Electrical Power and Energy Systems 45 (2013) 137–141

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Usage of nanotechnology based gas sensor for health assessment and maintenance of transformers by DGA method

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ARTICLE INFO

Article history:
Received 20 January 2012
Received in revised form 14 August 2012
Accepted 19 August 2012
Available online 6 October 2012

Keywords:
Analyzer
Dissolved gas analysis
Fault diagnosis
Gas sensor
Nanotechnology
Optimum temperature

ABSTRACT

Present day power system is essentially a complex mesh of various important components with power transformer as one of the key elements. For the reliability of power supply, a robust maintenance tool for power-transformer is highly essential. To cater for this demand a portable, online diagnostic device is developed which can record the temperature and quantify the concentration of some of the dissolved gases in transformer oil with the help of a non-invasive sensor fabricated by nanotechnology. After conditioning the signals, the data are transmitted to the nearest substation for storage in computer. For the purpose of analysis and health assessment of the transformers from a remote place, the computer is made accessible through network. From the data of five gases, different faults, if they are occurring inside the transformer, can be predicted. The fault diagnosis is performed by dissolved gas analysis (DGA), which is one of the proven methods widely used during the last two decades.

1. Introduction

In the present day industrial world no compromise can be made on the quality and reliability of uninterrupted power supply. Power transformers are one of the major capital investments in a power system network. Appropriate maintenance, including insulation reconditioning and timely filtration, can extend the life of a transformer to more than even 60 years. In the existing system, maintenance personnel periodically take transformers and circuit breakers offline, in order to check the operating conditions of the equipments. With this method, still there are catastrophic failures, not to mention about the fruitless maintenance. Researchers like Bernadic and Leonowicz have introduced practical approach to power system fault location in power network [20], which could be helpful to locate a faulty transformer. A growing need for lower cost and more accurate diagnostic tools, have led to an introduction of online monitoring system based on artificial intelligence and various analytical techniques in maintenance of electrical power substation. One of the most informative methods for the detection of fault gases is the dissolved gas analysis (DGA) technique [1,2]. Souahla et al. have suggested a new multilayer perception neutral network for decision making in DGA [21]. In this method a sample of the oil is taken from the unit and the dissolved gases are extracted. Then the extracted gases are separated, identified, and quantitatively determined. At present this entire technique is best done in the laboratory since it requires precision operations. Since this method uses an oil sample it is applicable to all type units and like the gas blanket method it detects all the individual components. The main advantage of the DGA technique is that it detects the gases in the oil phase giving the earliest possible detection of an incipient fault. This advantage alone outweighs any disadvantages of this technique. Traditionally, DGA has been carried out by taking a sample of oil from the transformer, sending it to a laboratory and waiting for the results from the gas chromatograph [3]. Unless there was any suspicion of a problem in the transformer, samples might be taken at intervals of up to one year, depending on the maintenance regime of the operator. This means that a fault that develops over a shorter period of time than the sampling interval can be missed, leading to possible catastrophic failure of the transformer. Manual sampling can also lead to errors in the analysis. For example, bad sampling techniques can introduce contaminants into the oil, and inappropriate storage can mean loss of gas from the oil between the time interval taking the sample and analysis in the laboratory. Results can vary from laboratory to laboratory, and even between users of the same equipment. A Round Robin test co-ordinated by Michel Duval for Cigré showed spreads of several hundreds of percent between identical samples tested in different laboratories using various techniques. This can lead to uncertainty in diagnosing the results, especially when looking at trending of gas concentrations. It has been observed that if service provided to the transformer is scheduled

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http://dx.doi.org/10.1016/j.ijepes.2012.08.044

properly, it extends the life of the equipment [22]. Till now experiences with laboratory analysis of dissolved gases (DGA) has been considered as a baseline. However the dynamic behavior of dissolved gases requires continuity and trending, which are unlikely to be captured through periodic manual sampling. To overcome these short comings a gas analyzer is developed to sample the oil continuously in 24×7 modes in the present work. The main component of the gas analyzer is the gas sensor developed with the help of nanotechnology. Semiconductor oxides like SnO_2 [4], Ga_20_3 [5], WO_3 [6], TiO_2 [7] were reported for detection of different hydrocarbon gases but at a quite high sensing temperature (150–450 °C). However nanoparticles help to sense the gases at low temperature and with higher sensitivity. In this research work effort has been given to design and develop a gas sensor from the thin film of doped zinc oxide (ZnO). It is inexpensive, relatively abundant, chemically stable, easy to prepare and non-toxic. For these properties it finds its usage in a large number of areas. Nunes et al. [8], published a report on ZnO sensor for methane detection at low temperature (100–200 °C) but no detail study on dynamic response is reported. In work we have synthesized ZnO by chemical precipitation method [9]. To increase the sensor sensitivity pure ZnO was doped by various concentration of manganese (0.5%, 1.5% and 2.5% by weight).

There are a few commercially available techniques currently used for online detection of dissolved gases in the transformer oil. Different technology based methods are applied in management of power system [23]. Most of the techniques are based on the measurement of a particular gas concentration in a sample of gas extracted from the oil, mainly by using gas chromatograph. These devices are costly and require offline operations (calibration, maintenance, etc.), and the need of sample preparing. In the case of other transducers which are based on infrared technology, there are others inconveniences, such as the limited range of measurement in the low ppm region. Broadly, the three main families of gas sensors are spectroscopic, optical and solid state. Spectroscopic systems are those based on the direct analysis of fundamental gas properties, such as molecular mass or vibration spectrum; optical sensor systems are based on the measurement of the absorption spectra after light stimulation; and solid-state ones are based on the change of physical and/or chemical properties of a sensing material after gas exposure. These changes depend on the gas sensing material and usually involve changes in its electrical properties. In the past Zylka and Mazurek [10] has developed a portable analyzer, fitted with more than one electrochemical gas sensors, for online monitoring of the transformer. In his prototype he used four sensors to detect four types of gases dissolved in the oil. Benounis et al. [11] developed an optical fiber sensor to follow the aging of the transformer oil. An effort has been made by the authors to develop a prototype for online monitoring of the transformer in their research work [24], this work further deal with the fault diagnosing techniques by detecting more number of gases. Numerous researchers have done fault prediction of transformers with the help of DGA and majority of them deals with the fault classification based on the results of gas chromatograph [12].

Novelty of this work lies in the development of a prototype gas analyzer for monitoring the health of the transformer. The gas analyzer uses thin film sensor to detected five dissolved gases in the oil and thus helped in diagnosing major faults occurring inside the transformer. The characteristic of the sensor is that it can sense five gases at different temperature.

2. Methodology of dga

The volume of the system has to be considered when talking about rates of gas evolution. The gases are reported in terms of concentration in parts per million (ppm) and the total gas generated by a fault will be dependent on the total volume of oil the system. To determine rates of gas generation it is necessary to collect samples at different times. Normal aging of the insulating oil will give rise to a slow accumulation of gases over a semiannual sampling period. A moderate accumulation of gases over a monthly interval can indicate an incipient fault, while a rapid accumulation (i.e. over 10% per month) of gases is indication of an active fault. The transformer oil contains number of dissolved hydrocarbon gases; their concentration gives us an indication of the health of the equipment [17]. The fundamental chemical reactions are involved in the breaking of carbon–hydrogen and carbon–carbon bonds. Analysis of the quantity of each of the fault gases present in the fluid allows identification of fault processes such as corona, sparking, overheating and arcing. Table 1 indicates the upper threshold limit of concentration for the dissolved gases in the transformer oil developed at California State University Sacramento in co-operation with Pacific Gas and Electric Company [19]. Table 2 gives the average gas composition present in the transformer oil in volumetric proportion. From Tables 1 and 2 we can infer that H_2, CH_4, C_2H_6, C_2H_2 and CO gas constitute nearly 97% of the total dissolved combustible gases (ppm content of six gases namely hydrogen, methane, ethane, ethylene, acetylene and carbon monoxide constitute TDCG). Increase in the content of these gases gives an indication of a fault occurring inside the transformer. According to the properties of ZnO, it is highly selective towards hydrogen, methane, ethane, acetylene and carbon monoxide at different optimum temperature but they also demonstrate fairly significant cross-sensitivities. Though transformer oil has number of dissolve gases which can be sensed by ZnO, we have studied five main combustible gases namely hydrogen [7], methane [13], ethane, acetylene and carbon monoxide [14,15].

3. Experimental setup

Fig. 1 shows the schematic representation of the placement of the gas analyzer near the transformer. The gas extraction unit along with the sensor is mounted inside a pipe, which is fitted to the oil drain valve at the bottom of the transformer oil tank. The arrangement is such that the sensor is protected against the environmental hazards. Two solenoid valves that are fitted at two ends of a pipe, controls the sampling time of the oil. This is done by adjusting the opening and closing timings of the valves. For some time the oil is trapped inside the pipe, during that time period all the five gases are detected and quantified. With this one cycle of operation is over, after that the outlet valve opens, the tested oil is pumped back into the transformer tank. The sampling time can be adjusted by controlling the timings of the valve operation.

Fig. 2 shows a prototype setup for testing the fabricated sensor, which is an important part of the gas analyzer. Initially test runs were done with high purity (99.9%) hydrogen, methane and carbon monoxide of known concentration. Thin film of manganese doped zinc oxide material, synthesized by chemical precipitation method acts as a gas sensing material. This thin film is coated on a glass

Table 1
Shows the guidelines developed at California State University Sacramento to indicate the level of the gases.

Gas	Normal (ppm)	Abnormal (ppm)
Hydrogen	150	1000
Methane	25	80
Ethane	10	35
Ethylene	20	150
Acetylene	15	70
Carbon monoxide	500	1000