DGA system utilising semiconductor gas sensors

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ABSTRACT

Thermal and electric faults developing inside transformers lead to the generation of gaseous products dissolving in the insulating oil. Chromatographic analysis of the gas products composition and concentration (DGA) is a routine procedure used in test and maintenance of the transformers. Unfortunately DGA is rather a laboratory method and cannot be applied in the field during the transformers exploitation.

The research aimed at working out a portable system for fast, introductory DGA analysis by means of semiconductor gas sensors. DGA procedures, test system construction and efficient gas extraction methods as well as the results of various oil sample tests are discussed. Unexpected impact of the extraction method on the sensor response is also mentioned.

Keywords: dissolved gas analysis, transformer diagnostics, gas sensors, oil

1. INTRODUCTION

Insulating mineral oils are widely applied in high-voltage (HV) insulator arrangements of low, medium and high power transformers. The oils in this kind of HV constructions accomplish two main tasks. They are utilised as a liquid insulating medium and in transport and dissipation of the excessive amounts of thermal energy generated in the transformer core and windings.

Thermal (overheating of wires as well as a solid and liquid insulation) and electric (related to flashovers, line-to-line and earth faults) defects developing inside a transformer lead to the generation of gaseous products saturating the oil. Composition of the volatile matters dissolved in the insulating oil filling the transformer tub fluctuate in course of time. This disadvantageous phenomenon may be however kept under the control and utilised for non-invasive examinations of the transformer during its continuous exploitation.

Chromatographic analysis of the composition and concentration of the gaseous products present in the oil (*Dissolved Gas Analysis* DGA) is considered today as a main standard procedure used in long-term maintenance and management of the power transformers. Tests are carried out each 6-12 months and consist in sample collection (approx. 1 l of the oil) from the tub, vacuum gas extraction and determination of the proportions of the individual gaseous constituents by means of *Gas Chromatography* (GC) [1]. The described above procedure takes on average a few days what may interfere with the credibility and reliability of the test results while the proper sampling procedures and the time taken between the sampling and the measurements are critical [2].

The insulating oil before having been used for filling the transformer tub is initially centrifuged and degassed but when exploited it absorbs gases from the air. Combustible gases (H_2, CH_4, C_2H_X, C_3H_X, C_4H_X) and gaseous combustion products (CO and CO_2) appear in the oil as a result of the ageing processes and faults.

A great number of scientific publications concerning DGA has been issued and a considerable part of them deals with methods of the transformer internal fault classification based on the results of GC DGA [3-4]. One analysing these methods must find that from the assessment of the liquid insulation condition point of view the key task is to determine composition and concentration of combustibles (H_2 and low hydrocarbons CH_4 and C_2H_X) and products of their combustion (CO and CO_2) as well as the rate of their concentration fluctuations [5].

Taking into account the specificity of the oil sampling and pre-treatment operations as well as the equipment fragility (gas chromatographs) it should be stated that the standard DGA procedures cannot be applied for fast carried out in the field introductory analysis and for the on-line supervision of the oil-insulated high-power appliances.

Experience of the last few years shows that the semiconductor gas sensors together wit carefully selected and optimised gas extraction method create a possibility of the preliminary DGA being carried out in the field or implemented for the on-line tests.

2. EXPERIMENTAL

Application of the semiconductor gas sensors ensures miniaturisation, full mobility and microelectronics compatibility of the prototype DGA system. Four commercially available inexpensive AF series gas sensors have been chosen (AF10, 20, 50 and 56 for H_2, CO, CH_4 and C_4H_{10} respectively). From many of the available and suitable degassing methods two have been selected: the thermal and ultrasonic one. All investigation tests were run on samples taken from the existent transformers which were also subjected to GC DGA examinations.

The prototype test arrangement (Fig. 1) consisted of the oil vessel (volume approx. 1 l) covered with a lid with the gas sensors attached. Sensor heaters were supplied from a stabilised laboratory DC power supply with voltage regulated from 4.6 to 5.4 V.

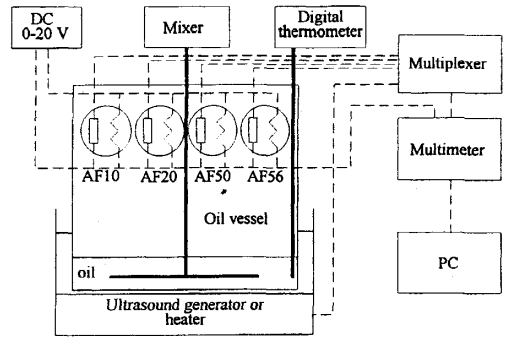

Fig.1 Schematic test system setup

Measurements of the sensor resistance responses were done using a four channel multiplexer (IPACO CAM) and a digital multimeter (HP34401).

HP Vee (*Visual Engineering Environment*) software was implemented for control of the measurement set-up and recording of the data using GPIB interface. A laboratory ultrasonic washer coupled with the oil vessel by a water bath was employed as the ultrasound source. The washer operation was also controlled by the multiplexer relay switch.

3. DISCUSSION

Preliminary measurements of the long-term sensor stability were carried out for various heater supply voltages ranging from 4.6 to 5.4 V (sensor heaters are designed to gain the optimal temperature at 5.0 V but by varying the supply voltage one can shift the sensitivity and selectivity of the semiconductor gas sensing devices).

Results of the tests conducted for 12 hours indicated a satisfactory stability of the resistance response of the AF20, 50 and 56 sensors over a wide range of the active layer temperature while the hydrogen sensor (AF10) exhibited considerable resistance fluctuations with a tendency to rise with the increasing heater supply voltage . Fig. 2 and 3 demonstrate the

stability test results carried out for low (4.6 V) and standard (5.0 V) sensor heater supply. The most stable sensors from the tested batch were selected for the subsequent measurements.

The erratic H_2 sensor response in pure air led to the employment of the following measurement regime: recording of the initial resistance changes over approximately 60 s after introducing an oil sample into the oil vessel (without having reached a stable baseline), activation of the gas extraction process (120 s for ultrasonic one or until the oil reached 50°C), termination of the degassing (and cooling of the vessel in the thermal method) and the final recording of the baseline drift (100 s). Variations of the baseline in course of the extraction process were extrapolated on the basis of the data gathered in the pre- and post-extraction intervals. Gas-in-oil concentration was calculated from the following expression (1):

$$c_{sr} = \int_{t_1}^{t_2} \left(R_e / R_a - 1\right) dt \Big/ t_2 - t_1 \qquad (1)$$

where R_e is the sensor resistance when the extraction is performed, R_a is the extrapolated baseline sensor resistance, t_1 and t_2 are the time of the extraction activation and termination respectively.

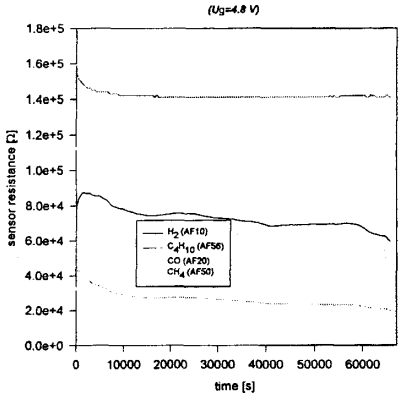

Fig. 2. Long-term sensor stability (low heater supply voltage)

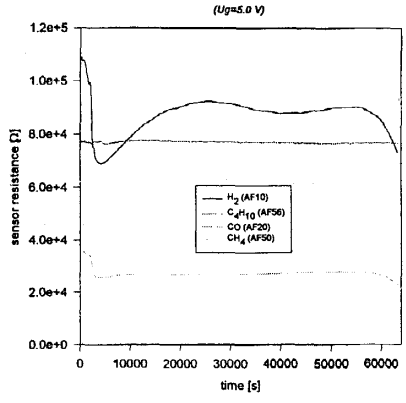

Fig. 3. Long-term sensor stability (standard heater supply voltage)

System start-up time was estimated to be around 60 min but it may be considerably shortened (even to approximately 15 min) by the initial increase of the sensor heater supply voltage to its maximal allowable value.

Figures 3 and 4 graphically demonstrate the most characteristic exemplary resistance responses registered for the thermal degassing method for various heater supply voltages.

In case of this method activation and termination of the heating are manifested by a minor change in the resistance decay ratio. The changes are more clear when the vessel is cooled to the ambient temperature on the termination of the extraction. Drop in the sensor response during the extraction in comparison to its post-extraction values is perceptible but very long time (a dozen or so minutes) needed by the system for a subsequent stabilisation makes it difficult to reconstruct the baseline and hinders the quantitative analysis. It should be then stated that the thermal degassing method is not a perfect solution of the gas removal from the oil samples (in DGA context) due to very long measurement time and hazards of the thermal oil decomposition.

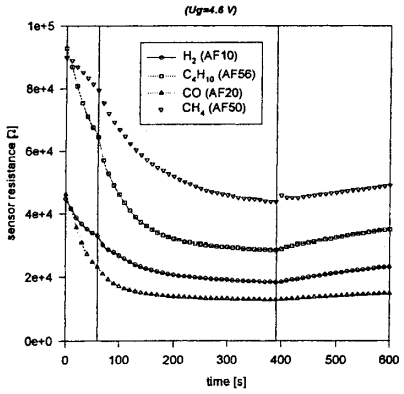

Fig. 4. Resistance responses - thermal extraction method

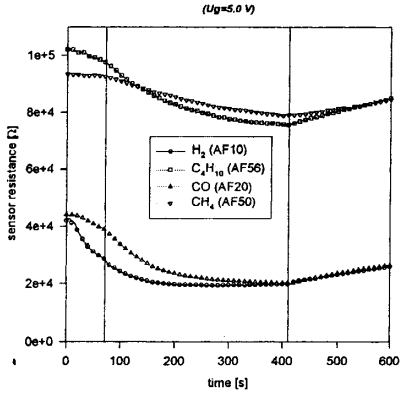

Fig. 5. Resistance responses - thermal extraction method

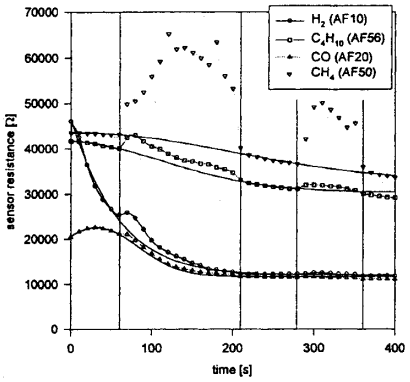

Fig. 6. Resistance responses - acoustic extraction method

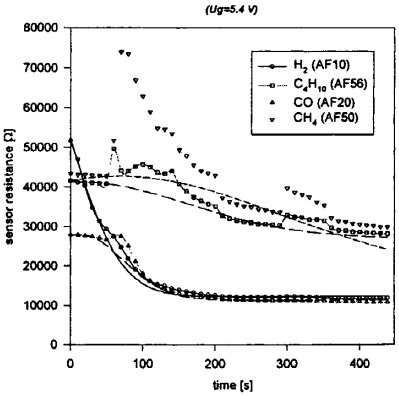

Fig. 7. Resistance responses - acoustic extraction method

Figures 6 and 7 show exemplary resistance responses recorded for the thermal degassing method for various heater supply voltages (5.0 V and 5.4 V respectively).

When the acoustic method is applied response of the sensors between the start and the end of the degassing is very sudden and intense. But its pattern is diametrically opposed to the one observed in the thermal method. The gas discharge from the oil induce a reversal sensor response, which is inconsistent with the theoretical model of the semiconductor gas sensor response in the reducing gas atmosphere. It seems to be possible that this astonishing effect may be associated with some undetermined mechanism of the SnO_2 layer activation by the acoustic energy.

Attempts made to quantify the content of the basic gases in the test oil samples brought some satisfactory results. It should also be mentioned that the AF series gas sensing devices utilised in the prototype set-up allow for more precise measurements when the heater supply voltage differs from the one suggested by the sensor manufacturer. AF50 and 56 sensors also slightly respond to some volatile matters present in the pure centrifuged and degassed oil ready for filling the transformer (see Fig. 8 and 9).

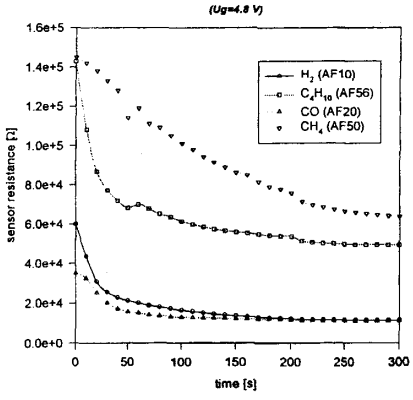

Fig. 8. Resistance responses in pure oil - acoustic extraction method

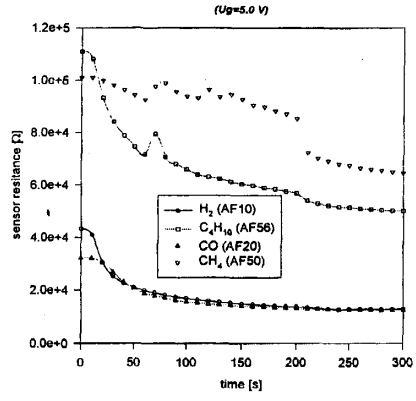

Fig. 9. Resistance responses in pure oil - acoustic extraction method

3. CONCLUSIONS

Concluding the discussed results and observations it should be stated that:
- application of the semiconductor gas sensors, in spite of their limited long-term stability, sensitivity and mainly selectivity is possible in some basic DGA analysis
- the ultrasonic gas extraction method possess many advantages comparing to the thermal one (high efficiency, short system response time, low power consumption, no danger of the oil decomposition) and seems to ideally suit DGA applications
- there are some necessary modifications of the test vessel and the measurement scheme
- the reversal sensor response phenomenon requires more comprehensive research

4. ACKNOWLEDGEMENTS

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