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IMPROVEMENT OF THE CLASSIFICATION SYSTEM FOR POWER TRANSFORMER DEFECTS

The object of the study is power transformers, namely, their diagnostic systems, taking into account defects and emergency processes, when determining the state of the equipment. One of the most problematic places is the lack of study of operational problems that require the implementation of a set of preventive measures. Experience of operation of power transformers shows that after the normative term of service a large part of the transformers retains its ability under the conditions of adherence to acceptable load modes, timely repairs and their quality performance. The study used an integrated approach to solving the tasks, including world experience, synthesis of results and retrospectives, methods of technical diagnostics, theory of decision-making. In developing the classification of defects an attempt was made to exclude the deficiencies found in other approaches and proposed the diagnosis on the principle of «from general to specific». It is substantiated that the proposed advanced classification system of defects of power transformers, in which an attempt was made to eliminate the defects found in other approaches, allows to divide the abnormal processes that cause the defect, and the structural elements of the transformer. Due to this classification system takes into account a number of most common defects of power transformers and the reasons for their occurrence. A new approach to the classification of defects in power transformers can also take into account the processes that occur in them.

Keywords: *own normative term of service,* aging power equipment, diagnostic systems of the power transformers.

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ВДОСКОНАЛЕННЯ СИСТЕМИ КЛАСИФІКАЦІЇ ДЕФЕКТІВ СИЛОВИХ ТРАНСФОРМАТОРІВ

Об'єктом дослідження є силові трансформатори, а саме системи їх діагностування з урахуванням дефектів та аварійних процесів під час визначення оцінки стану обладнання. В ході дослідження використовувався комплексний підхід до вирішення поставлених завдань, включаючи світовий досвід, синтез результатів та ретроспективи, методи технічної діагностики, теорію прийняття рішень. В ході розробки класифікації дефектів була зроблена спроба виключити недоліки, виявлені в інших підходах, і запропоновано діагностування за принципом «від загального до конкретного».

Ключові слова: *власний нормативний термін служби, старіння енергетичного обладнання, діагностичні системи силових трансформаторів.*

Introduction. High-voltage power transformers are the most important and expensive elements in the distribution system of electric energy. Reliability of electrical networks in most cases is determined by the reliability of high-voltage power transformers. Gradual aging of high-voltage power equipment takes place in all industrialized countries. Increasing the voltage levels and reducing the strength of the latest generations equipment has sharply raised the question of assessing its status and degree of risk beyond the normalized service life [1, 2].

In Ukraine, the number of transformers that exceeded its resource reaches 40 %, and for generating transformers with a capacity of more than 250 mVA, this figure is even higher and reaches 70 % [3, 4]. At present, in the Soviet Union countries energy system, about 45 % of transformers are in service for more than 20 years, 35 % over 25 years [5, 6]. A similar picture of the aging of the power transformers park is also observed in foreign power systems. So, for example, according to the US Electricity Institute's EPRI, in 2000, about 65 % of power transformers in US networks worked more than 25 years. About 30 % of transformers are over 30 years old in Japan.

Thus, the reliability of power high-voltage transformers, and, as a consequence, the reliability of the grid as a whole, will be determined by the reliability of transformers with a long service life, which far exceeds the estimated value.

Despite the fact that the design and manufacture of PT (power transformer) in Ukraine, was realised at a level not inferior to the best foreign firms, in operation they require the implementation of a set of preventive measures: chromatographic analysis of oil, electrical tests, current and capital repairs, etc. Because of the inadequate operation, as well as the physical and moral aging of equipment, the probability of accidents PT today is quite high. This, in turn, can lead to the following consequences:

- loss of the unit as a material value or the need for large investments for equipment restoration;
- «domino effect» probability, when the emergency process affects neighbouring equipment and the environment;
- a break in the electricity supply of consumers.

The latter circumstance can be a significant loss in a market economy, which in the end may exceed economic losses for the first two reasons. The problem is exacerbated by the fact that in modern electric networks, the operation of equipment that is exhausting or has long ago exhausted its normative resource continues and will continue.

Therefore, it is relevant to study the systems for diagnosing power transformers in order to generalize and simplify the classification in order to increase the efficiency of their operation.

The object of the study is power transformers, namely, their diagnostic systems, taking into account defects and emergency processes, when determining the state of the equipment.

As a result of the features of operation of high-voltage power transformers analysis, a number of problems have been identified that negatively affect the reliability of the functioning of electric networks in Ukraine:

1. The aging of power high-voltage transformers and the extremely low rates of their replacement, lead to the fact that the operation of transformers that have worked out their normative resource. In this regard, the greatest significance are the issues of improving the diagnostics of the state of such transformers and extending their service life.

2. About 30 % of the total number of technological violations of power high-voltage transformers is accompanied by internal short circuits, 24 % of which occurred with ignition and inflammation of transformers. In this case, the specific damage of transformers with internal short circuits permanently increases during operation. Transformer oil is the informative medium in the state of which 70 % of defects of power high-voltage transformers are detected.

3. The traditional system is not always able to assess the state of the working outdated equipment reliably. The existing system of diagnostics of the state of transformer oil does not allow to detect transformers with abnormal aging of oil at an early stage, that is, before these indicators have reached their limit values. The absence of the possibility of predicting the values of the characteristics of insulation, does not allow to realize the transition to repair and maintenance of transformers by their condition.

4. The most problematic defects in power transformers are: insulation failure between parallel branches, oil drainage, failure of the main and longitudinal insulation, troubles in the oil purification system. Classification of internal damages showed that the reliability of a modern transformer is largely determined by its isolation.

The aim of research is to improvement of classification system of defects and emergency processes in them to increase the effectiveness of measures in assessing them. To achieve this aim, it is necessary to perform the following objectives:

1. To research of systems of diagnostics of power transformers.

2. To research of defects of power transformers.

Research of existing solutions of the problem

According to the statistics of damages arising in power transformers [7–9]:

- about 22 % of technological violations are due to aging of materials;
- 19.4 % – defects in design and manufacturing;
- 16.8 % – the disadvantages of exploitation;
- 10.3 % – external influences;
- 5.8 % – unmatched modes in the network;
- 4.2 % – repair defects;
- 3.5 % – climatic and external influences.

From the analysis of literary sources [10–12] it was established that the parameters of diagnosing the processes of thermal wear of insulation are:

- the multiplicity of the current strength consumed by the power transformer;
- the excess temperature of the windings over the ambient temperature;
- the temperature of the windings, the temperature of the oil;
- the speed of thermal wear of the insulation windings.

The traditional approach to assessing the technical condition of transformers during operation is presented in [13]. In this approach, the transformer is presented as separate components: winding, core, insulating fluid, inputs, switching device, tank and associated devices [14].

The scope of the known tests has been supplemented with new ones, through which measurements can be made on a working transformer (acoustic and electrical measurements, vibration, acoustic and thermo-visual inspection [15], etc.). But in essence, an approach based on the monitoring of the established characteristics is maintained. The main disadvantages of the traditional system of monitoring the state of transformer oil [5, 14] are as follows:

1. Absence of direct dependence between controlled parameters and functional capacity of the transformer (safety margin).

2. Possibility of incorrect diagnosis and unreasonable actions (unnecessary drying due to the small value of insulation resistance, rejection of the core by the data of idle losses at low voltage, incorrect interpretation of signals of partial discharges, etc.).

3. Excess test volume (in many cases, only 5–10 % of the tests are effective).

4. Failure to consider possible defects that are not detected by the set volume of the test (e. g., pollution of the insulation, local humidification and insulation aging, deterioration of contact resistance, etc.).

5. Practical impossibility of foreseeing the future state, including the residual isolation resource.

Recently, for the purpose of assessing the status of power transformers, an integrated diagnostic survey is increasingly used, which consists of defining the nature and level of defects in all systems and nodes of transformers [16, 17]. The program of complex diagnostic examination includes the following stages:

- analysis of accidents and typical defects of this type of transformers;
- an overview of the transformer and the collection of technical information (on modes of operation,

load, short-circuit currents and operating voltage, features of operation, consumers, climatic conditions, atmospheric pollution, etc.);

- analysis of technical documentation and results of operational measurements;
- electrical measurements on the disconnected transformer (tgδ and R isolation of windings and leads, resistance of direct current windings, idle speed and short circuit resistance, etc.);
- measurements on the working transformer in load and idle modes (measurement of partial and other electrical discharges, location of discharges with the help of acoustic devices, thermo-visual inspection of all transformer nodes, vibration testing of the tank as well as oil pumps);
- sampling of oil from a tank, oil-filled inlets, contactors of the device of regulation under voltage and carrying out of physical-chemical analyzes in the laboratory;
- preparation and issue of a technical report, which presents the results of the survey and their analysis, a conclusion on the condition of the transformer and recommendations for further operation, and, if necessary, the volume and method of repair work.

The most significant disadvantage of complex diagnostic examination [5] is the high cost of conducting such an examination and, consequently, the impossibility of performing it on all transformers. An alternative to complex diagnostic examination [5], can serve as a diagnostic technology by ranking the equipment according to the technical condition and determining the part of the equipment that really needs a comprehensive survey. Ranking technology can be based both on the experience of operating the same type of equipment, and on determining the most likely defects of transformers and the degree of their danger for this design in these operating conditions.

The investigation of defects in power transformers and the analysis of various proposed classifications in [13, 18, 19] showed that such classifications have a number of drawbacks. In particular, in [13] the classification of defects in power transformers is reduced to two groups – thermal and electrical defects, which does not take into account all the diversity of possible damages in the transformer. The logic scheme for the transformers defects classification, which is given in [18], does not link the damage with specific structural elements of the transformer. In [19] defects are largely duplicated for each constructive system of the transformer.

Summing up the above analysis of literary sources, it should be noted the absence of a section of abnormal processes that cause the defect, and the structural elements of the transformer. This emphasizes the necessity of diagnosing from the fact that there is an abnormal process throughout the object and duration in the direction of detailing the nature of the process, specifying the place of the defect or both at the same time.

Research results. In the automated diagnostic systems [2] the classification of defects should facilitate the consistent involvement of various diagnostic methods for the most reliable and economical detection and assessment of the danger degree, as well as for the most accurate localization of the defect.

The most important direction in optimizing the operation of high-voltage transformers is the concept of transition to repair and maintenance of transformers by their condition. This transition implies not only high probability in assessing the state of the equipment, but also the ability to predict its behaviour, which is currently absent. Presently, expert systems and systems for monitoring the condition of power transformers are widely used [4]. Despite the wide range of controlled parameters (including live working), these systems have a significant drawback – decision-making methods are based on the traditional diagnostic system. There is a discrepancy between the use of modern information systems and measuring instruments and methods of processing received information.

Taking into account the considered classifications, proposed to use an improved defect classification system (Fig. 1), which eliminates such limitation as discussed in [13, 18, 19]. Such a system of defects classification of power transformers in most cases is sufficient to assess the state of the transformer in the first phase of the diagnosis.

Among the most problematic are the following defects in power transformers, such as: failure of isolation between parallel branches, oil drain, and failure of the main and longitudinal insulation, disturbances of the oil purification system. Classification of internal damages of transformers showed that the reliability of a modern transformer is largely determined by its isolation.

An advanced classification system of power transformers defects was proposed, in which an attempt was made to exclude shortcomings found in other approaches, it allows to divide the abnormal processes that cause the defect and constructive elements of the transformer. Such a classification system takes into account a number of most frequent defects of power transformers and the causes of their occurrence.

Summary

1. As a result of the analysis of the current state of power equipment of Ukraine and the CIS countries, it was discovered that most of the damage that occurs in power transformers is due to:

- aging of materials;
- defects in design and manufacturing;
- operating defects;
- external influences;
- unmatched modes in the network;
- defects in repairs and climatic and external influences.

Research of the systems of diagnostics of power transformers has shown that in each approach try to use a wide range of similar types and methods of tests of power transformers, but at the same time a certain mechanistic approach is seen when a new type of test is used without an analysis of its economic efficiency.

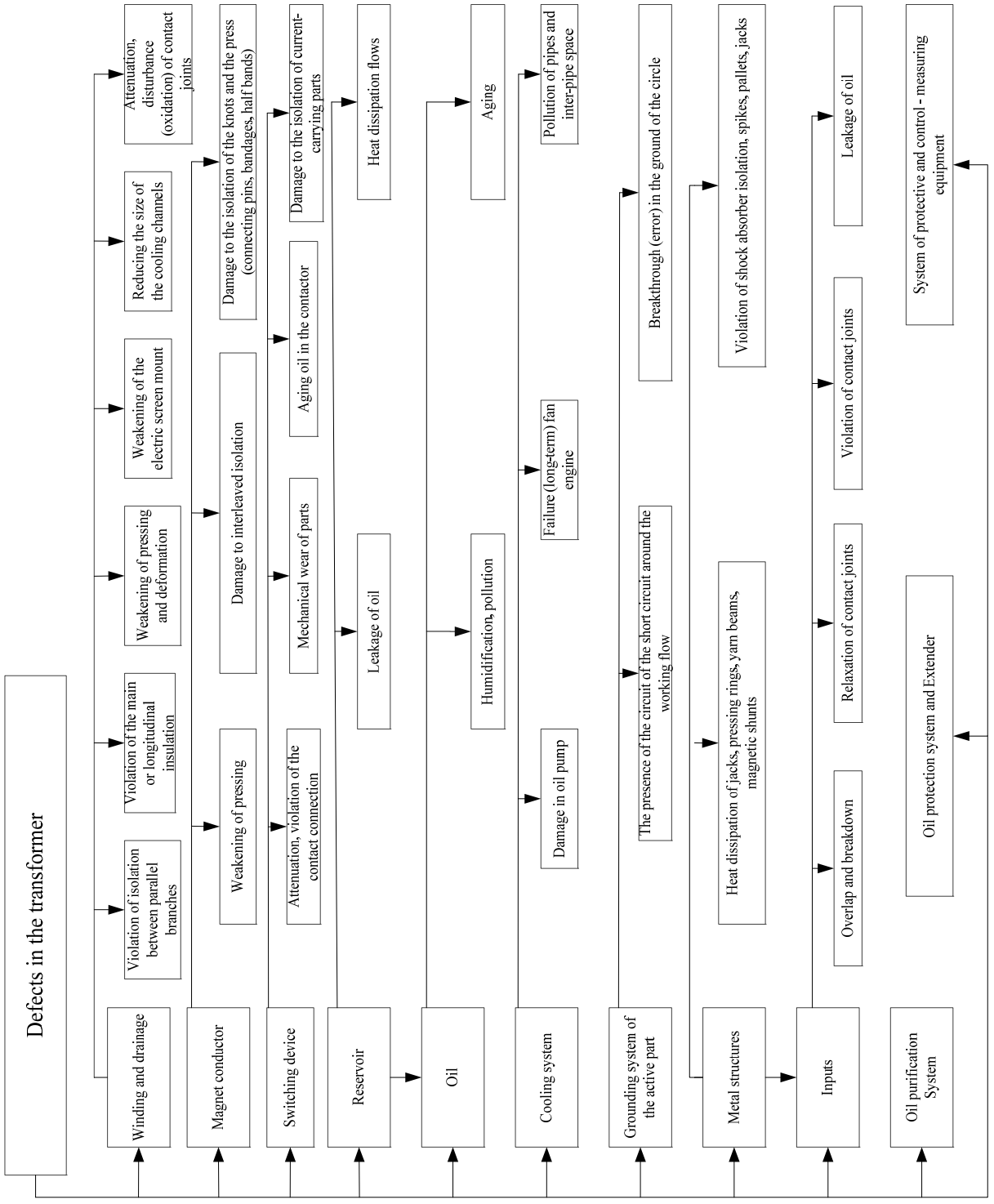

Fig. 1. An advanced system of classification of power transformers defects

2. In the study of defects of power transformers, it was found that the classification of defects should facilitate the consistent involvement of various diagnostic methods for the most reliable and economical detection and assessment of the degree of danger, as well as for the most accurate localization of the defect.

Improvement of the classification system of defects of power transformers makes it possible to exclude the deficiencies found in other approaches and the diagnosis on the principle of «from general to specific» is proposed. This approach to the classification strictly separates the abnormal processes that cause the defect, and the structural elements of the transformer; diagnostics begins with the statement of the fact that an abnormal process exists throughout the object and continues in the direction of detailing the nature of the process, specifying the place of the defect or both at the same time.

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