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RESEARCH

Modern Approach to Problems of Transformer Oil Purification

Proper maintenance is the main condition for normal functioning, good work security and long exploitation period for energetic transformers that are part of system for production and distribution of electric energy. Modern and in world highly accepted concept of power transformers maintenance assume that activities of periodical purification of transformer oil are performed, in order to lower the concentration of water and gasses dissolved, as much as possible, and also in order to eliminate solid products of oil oxidation process and of degradation of paper isolation and of the transformer internal area, as well.

Keywords: *transformer oil, purification, absorbents*

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1. INTRODUCTION

Power transformers are complex and responsible elements in systems for production and distribution of electric energy. Proper functioning, work security and working life of transformers are directly conditioned by the state of their isolation system, which in basic are made of layers of special paper and transformer isolation oil.

Paper isolation provides mechanical strength, dielectric strength and dielectric distance, while isolator oil has the function of providing cooling, dielectric strength and paper isolation protection.

During the exploitation period of the transformer degradation processes occur in the paper and oil isolation. These processes involve series of mutually connected physical - chemical reactions and phenomena, which have the common name aging. Aging of the oil-paper isolation causes the exploitation characteristics of transformer to lower. According to the recommendation defined by IEEE standards an end to the exploitation period of power transformer is the moment when the paper isolation looses 75% of its starting tensile strength. Considering the fact that the paper and mineral oil are of organic origin, as a main cause of the aging process different oxidation processes and reactions can be defined. Maintenance of the power transformers causes the need to exclude all the aging process products from the oil content. It is very important, considering the previous, to lower the water and dissolved gases concentration, as much as possible, and to eliminate the solid products of oil oxidation and paper isolation and transformer internal area degradation.

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1.1 Water in transformer oil

Water in transformer oil penetrates from atmosphere or is developed as a product of chemical reactions. In isolator oil, water can be in one of states, as following:

a) in dissolved state

b) in state of emulsion (little drops mixed with oil)

c) in free state at the bottom of the transformer container

Even very little quantities of water can have significant influence to exploitation characteristics of transformer. In this sense, the existence of emulsified water is much more dangerous from dissolved state. By the curve shown in Figure 1., the relation between the dielectric strength and the quantity of emulsified water in mineral isolator oil is presented.

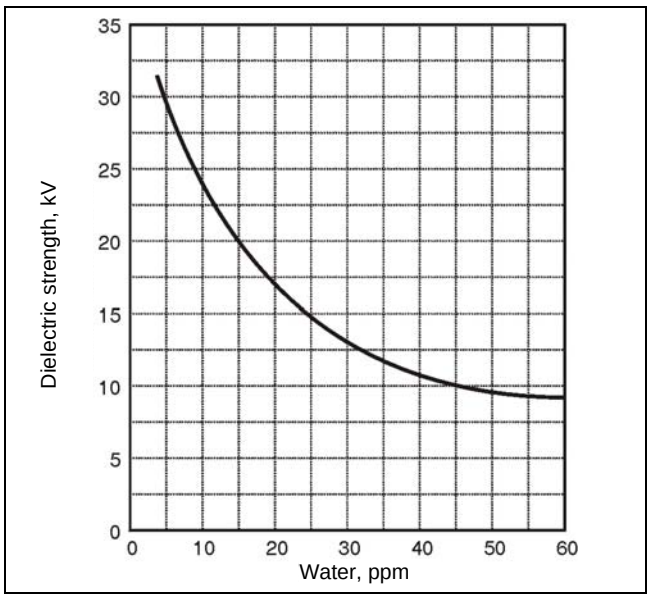

Figure 1. Influence of the water concentration to the dielectric strength of the transformer oil

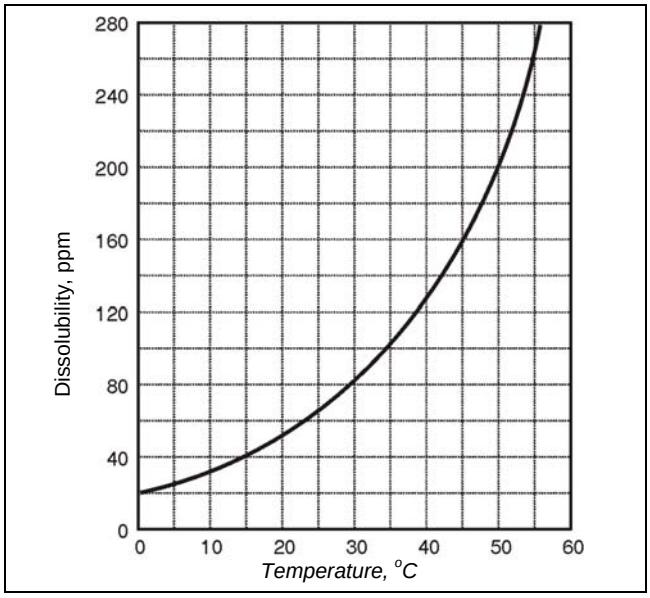

Figure 2. Diagram of the water dissolubility in transformer oil depending on the oil temperature

Water quantity that can be dissolved in oil rapidly grows with the oil temperature growth (Figure 2.). This has to be considered during the selection of conditions by which the separation of water from oil would be done, because the oil which is purified at higher temperatures can lose significant part of dielectric strength, when the transformation of dissolved water into emulsion happen.

Paper isolation in transformers is very porous and can absorb a very large quantity of water. Together with growth of dissolved and emulsified water quantity in isolator oil, the quantity of water which paper isolation absorbs grows. As a consequence the huge lowering of isolation dielectric strength happen. Once absorbed, water is very hard to remove. Therefore, it is of a vital significance to prevent the absorption to happen, that is, it is necessary to hold the content of water in isolator oil at the lowest possible level.

1.2 Oxygen in transformer oil

Contamination of isolator oil with water is the most usual cause of its aging and degradation. Somehow less usual, but much more serious phenomena is the oil contamination with oxidation processes products in form of resinoid and acid formations and precipitations. Oxygen presence inside the transformer is the basis for appearance of oxidation processes. Considering this, transformers with free air holes (without additional filters for air drying) are much more endangered compared to closed transformers and to transformers with the layer of nitrogen above the oil. Oxidation level depends on the oil temperature, with higher temperatures related to the more intensive oxidation processes. Because of this, it is important to avoid transformer overloading in summer period.

Products of oxidation processes are mostly deposited on walls of transformer container, which, beside other consequences, causes the lowering of heat conductivity thus lowering the possibility of isolator oil cooling. If this process develops uncontrolled, the oil flow through cooling channels can be blocked by deposited layers, therefore causing overheating and extensive degradation processes. If appropriate measures are not taken, these transformers very quickly come to state in which further exploitation is impossible. Transformers reconstruction in this case is very complicated and very expensive.

1.3 Basic tests for determining of transformer oil state

The development of degradation processes, that is of aging processes can be monitored and quantified by the whole series of tests, from which the most important and the mostly applied are as follows:

1. Water content – test ASTM D 1533

Water represents the factor, which extensively influence the quality of trafo oil and exploitation characteristics of transformer. The water content should be held at the lowest possible level (up to 30 ppm, at most).

2. Dielectric strength – test ASTM D 877, D 1816

This characteristic is very significant and is usually investigated first at trafo oil. Physically, it represents

the voltage at which the trafo oil starts to conduct. Its value should be held at the highest possible level. The lowering of this value mainly indicates the growth of the water content in oil.

3. Neutral number - acidity number – test ASTM D 974

Its unit is mgKOH/g, that is, it represents milligrams of caustic potash, which is added to the gram of oil in order to neutralize acidity. The new trafo oil has almost no acid if the procedure of storage and transformer filling was adequately done. The value of acidity number for new oil is below 0,05. Acidity number grows with the development of oxidation processes in oil and is directly connected with the oxygen content in oil. As the limit point after which the procedures for acid lowering should be done is the acidity number value of 0,2. At values of 0,4 resinoid layers are already formed, which drastically influence exploitation characteristics of transformer.

4. Intersurface stress – IFT test – test ASTM D 971

It represents the characteristic, which define conditions when the formation of resinoid layers is possible, though it does not mean that these layers are necessarily formed. Physically it represents the force needed to break up the oil film, which exists at the boundary area between oil and water. Its unit is N/m (or mN/m). The value for the new oil is approximately 40 mN/m. Values that are satisfactory are ones higher than 22 mN/m. Oil with this parameter value between 15 and 22 mN/m should be regenerated, while values under 15 mN/m almost certainly indicates the existence of resinoid layers.

5. Power factor – test ASTM D 924

Physically, it represents the cosine (or tangent) of angle between the vector of alternating stresses run through the isolator oil and the vector of resulting current. This test determines the existence of dielectric losses in oil, that is, the losses due to the oil heating. This angle is very small, therefore for new oil the value of angle cosine does not overrun 0,05%. With water content and degradation and aging products growth, increase of losses occurs, which is represented by the increase of power factor.

6. Oxidation inhibitors – test ASTM D 2668

This test determines the content of the oil additive which is the oxidation inhibitor, that is, antioxidant and directly influence the reduction of oxidation processes in oil and decrease its aging. Additive, which for this purpose is added to trafo oils, is known under the abbreviation DBPC (2,6 ditertiary-butil-para-cresol). Its concentration in new oil is between 0,15% and 0,30%. When its concentration goes under the value of 0,08% it should be re-added, that is, the oil should be added with inhibitor.

7. Gaseous-chromatographic analysis

Gaseous-chromatographic analysis determines the concentration of particular group of gases in the trafo oil. Increase of their concentration above permitted limits indicates to various problems, which can appear during the exploitation. The most common gases investigated are as follows (values which are upper limits for normal concentration are given in brackets, in ppm units): Hydrogen – H_2 (200); Acetylene – C_2H_2 (8); Methane – CH_4 (50); Ethylene – C_2H_4 (80); Ethane – C_2H_6 (35); Carbon-monoxid – CO (300); Carbonic acid anhydride – CO_2 (2000);

2. METHODS OF MAINTENANCE AND PURIFICATION FOR ISOLATOR OILS

Due to the significance of long-term and adequate transformer exploitation, and considering the complexity of degradation and aging problems for transformer isolation, in nowadays practice, the whole series of methods have been developed, which are mainly aimed towards improvement of transformer isolation state through the following procedures:

- dehydration (water removal)
- degasification (oxygen and other gases removal)
- removal of various oxidation processes products
- filtration.

The mostly used methods are as follows:

- *natural sedimentation* - based on water and precipitation removal at the bottom of transformer container in natural way, while the transformer is disconnected from the system at least for 24 hours. After that, the oil is pumped out from the upper level, the water and precipitation are removed from the bottom, cleaning and again oil filling is done. Method is rather slow and needs a lot of work done and is unsatisfactory efficient for rigorous demands according to standards defined.
- *filter presses* - can be of various constructions but most of them are based on the principle of forced oil circulation through series of materials with filtering and absorbing properties (e.g. filter paper). Method cannot be used for oil degasification. For the full effect of water removal, filtering elements must be replaced and dried very often.

- *centrifuges* - are based on classic method of water from oil separation due to the centrifugal force. The main advantage of these devices is in large quantity of oil that can be processed in certain period of time. They can be used only for rough purification since the effect is much lower compared to other methods. They do not separate the water dissolved, neither can do the degasification or filtration, therefore they must be combined with additional devices. Classic procedures (filter presses and centrifuges) demand extremely big and heavy machinery that pollutes the environment and spends enormous electrical energy during working.
- *portable devices with filter elements* - are often used because of their small dimensions, easy handling and a lot of other advantages compared to big filter presses. Within these devices, various ready-made filter elements - cartridges, are combined, that can filter oil from 1 μm to 25 μm. Devices can have elements for water separation, as well.
- *coalescer filtration* - relatively new method developed, based on method for filtration of airplane fuel. In filter elements made of porous fiberglass merging of little water drops and then their removal are done, due to the increase of differential pressure. Method has advantages compared to centrifuges, but the main weakness is filter elements sensitivity to solid particles in oil.
- *vacuum dehydration* - is broadly accepted and very efficient method based on isolator oil heating and then its exposure to the vacuum. Under these conditions the water vapor point is significantly lowered and extensive separation of water from oil is done. This method can be used for very efficient degasification. The main weakness of method is the need to heat the oil in purification process. Increase of isolation oil temperature above 65°C, then drying in vacuum, causes the loss of very important oil fractions necessary for good isolation quality of oil. At lower temperatures or vacuums, efficiency of drying decreases rapidly.
- *absorbents application* - this method is based on usage of exceptional properties of group of materials that are natural or industrially made and all have exceptional absorbent power, that is, they have all the capability to bound various materials to its molecular structures (from where comes the name of molecular sieve).

3. WORKING PRINCIPLE AND BASIC CHARACTERISTICS OF EKKOM-2 DEVICE

Designing of EKKOM - 2 device was done after detailed analysis of methods that are used in industrial practice, of world trends and of rigorous demands defined by standards in this area. The goal was to design the device with properties as follows:

- *high efficiency of the purification process*
- *joining of the most important procedures at one device*
- *economic working process*
- *mobility and small dimensions*
- *flexibility*
- *easy handling and maintenance*
- *satisfaction of rigorous ecology criteria*

Device is sophisticated design of standard portable filter aggregate with added modulus with carefully chosen and processed absorbent filling.

The device can be used in field and in workshops or utilities. It can process isolator oils from reservoirs, tanks or directly in transformers. Transformers needs not be disconnected from system during the process. Only one worker with minimum of manual labor serves device.

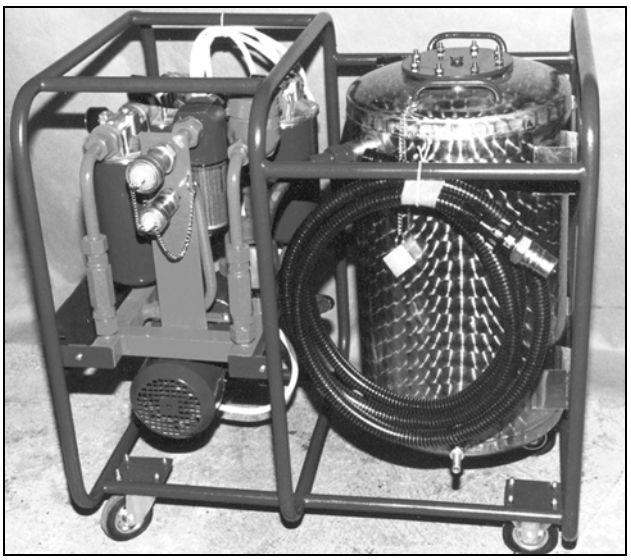

Figure 3. Device for transformer oil purification, EKKOM - 2

Device flexibility is in possibility of its combination with other devices and systems for purification. The device is mainly used in precisely defined time intervals, predefined by the plans for transformer system maintenance, while at very large transformers it is possible to built it in as a part of standard equipment, where the continual purification of oil

filling is achieved with occasional replacement of filter elements and of absorbent filling. This method is also recommended for transformers whose proper and long term functioning is of a vital significance at national level.

By selection of certain absorbent filling, device can be adjusted to various transformer oil regeneration procedures. Absorbents are granulated, neutral to all oil kinds and with large absorption capacity.

Standard device type has the absorbent type of aluminum origin, with zelites structure with extensive power to absorb water (up to 15% of its volume). For average water contamination at transformer oil, one filling with this absorbent can perform removal of free and emulsified water (absorbent can not react with chemically bounded and dissolved water) from approximately 80 tons of transformer oil.

Absorbents for removal of transformer oil degradation process products and for lowering of its acidity can be used, beside the standard type absorbents. Special kind of clay, processed previously, and certain granulated absorbents of aluminum origin in zelites form, belong in this group of materials, also. Absorbent materials that have the capability to reduce acidity of mineral oils are often called ionic inverters, though this name points to materials which have the possibility to "exchange" the acid molecule with water molecule.

From aspect of working methodology, procedure of transformer oil regeneration and purification with removal of degradation products and acids, is significantly slower compared to classic methods of filtration and dehydration. Trafo oil flows through the device with low speed (in order to obtain longer contact with absorbents materials necessary for proper procedure) and it is recommended that complete volume of oil do several passes with pauses after each passage. This way, the "in depth" regeneration is done, because the treated oil goes into the trafo and does the collecting of acidity remaining from transformer paper isolation. Relatively big consumption of absorbents materials is the characteristic of such a procedure. For solving a problem of increased water content, by absorption method, approximately 5 kg of absorbent is needed for 10 tons of oil, while for the regeneration of the same quantity of aged oil, from 150 kg up to 500 kg of absorbent, is needed, depending on the type of absorbent and on the level of aging for oil.

Basic functional chart of EKKOM-2 device is presented in Figure 4. The device design is made for two kinds of working regime, as shown below:

1. absorbent treatment working regime (dehydration, degasification or deacidification) - the first hydraulic circle,
2. Oil filtration working regime - the second hydraulic circle.

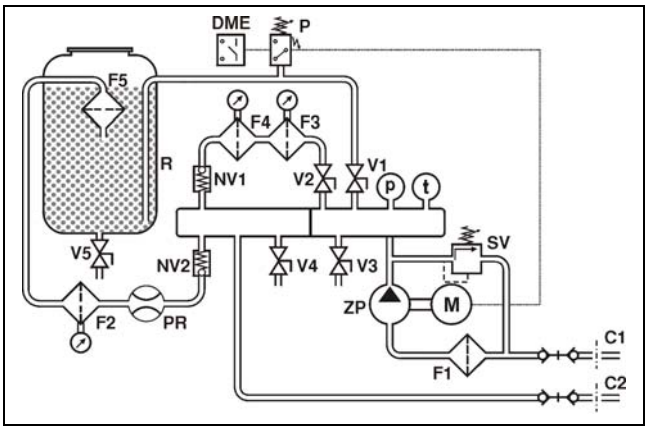

Figure 4. Basic functional chart of EKKOM-2 device

- M - driving electric motor
- P - gear pump
- SV - safety
- R - modulus with absorbent
- C1 and C2 - flexible hydraulic pipes that are placed into transformer
- F1 - F6 mechanical filters of various fineness
- p - manometer for control of pressure in system
- t - thermometer for control of oil temperature in system
- PR - flow meter for measuring the quantity of oil that passed through the modulus with absorbent
- P - presostat, electro-hydraulic switch
- V1 and V2 - main control valves that enable the selection of working regime of the device
- V3 and V4 - valves at transfer line at input and output of the system
- V5 - valve for oil draining from modulus with absorbent
- NV1 and NV2 - irreversible valve.

Working in, so called, first hydraulic circle, assumes the realization of forced circulation of transformer oil through the modulus with absorbent. During the circulation reaction between absorbent and polar molecules of water and oxygen happens and further their structural bounding. This way, the separation of most part of free and emulsified water is done, as well as of one part of dissolved water. Absorbent bounds to its structure oxygen and other gasses that are present in oil in small quantities.

Working in the first hydraulic circle also assumes the passage of oil through filters F1 and F2, thus enabling separation of mechanical admixtures, impurities and particles of various structure with size bigger than 25 μm, originated from degradation processes in transformer oil.

In order to achieve satisfactory quality of dehydration and degasification processes, it is necessary that the complete oil pass at least twice through the whole hydraulic circle. The quantity of oil that passed through modulus with absorbent is controlled by the flow meter.

4. CONCLUSION

It is important to emphasize that the design of EKKOM - 2 device and the purification technology itself provide the high level of ecology aspects of purification process, during which the leakage of isolator oil is totally prevented, thus preventing environment contamination.

All elements built in devices of EKKOM serie are made by famous world manufacturers and satisfy the highest quality criteria. The device is in application in several europian countries. EKKOM device passed detail investigation and certification processes in Russian Federation and has the appropriate certificate Rosstandrad.

Due to efficiency and economic aspects of purification process, the device can be broadly applied also in area of hydraulic working fluids maintenance, for which, depending on the design of specific hydraulic system, purification process parameters and types of absorbent materials and mechanical filters are defined.

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