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INSULATING OIL REGENERATION AND ITS INFLUENCE ON THE TECHNICAL SAFETY OF TRANSFORMERS

Key words

Paper-oil insulation, insulating oil, diagnostics of transformers, oil regeneration.

Abstract

Insulating oils are the coolants of the transformer winding. During the operation, they are subjected to numerous and diverse extortion; they accumulate destruction of a variety of products of structural elements of the transformer in themselves and, as a result they change their own properties. The systematic analysis of composition and characteristics of the insulating oil provides information about the condition of the whole transformer. The article presents the results of an investigation of insulating oil condition during operation of a transformer, and it proposes actions to monitor the insulation oil and prolong its service life. Regular tests allow the regeneration of oil (e.g. by vacuum treatment, drying) at the right time, which eliminates the need for costly oil exchange in many cases. Monitoring of the insulating oil also has a large impact on the technical safety, which is related to risk mitigation of major accidents, such as electric shocking or even transformer explosions. The obtained results confirm the validity of the insulating oil regeneration process as

a method for decreasing operating costs, which is simultaneously efficient and environmentally friendly.

Introduction

The proper functioning of the transformer is determined by the condition of the oil-paper insulation. Transformer oil serves as a coolant, restricts the access of air, protects against corrosion, and serves electrical insulating functions. The main factors that affect the intensity of the transformer oil aging process during operation are high temperature, the impact of oxygen, the presence of water, the catalytic effect of the copper and the depolymerization of cellulose in paper insulation. The cellulose insulation is intended to protect windings made of electrolytic copper [1, 2]. The stability of the transformer insulation determines the transformer operating time and depends on many factors, such as temperature, humidity, impurities, winding displacement at points of expansions and contractions, and vibration [3, 4]. The more wetted cellulose is, the faster the process of depolymerization goes. Under the influence of load and time, the transformer occurs the aging process. The nominal life of a transformer is estimated at approx. 30 years; however, economic considerations have shaped the trend of maximizing the functional life transformers, which entails the need to carry out the regular inspections, modernization, and repairs. These actions are intended to ensure the faultless operation of transformers [5].

Extending the functional life of a transformer requires the fulfilment of the following basic conditions affecting its operation [1]:

- Protection against external factors;
- Maintaining the temperature and the load;
- Controlling the insulating oil parameters;
- The implementation of maintenance and renovation; and,
- Conducting a comprehensive diagnosis of the unit's technical condition.

One of the primary transformer operation management tools is their comprehensive diagnostics [6]. Proper control of the technical condition of the transformer is based, inter alia, on the determination of moisture and aging of paper insulation, insulating oil moisture measurement, measurement and localization of partial discharge, dielectric loss factor measurement at high voltage and winding resistance, transformer winding deformation detection, and the investigation of gases dissolved in the oil (DGA – *Dissolved Gas Analysis*) [3, 7]. The diagnostic tests selected depend on the type and power of the transformer. It is necessary to appropriately select suitable research techniques, because transformer failures have very serious consequences, both technical and economic. For example, these are power failure costs and the costs of repair and replacement of damaged equipment and facilities, including the contamination of the area. An improperly supervised and maintained transformer can cause environmental problems associated with the possibility of still commonly used mineral transformer oils entering into the environment. Preferably, it would be the best to avoid it leaks into the ground and, consequently, contamination of water reservoir and watercourses [1, 8].

Transformer oil exploitation involves the gradual deterioration of its operating parameters, often as a result of contamination, which may be impurities such as sand, corrosion products, microfiber cellulose, or chemicals such as water, furan derivatives, organic acids, and gaseous products [9].

If irregularities of the technical condition of the transformer or transformer oil, they can be removed depending on their degree of complexity.

One of the major solutions is the regeneration of the oil. This procedure allows improving the operating characteristics, and thus extending the faultless operation of the transformer.

1. Insulating oil regeneration methods

For transformer oil regeneration, physical, chemical, and physico-chemical methods are applied. The selection of the appropriate method depends on the degree and the type of oil contamination. Moisture can be removed by draining oil, solid contaminants are removed by appropriate purification, and gaseous products are removed by degassing the transformer oil. For transformer oil purification, the following methods are applied [1]:

- Filtration,
- Centrifugal separation,
- Sorption, and
- Electrostatic separation.

Filtering methods are based on the use of porous materials and allow removal of solid contaminants such as metal particles, carbon black, microfibers, etc. Filtration methods include gravity filtration, in which the oil flows through the filter by gravity forces, pressure filtration, wherein the oil passes through the filter due to the pressure difference before and behind the barrier filter, filtration through extrusion, wherein the solid particles are separated from the oil as a result of extrusion through a filter using a press. The advantage of filtration methods is their high process effectiveness.

The centrifugal methods use the phenomenon of the movement of the impurities contained the oil to separate them. The rates of deposition of the particulate impurities contained in the oil depend on the size and the density difference between them and the oil. In practice, two methods for producing centrifugal force field are used: driving the oil in centrifugal rotation in a stationary apparatus called a hydrocyclone or putting the oil into a centrifuge, which is the more popular technique. The advantage of using these techniques is the ability to quickly remove water and solid contaminants.

Sorption methods are based on the selective retention of the contaminants using absorbents, including aluminosilicates. Selectively removing polar impurities improves the colour of the oil, the thermo-oxidative stability, and dielectric properties. The methods of sorption also reduce acidity and the content of the resins and asphaltenes. A common sorption method is the percolation method, which involves passing oil through an adsorbent layer usually placed in a column. This method may use both stationary and portable devices. The advantages of sorption methods are the low cost of the purchase and maintenance of the apparatus, and the fact that they do not require high pressures and temperatures. The disadvantage is the problem of the waste management of sorbents.

Electrostatic methods rely on the release of polar impurities (endowed with a partial electrical charge) that are deposited on the respective electrodes constituting the cover of the capacitor. Electrostatic methods allow for the removal of moisture as well as solids from transformer oils, which translates into an improvement in the dielectric parameters and physicochemical.

2. Research methodology

As the object of investigation, insulating oil working in a 49-year-old transformer with a power 3.6 MVA was chosen. This oil had not been subjected to physical and chemical analysis for over 10 years, which makes it a suitable subject for study. Special analysis for insulating oils collected from such power transformers were performed, including the following: visual evaluation of the sample oil (clarity, separated water content, the content of foreign bodies), acid number, flash point, and the content of dissolved water. Analysis of the insulating qualities of the oil was also performed: breakdown voltage, resistivity, and dielectric loss factor. The used methods have a technical meaning and allow the correct diagnosis of the technical condition of transformers. Appearance evaluation of the transformer oil is based on visual observation of a sample having a thickness of about 10 cm in transmitted light at ambient temperature. This method allows determining the clarity of oil, the presence of visible contamination, and separated water. Water content determination was performed by coulometric titration using a Metrohm apparatus proposed by Karl Fischer. The acid number was determined by acid-base titration with a glass burette and titrated chemicals. Determination of flash point was performed with a Pensky Martens closed cup semi-automatic apparatus by Herzog. To determine the value of breakdown voltage, automatic apparatus by MEGGER was used. For each sample, 6 determinations were performed and the relative standard deviation was found. Measurements of the resistivity and dielectric loss factor were made using an automatic oil tester by BAUR DTL C. The oil resistivity measurements were performed at a constant voltage at a field strength of 0.25 kV/mm after 60 seconds from the time of application of voltage. The oil tgδ measurement was performed under alternating voltage of 50 Hz frequency and an intensity of the electric field of 1 kV/mm.

To examine the degree of cellulose insulation aging, the measurement of the concentration and changes in the content of furan compounds in particular 2-furfural (2 FAL) was performed. The content of furan derivatives in the oil was determined using the authors' methodology developed under the guidelines of the standard PN-EN 61198:2002. Analyses were performed using a high performance liquid chromatograph Perkin Elmer equipped with a UV-VIS detector for separation using a C18 reverse phase column.

3. Test results

An exemplary analysis chromatogram of an insulating oil collected from a 49-year-old transformer with a power of 3.6 MVA is shown in Fig. 1.

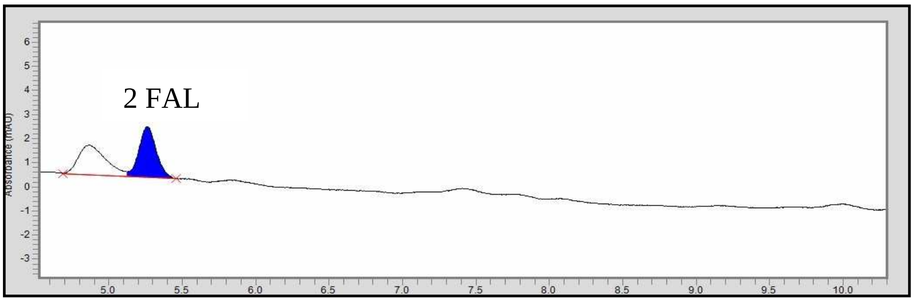

Fig. 1. The chromatogram of the transformer oil

In the chromatogram shown in Fig. 1, the peak of 2-furfural is marked. Based on a calibration curve prepared earlier, the content of 2-furfural in the test oil is 0.09 mg/kg. Such a low content of this compound in the oil provides minimal cellulose insulation aging, which has the non-negative effect on the mechanical strength of the cellulose. [10].

The results of physico-chemical properties of insulating oil are shown in Table 1. The tested oil successfully passed a visual assessment. It was limpid, and there was no separated water content or the presence of particulate matter. Resistivity, the dielectric loss factor, acid number, and flashpoint meet the requirements of the relevant standards. However, it was found that the value of the breakdown voltage is lower than required, which is undoubtedly a result of excessive water content in the oil, which was much higher than the permissible values. As a result, it was found that the test oil does not meet the requirements of the posed insulating oils in transformers group II in terms of breakdown voltage and water content. Allowing such oil to continue to work in the transformer without regeneration is therefore impossible. The oil was regenerated through the filtration under reduced pressure, after its previous heating to a temperature that allows the simultaneous dehydration. This procedure prevents the overheating of the oil during dewatering and its degradation and enables a reduction of the amount of heat energy needed to heat the oil. The properties of the regenerated oil are shown in Table 1.

Table 1. Transformer oil test results

Type of the test	**Unit**	**Assessment criteria**	**The required value**	**The oil sampled from the transformer**	**The oil after regeneration**
The clarity	–	PN-EN 60296:2012	Limpid	Limpid	Limpid
The separated water content	–	PN-EN 60296:2012	Does not contain	Does not contain	Does not contain
The suspended solids content	–	PN-EN 60296:2012	Does not contain	Does not contain	Does not contain
The breakdown voltage	kV	PN-EN 60156:2008	≥ 40	28.7*)	68.8*)
The relative standard deviation	%	PN-EN 60156:2008	≤ 20	19	10
The resistivity at 50°C	Ωm	PN-EN 60247:2008	$\geq 5 \times 10^9$	5.8×10^{10}	7.4×10^{10}
The dielectric loss factor Tgδ (50ºC)	–	PN-EN 60247:2008	≤ 0.07	0.003608	0.003225
The water content by Karl Fischer method	ppm	PN-EN 60814:2002	≤ 25	31.1	13.1
The acid value [mg KOH/g]		PN-ISO 6618:2011	≤ 0.25	0.09	0.09
The flash-point	°C	PN-EN-ISO 2719:2007	≥ 130	154	154
2 FAL content	mg/kg	PN-EN 61198:2002	-	0.09	0.09

*) The arithmetic mean of 6 measurements

As the presented data show in Table 1, after oil filtration under reduced pressure, the water content was reduced by 70%, which resulted in an increase in the value of breakdown voltage to the required level. Other parameters such as resistivity and dielectric loss tgδ were also improved. These data allow concluding that, as a result of insulating oil recovery by filtration under reduced pressure, it is possible to restore the oil properties required for the insulating oils used in transformers Group II.

Summary

In order to assess the technical condition and suitability for further transformer operation, a series of diagnostic tests were performed. Physical and chemical properties of the dielectric oil were investigated. Visual inspection of the sample, the acid number, water content, breakdown voltage, and dielectric loss factor were determined. Based on the test results, it was found that the tested transformer oil does not meet the requirements for insulating oils in transformers group II in operation. The oil contained too much water and had breakdown voltage below the required limit. The content of furan derivatives indicated a good state of transformer cellulose insulation. Taking into account the results of the analyses, it was decided to regenerate the oil such way that removing the excess water does not degrade the oil. The oil was filtered under reduced pressure. As a result of such a treatment, the water was removed from the oil, which raised value of the breakdown voltage to the required level. An additional benefit resulting from the purification of oil and reduction of its water content is to slow or inhibited degradation of cellulose insulation, which is hydrolytic and quickly occurs in the presence of water. Oil with such properties can be further exploited in a transformer in accordance with its intended purpose and technical parameters. However, due to the age of the transformer (49 years), there must be systematic control of the stat of the transformer oil and its regeneration, when necessary. This will enable the safe and reliable operation well beyond its originally estimated service life.

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Regeneracja olejów elektroizolacyjnych i jej wpływ na bezpieczeństwo techniczne transformatorów

Słowa kluczowe

Izolacja papierowo-olejowa, olej elektroizolacyjny, diagnostyka transformatorów, regeneracja olejów.

Streszczenie

Oleje elektroizolacyjne są czynnikiem chłodzącym uzwojenie transformatora. Podczas pracy urządzenia poddawane są one licznym i różnorodnym wymuszeniom, gromadzą w sobie różnorodne produkty destrukcji elementów konstrukcyjnych transformatora i, w efekcie, zmieniają swoje właściwości. Systematyczne badanie składu i właściwości oleju elektroizolacyjnego dostarcza więc informacji o stanie technicznym całego transformatora. W artykule przedstawiono wyniki badań stanu oleju elektroizolacyjnego w trakcie eksploatacji transformatora oraz zaproponowano działania mające na celu kontrolę stanu izolacji olejowej i wydłużenia czasu jej eksploatacji. Regularne badania pozwalają na regenerację oleju (np. poprzez wirowanie, osuszanie) we właściwym czasie, co w wielu przypadkach eliminuje konieczność kosztownej wymiany oleju. Monitoring właściwości oleju elektroizolacyjnego ma również duży wpływ na bezpieczeństwo techniczne związane z ograniczeniem ryzyka wystąpienia poważnych awarii, takich jak przebicia elektryczne, a nawet wybuch transformatora. Uzyskane rezultaty potwierdzają zasadność procesu regeneracji oleju elektroizolacyjnego jako metody obniżającej koszty eksploatacji, a przy tym efektywnej i przyjaznej środowisku.