narrower than that of the absorption spectrum. Aged oil samples with different aging extents were prepared in the laboratory using accelerated aging tests at 120 °C, under which 1 day of laboratory aging is equivalent to approximately 1 year of aging in the field. These aged samples were then tested using PL spectroscopy with a wavelength ranging from 150 nm to 1500 nm. Two main parameters were evaluated for quantitative analysis of PL spectra: The full width at half-maximum and the enclosed area under the PL spectra. These parameters were correlated to the aging extent. In conjunction with PL spectroscopy, the aged oil samples were tested for the dielectric dissipation factor as an indication of the number of aging byproducts. Interestingly, we find a correlation between the PL spectra and the dielectric dissipation factor. The results of PL spectroscopy were compared to those of UV-Vis spectroscopy for the same samples and the parameters extracted from PL spectra were compared to the aging b-products extracted from UV-Vis spectra. Finally, the corresponding physical mechanisms were discussed considering the obtained results and the spectral shift for each spectrum. It was proved that PL spectroscopy is a promising technique for the condition assessment of insulating oil when compared to conventional transformer oil assessment measuring techniques and even to other optical absorption techniques.

Keywords: insulating oil; thermal aging; condition assessment; photoluminescence spectroscopy

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1. Introduction

Condition-based maintenance techniques are the main predictive maintenance procedures that are widely employed by electrical utilities. They rely on the on-line monitoring,