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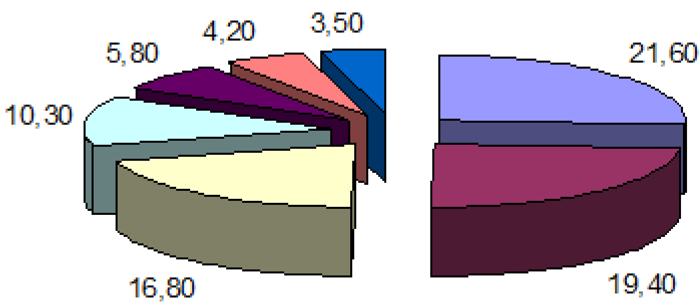
ANALYSIS OF THE MAIN CAUSES OF TRANSFORMER DAMAGE

G. N. Mustafakulova
Ph.D. Assoc. Academy of the Armed Forces of the Republic of Uzbekistan

Abstract
The permissible values of the operating factors and their number depend on the operating time of the transformer. The operational reliability of transformer equipment is directly related to its service life. The increasing nature of the transformer damage curve with time (or the "life curve" of a particular transformer) after it has reached its rated service life is similar to similar: the dependence of aging of all types of electrical equipment. The main feature of transformer equipment is that the service life is largely determined by the condition of oil-paper insulation in the process of its natural temporary aging and under the influence of external factors.

Keywords: transformer, operation, reliability, power, load, network, disadvantages of operation, repair defects, climatic and external influences.

Introduction



Pic.1. Power transformer failure statistics

As the analysis of the main causes of transformer damage shows, their reliability is most strongly reduced by defects in design and manufacturing, as well as shortcomings in the operation and repair of transformers.

Picture 1 shows the shortcomings of operation and repair of transformers in percentage terms.

At the present time, there is a worldwide trend of "aging" of the electrical equipment fleet, primarily of the most critical transformer equipment.

The results of the analysis of the disadvantages of operation and repair of the transformer are summarized in Table 1.

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Table 1

Cause of transformer failures	Failure rate, %
1-Changes in material properties (aging)	21,6
2-Defects in design and workmanship	19,4
3-Disadvantages of operation	16,8
4-Side influences	10,3
5-Non-calculating modes in the network	5,8
6-Repair defects	4,2
7-Climatic and external influences	3,5

For oil-filled transformers as a whole, their low level of maintenance and repair gives 21% of damage, i.e. almost as much as is caused by natural aging of the insulation.

The main thing that nowadays required the forced development of means and methods of monitoring the condition of transformers is the problem of their operation beyond the rated service life. A large number of transformers in operation have completed or are approaching the end of their rated service life. This situation has forced us to pay more attention to extending their integral service life (operating time) by means of effective condition monitoring and optimization of preventive measures.

Growth of damageability at operation beyond the rated service life increases costs for current repairs of equipment, increases the probability of accidental failure and due to this the volume of preventive measures increases. In conditions of market competition, reduction of equipment profitability leads to losses much higher than the cost of repairs - to loss of competitiveness. The need for thorough diagnostics of powerful electrical equipment today is generally accepted. This is due to its high production cost, significant costs for transportation, installation, etc., as well as financial costs due to violation of technological processes in case of under-extraction of electric energy. At the same time, organization of control of electrical objects at the modern level of instrumentation and software, as well as the possibility to perform these works by a limited number of specialists at their total cost is several orders of magnitude less than the cost of installed equipment.

Analysis of the ageing of power transformers shows that there is a steady increase in the share of worn-out transformers, which have a service life close to or exceeding the normative one. The rate of capacity growth in the global power industry has significantly decreased and significantly lags behind the increase in the volume of power transformers that have reached the end of their service life.

Against the background of an aging fleet of transformer equipment, the following challenges arise:

1. Operation of equipment after the expiry of its normalized service life.
2. Objective substantiation of the choice of priority and time sequence of re-equipment.
3. Under conditions of market relations, the ideology of the equipment maintenance system is changing. Energy companies are abandoning the planned replacement and repair of electrical equipment and are switching to a "state-of-the-art" maintenance system.

To solve these problems, it is necessary to know the regularities of electrical insulation aging.

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The aging of the insulation during the operation of the equipment is caused by the influence of a large number of different factors.

Data at the beginning of 2015 show that about 45% of transformers have exceeded 20 years of service life, and about 30% of transformers have exceeded 25 years. As of the end of 2018, the average service life of most electrical equipment in CIS power systems already exceeds half of the design life.

Significant wear and tear of electrical equipment leads to additional energy losses, reduced reliability of operation, and an increase in transformer accidents. The analysis of statistical data shows that in 2018 - 2019 there is a significant increase in transformer failures of power plants and substations of the CIS countries, the causes of which are associated with the aging of transformers and its inefficient operation. The consequences of transformer failures are the downtime of powerful equipment, accompanied by significant under-utilization of electrical energy.

The relationship between transformer lifetime and operating temperatures is well known as explained in chapter I. It is significant for utilities to study the operating temperature of the distribution transformer to establish the aging of such devices. The temperature of the winding and insulation are the basic factors that limit the transformer loading[16]. Therefore, transformer loading is highly dependent upon the operating temperature of the transformer, which means any change in transformer temperature could change the load capabilities and vice versa [40]. Further, temperature and aging of the transformer would affect the insulation level. The heat in the transformer, caused by losses in the transformer, must be transferred to the transformer oil and from the oil to the atmosphere [16]. External conditions such as ambient temperatures, wind velocity and direction, and solar heating affect the heat dissipation from a transformer [41]. Also, ambient temperature versus loading can be drawn for different types of transformer cooling. Based on this, the hot spot temperature and ambient temperature are important factors in determining transformer-aging rate while different load levels affect the aging of the insulation [2]. As mentioned in chapter I, the permissible loading of a transformer for normal life depends on many factors such as the design, the temperature rise at rated load, temperature of the cooling, duration of the overloads in addition to the load factor and the altitude above sea level. The relationship between transformer lifetime and operating temperatures is well known as explained in chapter I. It is significant for utilities to study the operating temperature of the distribution transformer to establish the aging of such devices. The temperature of the winding and insulation are the basic factors that limit the transformer loading[16]. Therefore, transformer loading is highly dependent upon the operating temperature of the transformer, which means any change in transformer temperature could change the load capabilities and vice versa [40]. Further, temperature and aging of the transformer would affect the insulation level. The heat in the transformer, caused by losses in the transformer, must be transferred to the transformer oil and from the oil to the atmosphere [16]. External conditions such as ambient temperatures, wind velocity and direction, and solar heating affect the heat dissipation from a transformer [41]. Also, ambient temperature versus loading can be drawn for different types of transformer cooling. Based on this, the hot spot temperature and ambient temperature are important factors in determining

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To explain the relationship between ambient temperature and the transformer loading is such that it causes:

a. An increase in ambient temperature, will result in increased need for loading, and thus increase the supply needed.
b. Ambient temperature is considered in the calculation of hot spot temperature in all transformer thermal models.

The second factor is governed by many influences such as thermal capacity, types of cooling and the effect of altitude. The permissible load for forced-oil-cooled transformer is presented in table.

Loading capability for forced-oil-cooled transformer

Percent of total coolers used in operation (%)	**Permissible load in % of name plate rating**
100	100
80	90
60	78
50	70
40	60
33	50

In the average ambient temperature with natural cooling is noted as 30°C. At this rate of temperature, the loading capability of a transformer is 100 KVA. When ambient temperature increase to 50°C, the permissible load equals 70 KVA and for oil-air-cooled and forced-air-cooled transformers, the permissible load reaches 80 KVA at 50°C. However, the average ambient temperature for water-cooled transformers is 25°C with loading capability 100 KVA while the permissible load can reach 85 KVA at 50°C. Further, oil-water-cooled transformers can work at 50°C with 90 KVA. Based on overload limitations, hot spot temperature of transformer can be designed to operate either up to 55°C above ambient temperature or up to 50°C rise above ambient temperature.

Most professionals in the power industry are very familiar with the fundamental principle of how a transformer functions electrically. A transformer is changing a voltage device composed

of a primary and secondary winding interlinked by a magnetic core. A three-phase power transformer used in transmission and distribution systems shares the same principle. However, its core is bigger to accommodate the three phase primary and secondary windings.
Additionally, insulation in the form of oil or paper is required to isolate the difference in potential between phases. Three phase transformer losses will generate enough heat so that external cooling systems must be added. A closer look at these characteristics is necessary to understand better the thermal aspects of power transformers. Insulation is required whenever there is a difference in potential between two points. In an overhead three-phase transmission line with bare conductors, no insulation is necessary between the conductors since air separation is used as an insulator, preventing the flow of current. However, in power transformers, distance between phase conductors is not an efficient way of separating the potential differences. As a result, paper is used as an insulator, allowing closer proximity between phases and thus maximizing space. By far, paper is the best insulating material used today because of its high dielectric strength properties. Paper insulation in a power transformer is installed between windings of the same phase, windings to ground, and windings from different phases. Other parts of the transformer also experience a difference in potential, such as the transformer tank wall with the windings, which also requires some form of insulation. In order to minimize the transformer's footprint, this distance must be shortened as much as possible. Transformer manufacturers shorten the necessary distance by using insulating oil, which not only insulates, but also serves as a coolant within the transformer. Thus, transformer insulation is the heart of transformer design, and maximum transformer performance during loading depends on the insulation's credibility. Transformer losses are one of the primary factors affecting this credibility, which is the focus of the next section. IEEE Standards and Temperatures In order to operate a power transformer, one must know its basic limitations. It is clear that the temperature produced by the transformer losses can affect the life span of the insulation. To ensure the longevity of the transformer, transformer manufactures must guarantee that their designs are capable of operating within specified standards. The ambient temperature, the average winding temperature, and the maximum winding hottest-spot temperature bound the operating limits. According to the IEEE C57.12.00-2000 standard, power transformer are rated on a maximum ambient temperature of 40° C, and the average ambient temperature shall not exceed 30° C in a 24-hour period. This standard also states that an average winding rise of 65° C shall not be exceeded when the transformer is operated at its rated load (KVA), voltage (V), and frequency (Hz). In other words, based on the ambient temperature criteria, the average temperature of the winding cannot exceed 65° C above ambient, when operated at rated conditions. Maximum hottest-spot winding temperature cannot exceed a value of 80° C above ambient. The IEEE C57.91-1995 states that under a continuous ambient temperature of 30° C, the maximum hottest-spot winding temperature should not exceed 110° C. If the transformer is operated continuously at this temperature, the normal life expectancy of the transformer is 21 years.

CONCLUSIONS

The main objectives of diagnostics of insulation aging in operation mode are:

- identification of transformer condition, in which it is possible to significantly reduce the service life at a given temperature of NNT assessment of the degree of moisture degree of oil aging and accumulation of active acids in the insulation;
- assessment of residual lifetime and detection of insulation ageing degree approaching the maximum permissible value;
- identification of abnormal heating of the insulation.

The analysis shows that control of its moisture content, presence of soluble acids in the oil and oxygen concentration in the oil is of significant importance in assessing the ageing of solid insulation.

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