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Diagnostics of power transformers operating for many years in the power supply system through gases in the composition of transformer oil

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Diagnostics of power transformers operating for many years in the power supply system through gases in the composition of transformer oil

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Abstract. Oiled power transformers and autotransformers 40-60 years ago are still in operation in Uzbekistan. At the same time, diagnostic methods for determining faults in transformers and autotransformers remained the same. This article partially analyzes the factors affecting the oils of power transformers and autotransformers used in the agricultural sector. It is known that transformer oil performs the functions of cooling and insulation. During use, the oil is in direct contact with air through the respiratory system. There is a process of transition of moisture and various gases in the composition of the air into the composition of the oil. By the composition of gases, it is possible to determine the reasons for the deterioration in the quality of the main and additional insulation of oil-immersed power transformers. The issues of influence on the state of insulation of marsh gases appearing inside (at the bottom) of the tank of oil transformers and partial discharges in oil-gas medium have been little studied.

1. Introduction

Most power transformers operating in a power system possess oil-paper insulation. A serious defect of this type of insulation, which is associated with long operation time, is an increase in the moisture content. Moisture introduces a number of threats to proper operation of the transformer, e.g., ignition of partial discharges (PDs). Due to the varying temperature of the insulation system during the unit's normal operation, a dynamic change (migration of water) takes place, precipitating the oil-paper system from a state of hydrodynamic equilibrium. This causes the PDs to be variable in time, and they may intensify or extinguish[1]. Transformer Oil Testing is a technique, which should be a part of any condition-based protective maintenance facilities[2].

2. Methods

Power transformers have a critical role in energy grids. As transformers age, their internal condition degrades, which increases the risk of failure. To prevent these failures and to maintain transformers in good operating condition is a very important issue for utilities [3-4]. Test values must be compared to previous or factory tests and an internal inspection should be considered before re-energized [5]. It should be emphasized that health index shows the overall degradation condition of a power transformer. If a diagnostic factor does not exceed the maximum permissible limit, the value of the health index shows a realistic condition of a transformer. If a diagnostic factor exceeds the permissible limit, according to a standard, the value of the health index may mask the true condition of the asset. This is the case for the autotransformer AT_4. If the dissolved gasses in oil are analyzed it can be seen that important quantities of ethylene C_2H_4 and acetylene C_2H_2 are present (quantities which exceeds the acceptable limits given by IEEE Standard C57.104-2008, respectively 50 for ethylene and 35 for acetylene). According to this Standard, ethylene shows thermal decomposition of the oil (overheated oil) and acetylene shows electrical arcing in the oil. Consequently, continued operation could result in failure of the transformer. Thus, the transformer should be removed from service.

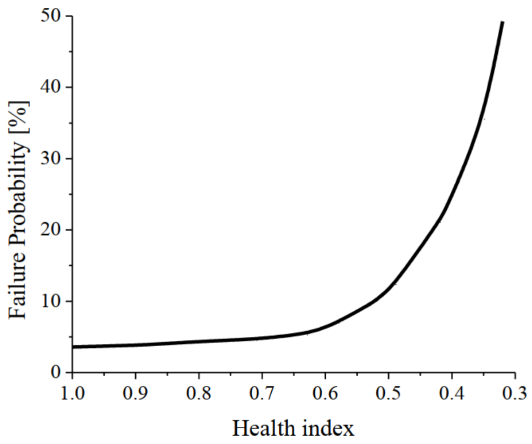


Figure 1. Variation of failure probability with health index *HI* for power transformers.

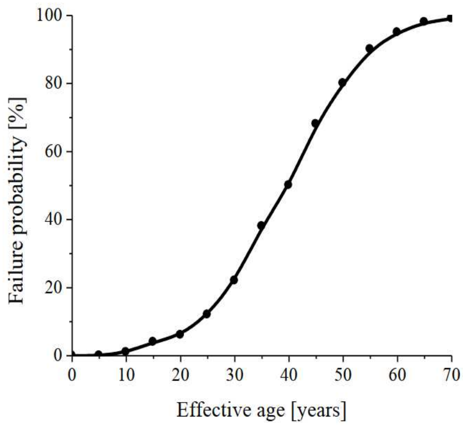


Figure 2. Failure probability versus effective age [5, 6].

Figure 1 shows the change in the probability of failure depending on the health index HI for power transformers. And Figure 2 shows the probability of failure versus the effective age of the power transformer.

3. Results and Discussion

Determination of breakdown voltage. If the voltage applied to the dielectric is gradually increased, the dielectric's resistance will drop sharply. This important condition, which turns into a dielectric conductor, determines the dielectric strength (kV / cm) of the oil. The voltage at which oil breakdown occurs is called the breakdown voltage (kV). A decrease in the breakdown voltage indicates, as a rule, that the oil is contaminated with various impurities.

$$\boldsymbol{E = \frac{U_{bdn}}{h}}$$

where $\boldsymbol{U_{bdn}}$ is the breakdown voltage; $\boldsymbol{h}$ is the distance between the electrodes.

The characteristics of spark discharges that occur inside power transformers are non-linear, and the shape of the currents consumed when connected to a source with a sinusoidal voltage is non-sinusoidal. When these currents pass through the network elements, the voltage drop across them becomes non-sinusoidal. The result is a distortion of the voltage picture at the input parts of the consumers. The lack of good contact with any of the three phases, which at first glance may seem simple, will negatively affect the quality characteristics of the entire power supply network.

Table 1 Operating and breakdown voltage of the transformer

Operating voltage of the transformer	Breakdown voltage of the transformer, kV
Up to 15 kV (inclusive)	30
15 kV to 35 kV (inclusive)	35
60 kV to 150 kV (inclusive)	55
220 kV to 500 kV (inclusive)	60

It is known that the formation of electric discharges in a uniform electric field occurs due to an electrode (usually a cathode), on which an effective electron is formed. That is, this collision of electrons causes an avalanche of electrons due to ionization.

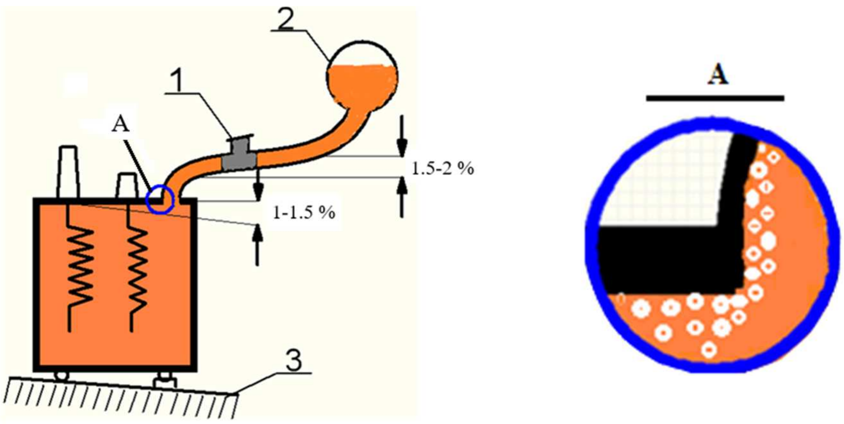
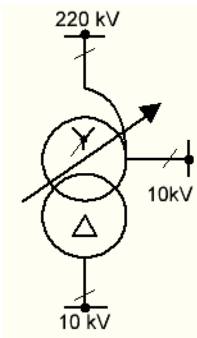


Figure 3. A schematic representation of a power transformer with an expansion tank and a connecting pipeline with a gas relay. 1-gas relay; 2-expansion tank; 3- soil (base).

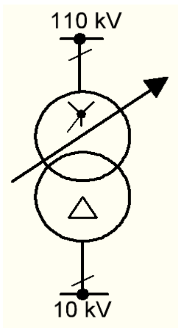
Typically, heating oil with subsequent release of gas (or gas bubbles) can be caused by the following reasons: short circuit between winding turns, and the so-called "steel fire", when the transformer core plates are galvanically connected to each other, causing losses and temperature rise. The above reasons, given the local nature of the impact, may not be detected by other types of protection. At the same time, the formation of flammable gases and pressure increases lead to severe accidents and failure of the transformer. In practice, the reasons given for the local (local) nature of the impact may not be detected by other types of protection. However, the formation of flammable gases and pressure build-up can lead to severe accidents and failure of the transformer or autotransformer. Figure 3 shows a schematic representation of a power transformer with an expansion tank and a connecting pipeline with a gas relay. The gas relay (position 1) is included in the cooling system up to the expansion tank 2. Section A shows an image showing the movement of gas bubbles to the top. To facilitate the passage of gases (gas bubbles), the oil pipeline together with the gas relay have a slight slope (which can be achieved by a slight "blockage" of the entire transformer). The slope is approximately 30. The gas relay is triggered when oil is displaced from the pipeline by thermal decomposition products. It should be noted that the drop in level can be caused by non-electrical causes, such as damage to the cooling system, which also leads to overheating and failure of the transformer. Structurally, the gas relay is included in the cooling system before the expander (Fig. 3).

To facilitate the passage of gases, the oil pipeline together with the gas relay have a slight slope (which can be achieved by a slight "blockage" of the entire transformer). The gas relay is triggered when oil is displaced from the pipeline by thermal decomposition products. It should be noted that the drop in level can be caused by non-electrical causes, such as damage to the cooling system, which also leads to overheating and failure of the transformer.

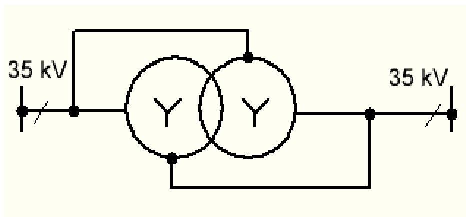
Positions a), b) and c) of Fig. 4 show schematic diagrams of power transformers such as: autotransformer, transformer and booster transformer for voltage regulation and the first two circuits are step-down, and circuit c) stabilizes the voltage. And in diagram d), a part of the single-line diagram is clearly illustrated, revealing the essence of the operation of switching devices as a separator and a short-circuiter. In case of intense gas bubbles due to internal damage (accidents and malfunctions), for example, turn-to-turn short circuit, relay protection using a gas relay is triggered and gives a command to open the Q2 switch installed at the beginning of the OPL2-220 kV line. This leaves the entire circuit without power for a short time.



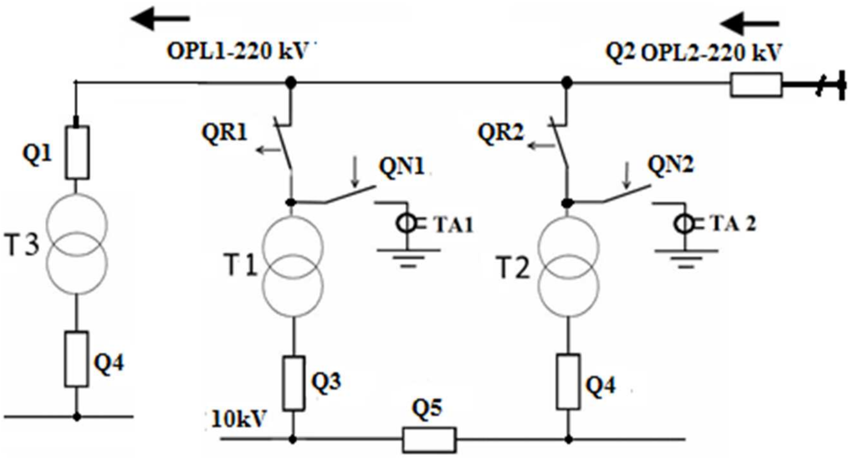
a)



b)



c)



d)

Figure 4. Conditional diagrams of power transformers and autotransformers in the electrical network.

Simultaneously the weight of the process will be controlled by the current transformer TA. Let us assume that the turn-to-turn short circuit occurred in the transformer T2. Then TA2 senses the absence of current (waits for the moment of complete disappearance of the current), and at zero value on the secondary winding of the current transformer gives a command to disconnect the QR2 separator. QR2 spread its electrodes at a safe distance and a visible open circuit is created. Then the Q2 switch is triggered again and energizes the circuit. And restores power to transformers T1 and T3. And T2 will be completely disconnected from the network. This operation helps to preserve the expensive windings of the power transformer and restores the power supply to the normally working parts of the electrical network. The reliability of the power supply is increased.

It is possible to use new innovative solutions for the current transformer installed in the short-circuit circuit. Under the leadership of Plakhtiev A.M. work is underway to create a new generation of current measuring devices and articles [8-9] show the results of the development of various options proposed by researchers, universal multidisciplinary non-contact magnetomodulation converters of large direct and alternating currents with an extended range for monitoring and control systems in the electric power industry of solar power plants, solar power plants, with direct conversion of solar energy into electrical energy using photo- and thermoelectric conversions, renewable energy sources, laser installations, as well as in industry, agriculture and water management. They differ from the well-known extended controllable range with small dimensions and weight. They have increased accuracy and sensitivity. The converters have simple and technologically advanced designs with low material consumption and cost and can contactlessly control large direct currents, as well as alternating currents.

Therefore, free, emulsion and binding water types were considered as the main factors. It was found that water in the form of an emulsion in the composition of the oil reduces the breakdown voltage of the transformer oil.

Based on the obtained data on dissolved gases (hydrogen, methane, ethane, methylene, acetylene) of power oil transformers of various brands, the following diagrams were built (see Fig. 5 and Fig. 6) diagrams (transformers with more than 30 years of operation were selected for analysis).

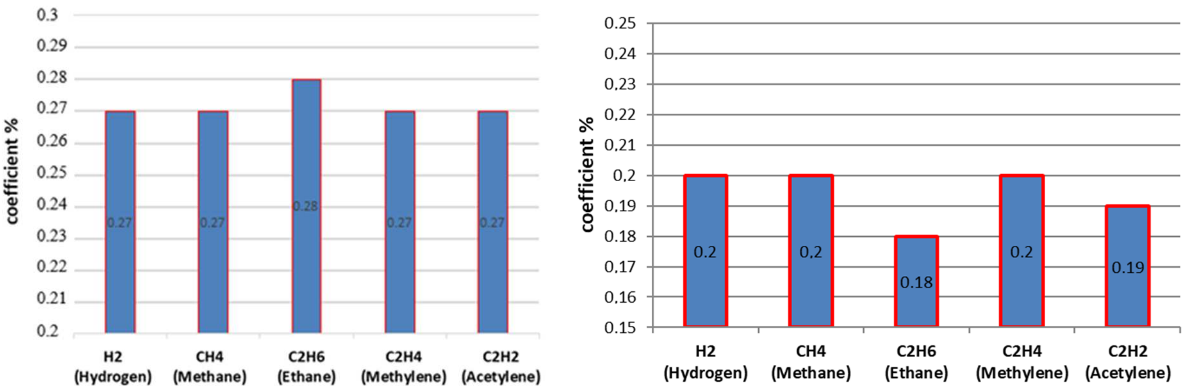


Figure 5. Diagram of the composition of the included gases in oil for a power transformer

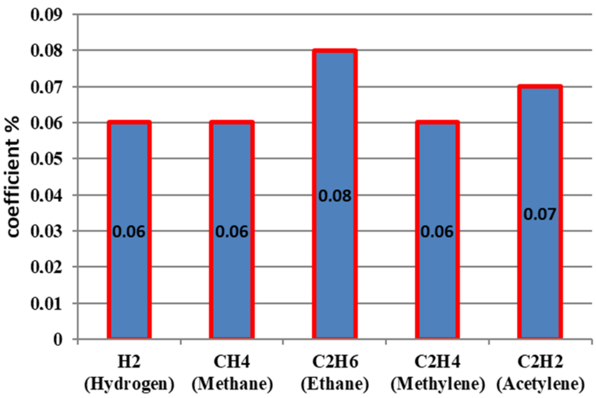


Figure 6. Diagram of the composition of the included gases in oil for a power autotransformer

It can be seen from the above diagrams that in old transformers and autotransformers, the main causes of failure are gases containing hydrocarbons.

4. Conclusion

This paper discusses issues related to the insulation of power transformers and autotransformers used in the agricultural sector. The problem is the increase in the service life of power transformers (autotransformers) and the backwardness of diagnostic techniques. Modern research makes it possible to determine the causes of defects by analyzing the composition of gas in oil. Relay protection can help reduce the damage from failures. The paper presents a practical diagram of the use of separator devices with a short-circuit switch, as well as information about innovative current transformers.

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