GAS ANALYSIS OF OIL TRANSFORMER AND ITS MONITORING IN LABORATORY CONDITIONS

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Abstract: *The Paper deals with the physical fundamentals of the monitoring of values of high-voltage oil transformer 22/0,4 kV by oil sensor of gases and moisture, optical temperature sensors and electric quantities analyser.*

Key words: Oil transformer, gas and moisture sensor, chromatography, monitoring, temperature sensor, gases.

1. Introduction

Electric and thermal stress transforms the dielectric oil into various gases. These gases indicate developing damage on the electric machine or apparatus and their early indication contributes to precocious intervention and financially demanding removal of the extensive damage. Created gas in insulating oil is dissolved in amount depending on the kind of the gas, quality of insulating oil, its viscosity, temperature and press.

Fault occurring in transformer can develop either slowly or quickly based on its kind. Therefore it is suitable to watch the transformer running in real time so that we can continually know what is going on inside. Because of the fact that transformer oil is dissolved into various gases it is most simple to observe right this medium.

For this purpose Canadian company GE Energy Services based on lifetime experience constructed and developed apparatuses Hydran.

2. Gas analysis released in the transformer oil

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

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 variant energy effects of faults, existing in 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 causes the accumulation of share of hydrogen H_2 and methane CH_4.

At high activity of partial discharges (fault contacts, arcs, partial breakdowns, short arcs) high power density (>1000 K), which causes repeated accumulation of hydrogen H_2 and bigger amount ethylenic 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) mostly hydrocarbons C_2H_2, C_2H_4, CO and CO_2 are released.

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).

Sensor detects gases and oil moisture, which is evaluated as absolute and relative. It is sensitive on 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 concrete gases but their composition values, i.e. 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 transformer and thus gives us the information of the current state of transformer. Timing scan of concentration of given gases also offers us information about the development of certain faults in the system.

Observing 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]. Other important factor influencing the functionality of 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 accelerating aging of the insulation. During the running of transformer or eventually overheated, water merges from solid insulation into oil which causes worsening of dielectric properties of oil, especially worsening of its breakdown strength.

Fig. 1. The sensor for the monitoring of transformer oil - Hydran M2 [7]

Based on the quantitative and qualitative analysis
Based on the quantitative and qualitative analysis of scanning 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 are emerging at which the oil temperature shifts within 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 being enriched with higher hydrocarbons. At the temperatures exceeding 500 °C (spark or arc) also more complex hydrocarbons emerge.

The key strengths of the sensor Hydran [8]:

- it warns early about the creation and development of damage which could subsequently lead to the damage on 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,
- the possibility of the operation even without the connection of external.

In addition it contains up to 4 analogue inputs used for measuring quantities 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 in real time directly in the Hydran system to apply computing modules such as the hottest wining point and its moisture, bubble creation temperature, transformer cumulative aging, cooling effectiveness etc.

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 in case of need. 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

The example from praxis can be the usage of the sensor Hydran M2 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.2).

Only one valve piece (one effluent located at the very bottom part of the cover) was used to measure gases concentration and moisture in the oil (Fig.1 or 2). The machine was installed without 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.

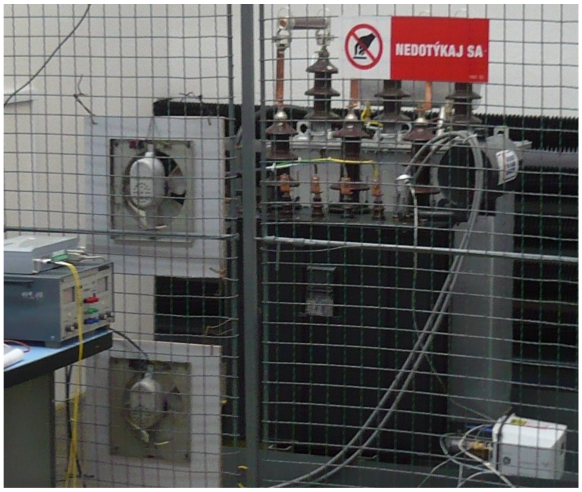

Fig. 2. View of the measured transformer in the Diagnostics Laboratory at the University of Žilina

Two optical readers with measuring unit Neoptix were used for measurement of the winding temperature.

These were installed on the upper and middle part of primary phase B before the operation. Currents, voltages, powers and harmonic analysis on the load side were monitored by power analyser DMK40 developed by the company Lovato. [3]

Before the launch of "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 "hot" transformer at approximately 10÷30% load, oil controlling tests were carried out based on the size of breakdown voltage and other insulation parameters. Tab.2 depicts the comparison of values of transformer oil tests "before the launch" and "during the operation" of machine.

Fig.3 depicts the monitored values of gas amounts, and water in ppm measured by the sensor Hydran and values of winding temperature measured with optical analyser.

It needs to be underlined that "before the launch" the transformer had been out of business for several years.

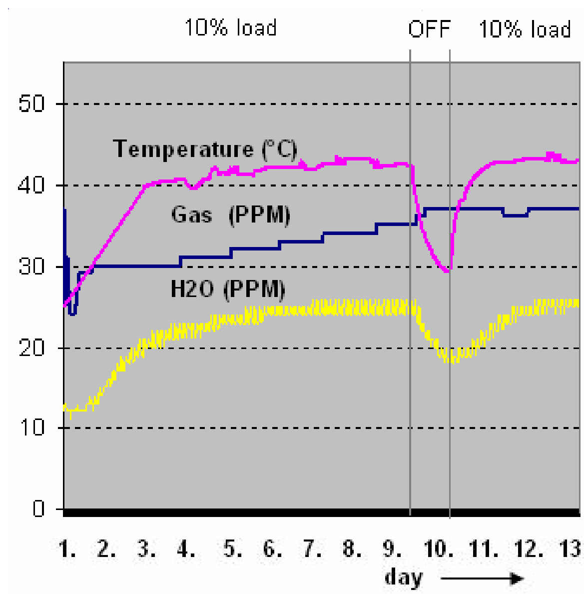

Fig. 3. Monitored temperature, gas and water during 13 days: 10% load - OFF (1 day) - 10% load

Table 1

Gas / water	water	$CO_2 + CO$	H_2	C_2H_4	C_2H_2
(ppm)	25	1390	26	19	< 1

Table 2

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

5. The analysis of measured values

Based on the measured values we verified the following statements:

1. Before the operation too big amount of carbon monoxide had been measured which shows high degradation of insulating paper as a consequence of longtime transformer´s layoff (Tab.1). As during the measurement of 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 transformer and at 10% load we can observe gradual growth of gas amount (slight growth of hydrogen). It was the consequence of heating of transformer by the previous currents and possible weak thermally flat partial discharges [1], where hydrogen emerges as a product of fission of aromatic hydrocarbons. The influence of acetylene and ethylene at such a low load can be neglected. Both gases emerge based on high temperatures as a consequence of high activity of partial discharges (faulty contacts, arcs, partial discharges).
3. After the launch of transformer and its subsequent load the temperature began to increment 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 observe fast exponential decrease of temperature by up to 75%. After the repeated switching on of transformer the temperature was stabilized at original 42 °C. After the change of load to 30% repeated increase of temperature appears again. Transformer reaches its characteristic running temperature at the full load.
4. One of other parameters we could observe was water content in transformer oil. We can watch very well here the accumulation of water after the launch of transformer. The accumulation of water content is connected with transmission of water stored in insulating paper during its heating. Increased presence of water is one of the crucial factors influencing the worsening dielectric properties of transformer oil (see Tab.2). The dependence of the amount of water in oil copies 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 of temperature up to 75% of the stable value, the gas was showing delayed (by up to 24 hours) very marginal decrease in ppm. The process of change in proportion of hydrogen and carbon oxide is thus very slow. It is a consequence of the fact that water in oil dropped 25% as a consequence of repeated transmission into paper insulation (Fig.3 at the time of switch off – 10th day).

6. Conclusion

On the transformer we studied the changes of capacities of gases, water and temperature of oil with the help of the sensor Hydran M2. We observed that depending on the used transformer load, stable water temperature and water content in transformer oil shift.

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

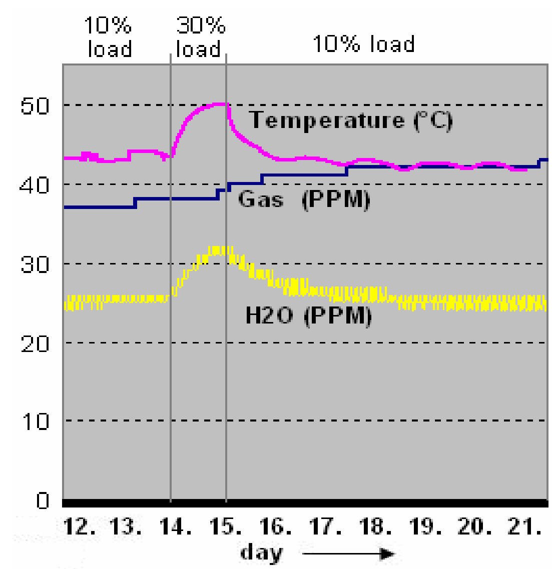

Fig. 4. Monitored temperature, gas and water during 10 days: 10% load - 30% load - 10% load

Acknowledgments

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