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Direct detection of acetylene dissolved in transformer oil using spectral absorption

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ABSTRACT

Dissolved gas analysis (DGA) is an effective method to indicate the health status of power transformers as miscellaneous dissolved gases are often related to the degradation of insulation materials and inner electrical faults. To realize real-time and accurate measurement of dissolved gas, direct infrared spectral absorption focusing on acetylene detection without an oil-gas separation process is proposed in this study. Based on Fourier transform infrared spectroscopy (FTIR), the infrared light transmission of transformer oil is explored, and spectral absorption parameter of acetylene in gas state and oil phase is compared and analyzed. In the laboratory, the sensitivity of direct acetylene dissolved in oil is tested and enhanced. It is confirmed that the transformer oil can transmit the infrared light, locating in the near infrared spectrum of 0.800–1.687 μm and 1.770–2.261 μm. It is also proved that the direct infrared absorption method can detect acetylene dissolved in oil at the central wavelength of 1.534 μm, laying the basis for new type of DGA technique without oil-gas separation.

1. Introduction

The power transformers are the most critical and expensive components in power grids whose failures have serious damages to electrical systems reliability, especially, the transformer fleets in several parts of the world are operating beyond their design lives, with higher than average loads. There is no doubt that transformer condition monitoring and fault diagnosis is a high priority [1,2]. Dissolved gas analysis (DGA) of transformer oil has been recognized as one of the most useful techniques to detect incipient faults (e.g. arcing, corona discharge, sparking, and overheating) of large oil-immersed power transformers [3]. On the basis of the fault gases information of concentration and increasing rate, the health status can be interpreted and obtained based on rules like the IEC codes [4]. Thus, the accurate and timely dissolved gas information from the DGA process is of great significance.

As to existing offline or online DGA facilities, there are two essential processes: oil-gas separation and gas detection. Presently there are a range of solutions and techniques for the two processes, of which more research is focused on gas detection. Researchers have been always striving to improve accuracy, sensitivity and selectivity of gas detectors, including gas chromatography (GC), thermal conductivity detector (TCD), semiconductor sensors, catalytic combustion detector, etc [5,6]. Novel optical techniques, such as Photoacoustic Spectroscopy (PAS) and Raman spectra analysis, have been also applied in the gas detection and high precision is

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achieved [7–9]. However, all the detection solutions are greatly dependent on oil-gas separation procedure and techniques like the headspace degassing [10,11], membrane separation [12], vacuum degassing [13,14], etc. The polymer membrane separation is one of the most prevalent way due to its easy installation and low cost. But the long response time (oil–gas equilibrium time as long as hours even days [12]) and complex equipment limit its practice in smart grid and the coming Energy Internet. Moreover, these methods are often prone to a certain deviation during the oil-gas separation, as a result, the accuracy of gas detector cannot be guaranteed. Mechanical degassing techniques, oscillation and vacuum degassing, also have these problems. That is to say, extraction of gas undoubtedly leads to uncertainties and ambiguities in gas concentration determination. Therefore, the oil-gas separation process is the core challenge to be solved.

Furthermore, Smart Grids and Energy Internet, have raised an increasing demand of online condition monitoring and diagnosis for the power transformers [15], which relies on more convenient and instant detection. However, only dissolved hydrogen detection directly by optical sensing is available so far [16,17], while the principle and technique is not suitable to acetylene sensing and detection as there is no proper acetylene sensitive materials. Acetylene is an important symbol gas of overheating faults and arc discharge [6], thus this manuscript attempts to detect acetylene without oil-gas separation in a new perspective by using direct infrared absorption spectrum.

2. Experiments of spectral absorption

2.1. Preparation of oil samples

Transformer oil, mainly acting as insulation material and coolant, has excellent properties on electrical and thermal aspects, and widely used in oil-immersed transformers, high voltage (HV) switches, HV capacitors, etc. In essence, transformer oil is a mixture of a variety of large hydrocarbon molecules, including isoparaffinic, naphthenic, naphthenic-aromatic and aromatic hydrocarbons [18], as illustrated in Fig.1.

KI 25X / 45X, meets the standards of IEC 60296-2003 (I), ASTM D3487-09 (II) and GB2536-2011, has been used in various high voltage levels power transformers including the 1000 kV Jindongnan Nanyang-Jingmen UHV AC Pilot Project, was selected as the test sample in this study. Key parameters of KI 25X / 45X were tested and given in Table 1. Five types of oil samples of different concentrations of acetylene gases were prepared according to IEC guidelines [19] through the use of an automatic degassing oscillator in the laboratory to simulate aged or degraded transformer oil in the field. The value of hydrocarbon gases were detected by conventional DGA method (the equipment type: Agilent 7890B) and the typical result was shown in Fig. 2.

The detailed proportions of the gases dissolved in the power transformer oil samples were listed in Table 2.

2.2. Experimental setup

A PerkinElmer manufactured Spectrometer FT-NIR/MIR, was used to conduct the infrared absorption spectrum of the transformer oil samples. The Fourier transform infrared spectroscopy (FTIR) device was used to obtain the specific infrared absorption spectrum of transformer oil. Although the wavelength range can be up to 350 cm^{-1}, the abundant and complex hydrocarbon group strongly absorb the mid-infrared and far-infrared light spectrum. In this sense, near infrared and partial mid-infrared spectrum are emphasized.

The experimental setup is shown in Fig. 3. A particular quartz container on the top right corner was used to hold the transformer oil, with a perfect quartz transmittance of 12,500 cm^{-1}–2100 cm^{-1} (0.800–4.762 μm). To verify the feasibility, the inner width of the quartz cuvette was set as 1 cm and 4 cm respectively.

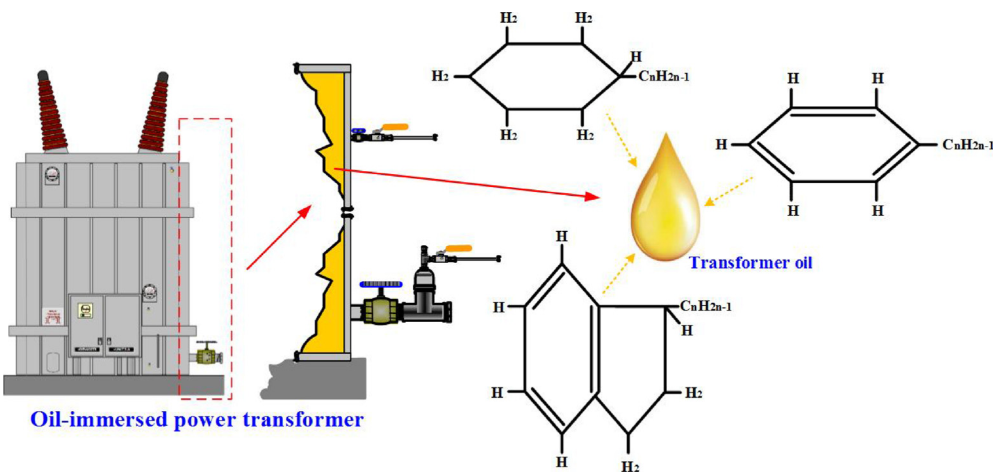

Fig. 1. Illustration of typical components of typical transformer oil.