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The monitoring of oil distribution transformers in laboratory conditions

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Abstract

The paper deals with physical fundamentals of monitoring the high-voltage oil transformer 22/0,4 kV by gas- and moisture-in-oil sensors, optical temperature sensors and an electric quantities analyser.

Keywords: oil transformer, gas and moisture sensor, chromatography, monitoring.

Monitoring rozdzielczych transformatorów olejowych w warunkach laboratoryjnych

Streszczenie

W artykule omówiono fizyczne podstawy monitorowania olejowych wysokonapięciowych transformatorów 22/0,4 kV przy pomocy analizatora zawartości wilgoci gazów w oleju, optycznych czujników temperatury oraz analizatora wielkości elektrycznych. Stwierdzono, że ze wzrostem stopnia zawilgocenia oleju w czasie pracy transformatora następują zmiany takich podstawowych jego właściwości jak napięcie przebicia, współczynnik strat dielektrycznych oraz rezystywność. Naprężenia elektryczne i termiczne skutkują powstawaniem w oleju szeregu gazów, które można wykorzystać do wczesnej diagnozy powstających uszkodzeń urządzenia elektrycznego. Uszkodzenia takie mogą powstawać w różnym tempie, dlatego optymalna do ich detekcji jest diagnostyka on-line. W tym celu kanadyjska firma GE Energy Services opracowała przyrząd Hydran umożliwiający analizę parametrów oleju. W artykule przedstawiono przykład praktycznego wykorzystania tego miernika, który wraz z pomiarami termowizyjnymi wykorzystano do monitorowania transformatora w laboratorium. Zaobserwowano, że w zależności od obciążenia następują zmiany zawartości wody w oleju transformatorowym. Podczas takiego procesu właściwości oleju pogarszały się.

Słowa kluczowe: Olej transformatorowy, czujnik gazu i wody, chromatografia, monitoring.

1. Introduction

Electric and thermal stresses transform the dielectric oil into various gases. These gases indicate development of a damage in the electric machine or apparatus and their early indication contributes to precocious intervention and financially demanding removal of the extensive damage. The created gas is dissolved in insulating oil in amount depending on the kind of gas, quality of insulating oil, its viscosity, temperature and pressure.

A fault occurring in a transformer can develop either slowly or quickly depending on its kind. Therefore it is suitable to watch the transformer operation in real time so that it is continually known what the inner condition is. Because of the fact that the transformer oil contains various dissolved gases, observing this medium is easiest.

For this purpose a Canadian company named GE Energy Services constructed and developed a device Hydran based on the lifetime experience.

2. Analysis of gas released in the transformer oil

According to [1], the effect of temperature, aerial oxygen, moisture and electric field in a transformer leads to formation of gas products of aging during the process of perpetual stress of the insulating system. At the same time it causes the decrease in the quality of insulating fluid and paper in the transformer. The quantitative state of gases in oil gives an overall picture on the condition of the whole transformer insulation.

Gas chromatography allows analytical observation of scanning products by dividing particular components of gases created in oil. These products of disassembly mutually differ as a consequence of various energy effects of faults existing in a transformer, as it is dealt here with different chemical bindings (binding energies).

Low intensity of partial discharges (trivial gases seals, defective impregnation) causes the creation of low power density, which results in accumulation of hydrogen H_2 and methane CH_4.

High activity of partial discharges (fault contacts, arcs, partial breakdowns, short arcs) high power density (>1000 K) causes repeated accumulation of hydrogen H_2 and bigger amount of ethylene hydrocarbons - acetylene C_2H_2 and ethylene C_2H_4.

In the cutoff case, i.e. thermal decomposition (at transformer overload, contact resistances on contacts), hydrocarbons C_2H_2, C_2H_4, CO and CO_2 are mostly released.

Observation of the concentration of H_2 and CO is of huge importance – hydrogen is the first gas released at the overload of transformer oil. On the other hand, carbon monoxide emerges during the degradation of insulating paper [2]. Another important factor influencing the functionality of a transformer is the water content in the system. Water is located in the form of moisture and is foremost absorbed in solid insulation, where it causes accelerated aging of that insulation. During the transformer operation or in the case of overheating, water merges from solid insulation into oil, which causes the worsening of dielectric properties of oil, especially its breakdown strength.

Based on the quantitative and qualitative analysis of the scanned gases, it is possible to consider not only the degree of heat aging, but also the kind of fault (mutual relation of given gases) which caused the acceleration of aging (partial discharges, electric arcs, local overheating). If very weak partial discharges emerge at which the oil temperature is contained in the range of 80 °C to 120 °C, only hydrogen appears in the gas. At the temperatures within the range of 120 °C to 200 °C also methane (CH_4) and ethylene (C_2H_4) can be observed. At the temperatures in the range from 200 °C up to 500 °C (partial discharge of high energy) the gas is enriched with higher hydrocarbons. At the temperatures exceeding 500 °C (spark or arc) also more complex hydrocarbons emerge.

Gas analysis in transformer oils leads to clear attachment of oil files to the cause of the fault, which can help determine the origin of the damage.

3. Description of the sensor Hydran M2

One of the latest and economically best accessible systems for the on-line monitoring of transformer oil is the sensor Hydran M2 developed by the Canadian company GE Energy Services – Syprotec (Fig. 1).

Fig. 1. The sensor for the monitoring of transformer oil - Hydran M2 [7]
Rys. 1. Hydran M2- czujnik do monitoring oleju transformatorowego [7]

The sensor detects gases and oil moisture, which is evaluated as absolute and relative value. It is sensitive to the presence of particular gases like hydrogen (H_2 – 100 %), carbon monoxide (CO – 18 %), acetylene (C_2H_2 – 8 %) and ethylene (C_2H_4 – 1 %). The system does not measure values of the given gases but their composition values, i.e. the overall amount of combustible gases. This amount is depicted within the range of 0 – 2000 ppm. The presence of these gases in the oil is the result of thermal and electrical stresses of a transformer and thus gives the information about the current state of the transformer. A timing scan of concentration of the given gases also informs about the development of certain faults in the system.

This sensor uses a polymeric membrane and a catalytic oxidation reaction that produces an electric signal proportional to the inflow of the dissolved gas.

Although this new sensor is highly selective to acetylene, it has the small cross-sensitivity to other gases such as hydrogen, carbon monoxide and ethylene. A fault generating acetylene can be quite serious even with only a few ppm of gas being produced; a level as low as 5 ppm can be sufficient to justify investigation. On the same transformer it may not be unusual to find over 100 ppm of hydrogen and up to 1000 ppm of carbon monoxide. Even a slight cross-sensitivity would deteriorate the acetylene reading below the acceptable level. This drawback is overcome by coupling the acetylene sensor with a classic Hydran sensor.

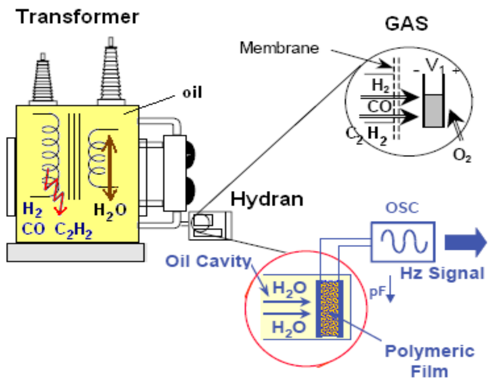

Fig. 2. Principled scheme of Hydran M2 function - GAS and H_2O (moisture) sensor –modification from [5] and [8]
Rys. 2. Zasada działania czujnika Hydran M2 – monitoring gazów i H_2O. Opracowano wg [5], [8]

Since the Hydran sensor measures the same gases to which the acetylene sensor is cross-sensitive, it is possible to use this to correct the acetylene sensor reading. The resulting accuracy for measuring acetylene is ±10% of reading ±2 ppm over a range of 3-500 ppm. The acetylene sensor is mounted on a common sampling head with the Hydran sensor allowing both sensors to be fitted on a single valve. [5]

The key strengths of the sensor Hydran [8]:

- it warns early about the creation and development of a damage which could subsequently lead to the damage of the transformer,
- hourly and daily trend (ppm change during the period) with alarm possibilities,
- memory of files dated up to one year back and up to 500 events with timed and dated mark,
- settable alarms to oil level and its trends,
- network possibilities,
- sensor and the system have auto-test and diagnostics,
- calibration is executed with the help of the software,
- remote or local configuration, calibration of the sensor and upgrade of the software,
- possibility of the operation even without the external connection.

In addition, it contains up to 4 analogue inputs used for measuring quantities such as current or voltage (to measure the load, temperature from various parts of machine, eventually the environment temperature). Thanks to this fact, it is possible to directly apply computing modules such as the hottest wining point and its moisture, bubble creation temperature, transformer cumulative aging, cooling effectiveness etc. in the Hydran system in real time.

The data is automatically worked up, archived and in case of reaching or exceeding the values (set by a user), binary outputs and communication in numeric form are activated. The system allows local as well as remote administration through RS232, RS485, modem or protocol TCP/IP.

Thanks to its robustness, resistance, speed of response, complexity of functions we deal with ideal monitoring for all kind of transformers (distributional 22/0,4 kV, 110/22 kV, transmitting 400/110 kV and regulating). Easy montage also allows easy relocation if needed. The system is convenient also from the point of view of the future development when it is possible to extend its functions or include them into the extensive monitoring systems as the sensor itself cannot make percentage discernment (it is not dealt with gas chromatography).

4. Description of experimental measurement

A practical example of the sensor Hydran M2 application is on the distribution transformer 22/0,4 kV, 30 kVA in the Diagnostics Laboratory of diagnostics of electric machines at the Department of Measurement and Applied Electrical Engineering at the University of Žilina (Fig. 3).

Only one valve piece (one effluent located at the very bottom part of the cover) was used to measure gas concentration and moisture in the oil (Fig. 1 or Fig. 3). The machine was installed without an additional oil hose, while it was not necessary to use additional pumps or other movable components. The oil circulation was ensured with passive circulation influenced by the pulsing of its temperature.

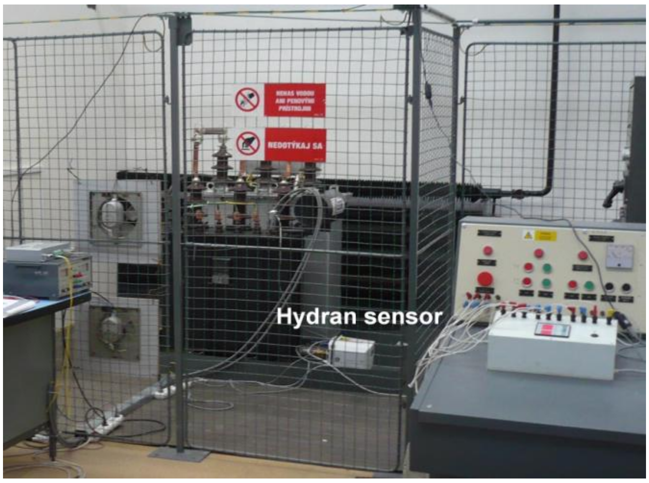

Fig. 3. View of the measured transformer in the Diagnostics Laboratory at the University of Žilina
Rys. 3. Widok testowanego transformatora w Laboratorium Diagnostyki Uniwersytetu w Žilinie

Two optical readers with a measuring unit Neoptix were used for measurement of the winding temperature. These were installed on the upper and middle part of the primary phase B before the operation.

The transformer bushings and tank were monitored with a thermovision camera (Fig. 4). Currents, voltages, powers and harmonic analysis on the load side were monitored by the power analyser DMK40 developed by the company Lovato. [3]

Before the launch of the "cold" transformer to the operation, the chromatography analysis of transformer oil had been carried out (Tab. 1) together with its breakdown and insulation probes. After two weeks of operation of the "hot" transformer at approximately 10÷30% load, oil controlling tests were carried out based on the size of the breakdown voltage and other insulation parameters.

Tab. 1. DGA analysis of transformer oil
Tab. 1. Analiza DGA oleju z transformatora

Gas / water	(ppm)
water	25
CO2 + CO	1390
H2	26
C2H4	19
C2H2	< 1

Table 2 presents the comparison of the values of transformer oil tests "before the launch" and "during the operation" of the machine. Fig. 5 depicts the monitored values of gas amount, and water in ppm measured by the sensor Hydran and the values of the winding temperature measured with an optical analyser. It should be underlined that "before the launch" the transformer had been out of business for several years.

Tab. 2. Oil parameters measured before and during transformer operation
Tab. 2. Właściwości oleju zmierzone przed i w czasie pracy transformatora

Tests	Before the launch	During the operation
Breakdown voltage (kV/2,5mm) - 23°C	77,9	41,3 (min.30)
Loss factor tg δ - 23°C	$0,7.10^{-3}$	$1,2.10^{-3}$
Loss factor tg δ - 70°C	$5,6.10^{-3}$	$10,3.10^{-3}$
Loss factor tg δ - 90°C	$15,6.10^{-3}$	$21,9.10^{-3}$ (max.100.10^{-3})
Rel. permitivity ε_r - 23°C	2,1907	2,1930
Resistivity ρ (GΩm) - 20°C	496,4	116,12 (min. 60)
Resistivity ρ (GΩm) - 70°C	99,1	51,23
Resistivity ρ (GΩm) - 90°C	51,1	22,54

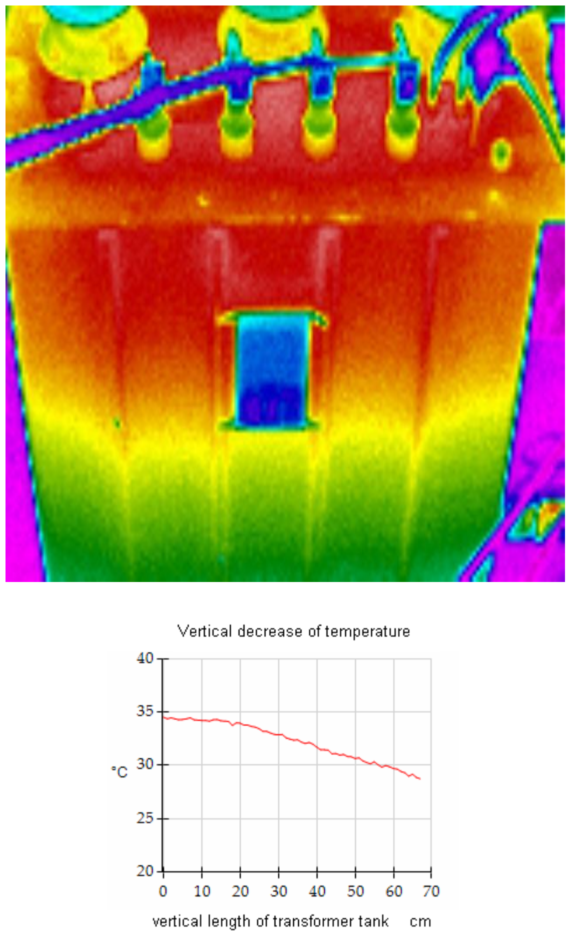

Fig. 4. Temperature distribution in the monitored transformer
Rys. 4. Rozkład temperatury w monitorowanym transformatorze

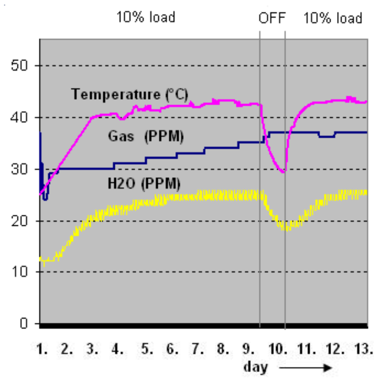

Fig. 5. Monitored temperature, gas and water during 13 days: 10% load - OFF (1 day) - 10% load

Rys. 5. Monitorowane wartości temperatury oraz zawartości gazu i wody w okresie 13 dni: 10% obciążenia – WYŁ (1 dzień) - 10% obciążenia

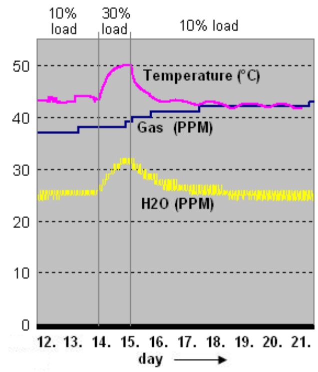

Fig. 6. Monitored temperature, gas and water during 13 days: 10% load - 30% load (1 day) - 10% load

Rys. 6. Monitorowane wartości temperatury oraz zawartości gazu i wody w okresie 13 dni: 10% obciążenia – 30% obciążenia (1 dzień) - 10% obciążenia

5. The analysis of the measured values

Based on the measured values, the following statements were verified:

1. Before the operation too big amount of carbon monoxide had been measured, which showed high degradation of the insulating paper as a consequence of long-time transformer layoff (Table1). Since during the measurement of the insulating resistance the polarization index of the machine was over the value 1,3, it was possible to set the transformer going.
2. After the launch of the transformer and at 10% load we could observe the gradual growth of the gas amount (slight growth of hydrogen). It was the consequence of the transformer heating by the previous currents and possible weak thermally flat partial discharges [1], where hydrogen emerged as a product of fission of aromatic hydrocarbons. The influence of acetylene and ethylene at such low load could be neglected. Both gases emerged due to high temperatures as a consequence of high activity of partial discharges (faulty contacts, arcs, partial discharges).
3. After the launch of the transformer and its subsequent load, the temperature began to increase from the original environment temperature of 25 °C to the temperature of 42°C within 2 days. Once the transformer was switched off on 10th day, we observed fast exponential decrease of the temperature by up to 75%. After the repeated switching on of the transformer, the temperature was stabilized at original 42 °C. After the change of the load to 30%, the repeated increase in the temperature appeared again. The transformer reached its characteristic running temperature at the full load (Fig.6).
4. One of other parameters we could observe was water content in the transformer oil. We could watch very well here the accumulation of water after the launch of the transformer. The accumulation of the water content is connected with transmission of the water stored in the insulating paper during its heating. The increased presence of water is one of the crucial factors influencing the worsening of the dielectric properties of the transformer oil (see Table 2). The dependence of the amount of water in oil copies the thermal dependence with very slight delay with visible effects: fast decline at the moment of switching off the transformer and the increase at the change of load to 30%.
5. After a few-hour decrease in the temperature up to 75% of the stable value, the gas showed delayed (by up to 24 hours) very marginal decrease in ppm. The process of change in proportion of hydrogen and carbon oxide was thus very slow. It was a consequence of the fact that water in the oil dropped 25% as a consequence of the repeated transmission into the paper insulation (Fig. 5 at the time of switch off – 10th day).

6. Conclusion

In the case of the described transformer there were analysed the changes of capacities of gases, water and temperature of oil with the help of the sensor Hydran M2. It was observed that depending on the used transformer load, the stable water temperature and water content in the transformer oil shifted.

The dielectric properties of the transformer oil deteriorated with the accumulation of water content during the operation and with the influence of other factors.

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