Method for increasing oil resources transformers with long-term operation

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Annotation. Estimates of the technical condition of equipment of power plants and substations are presented in the paper. They are associated with a high degree of deterioration of the power grid equipment, which affects the state and operating conditions of the equipment. The degree of these mutual influences and their laws can only be established with a general assessment of the state of entire equipment of the power grid facility. The selection of a rational system for the repair of power oil transformers of distribution substations involves a problem with multiple variables, based on the concept of reliability, aging, renewal and industrial diagnostics. It is recommended to conduct a comprehensive method of repair organization based on the individual observation by the Consumer for changes in the technical condition of the equipment during operation and the quantitative evaluation of the technical condition of the transformers with respect to the set of diagnostic parameters.

1. Introduction

Modern large industrial enterprises usually represent a complex technical system, one of the hazardous production facilities of which is power oil transformers, the state of which affects the productivity and safety of technological processes. The power transformer in the power system is one of the main components that determines the reliability of power supply. The need to operate power transformers with a long service life (exceeding the estimated time by a factor of 1.5-2) is considered as a characteristic feature of the economic development of the Russian energy industry now and in the planned future [1-4]. Improvement of the concept of warranty maintenance of transformers with a long service life sets the task of maintaining their functionality, and besides this, the reliability of electricity supply as a whole. One of the main ways to maintain reliability in such situations is to organize an effective monitoring of the condition of the equipment used. The technical assessment of the state of equipment in power plants and substations is considered as an urgent task.

2. Creation of a rational system for repair of oil transformers

An objective assessment of the "park" resource of oil transformers is necessary, within both the industry and certain energy organizations. At the same time, it is necessary to estimate the costs of extending the service life of the transformers since the service life of the equipment can be increased to that of parking only after the performance of preventive maintenance work.

The creation of a rational system for the repair of electrical equipment and power oil transformers of distribution and substations is a complex problem with numerous variables, based on the theory of

reliability, fatigue failure, recovery and industrial diagnostics. The essence of this kind of concept of maintenance and repair is that after a specific period of working out, at the time of the planned failure, various preventive works are carried out. The shorter the interval between the moment of the forecasted failure and the proper preventive effect produced on the equipment, the more effective the repair system is. With regard to electrical equipment, it is important to establish what characteristics to regulate and what conditions to take into account when assessing its technical condition.

The withdrawal of power oil transformers of distribution substations for repair is carried out on the basis of the principles of a functioning system of PPR (preventive maintenance) and regulatory documents. Therefore, it is necessary to pay attention to the existing systems of maintenance and repair, as well as a general assessment of the reliability of power oil transformers of distribution and substations [1-5].

3. Statistical processing of data on defects in the operation of transformers

Investigations were carried out from 2007 to 2017. 100 transformers with more than 20 years of operation, operated at large enterprises of the oil and gas complex in Salavat, made it possible to identify more than 1,300 defects, the type and place of which are given in Tables 1 and 2.

Table 1 shows the distribution statistics of the damage of power transformers by voltage classes, while their number was: 27% - for 35 kV; 47% - for 110 kV; 21% - for 220 kV; 2% - for 330 kV; 3% - for 500 kV.

Table 1. Statistics of the distribution of the number of damages of power transformers for voltage classes for 2007 - 2017.

	35 kV	100 kV	220 kV	330 kV	500 kV	Total Σ
Windings	128	98	19	2	0	248
Magnet wire	0	0	4	2	0	6
Cooling system	10	31	16	4	6	67
On-load tap-changer	7	111	51	2	10	181
Inputs	52	160	87	6	14	319
Oil leak	31	61	41	6	8	147
Passage oils	118	154	53	4	4	332
Total	347	615	270	26	42	1300

Table 1 shows the maximum damageability in percent due to: 26% - a drop in transformer oil, 25% - damage of high-voltage bushings, 19% - windings, 14% - on-load tap-changers, 11% - leaks, which has been confirmed earlier. Figure 1 and Table 3 show the "age composition" of the transformers.
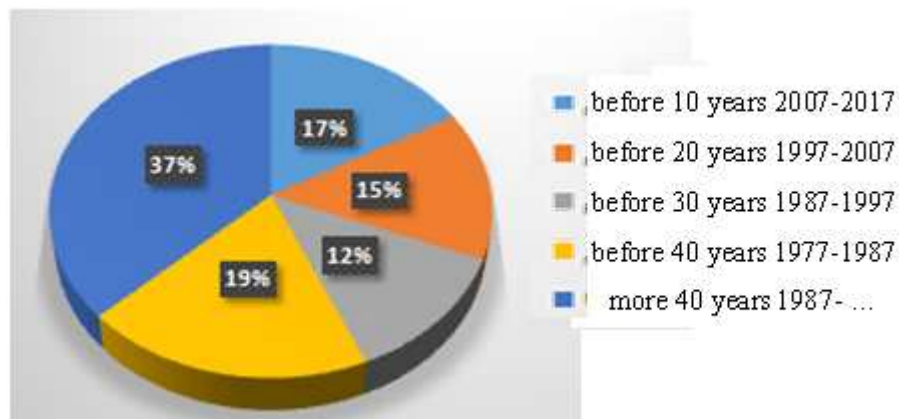
Figure 1. Distribution of transformers by service life

Table 2. Defects of power oil transformers

Defect type	Quantity	Share (%)
Blinker fault	21	4
No ground connection	30	6
Defects in the on-load tap-changer	10	2
Lack of oil	79	15
Malfunction of measuring devices	23	4
Faulty design	39	7
Leakage violation	60	11
Oil leak	176	33
Damage in the ShAOt	40	7
Pollution	61	11

Only in 30 cases, it is necessary to replace the whole transformer or its windings. The survey experience demonstrates that more than 70% of the damage can be detected without disconnecting the transformer from the network.

Table 3. Number of transformer defects by service life

Defects	Age of transformer					
	68-50	50-40	40-30	30-20	20-10	to 10
Oil leak	47	43	32	26	17	11
Impermissible leakage	23	15	9	7	4	2
Pollution	16	18	8	9	5	5
Lack of oil	27	21	13	7	9	2
Malfunction of the structure	16	10	7	4	2	0
Total	129	107	69	53	37	20

It is impossible to detect all types of defects at the same time; therefore, the main interest is given to disclosing the most frequent and most dangerous transformer damages for its performance.

One of the main methods of assessing the technical state of oil transformers is chromatographic analysis, which allows one to detect defects in equipment at an early stage of their development, to determine the nature of defects and the degree of damage.

A quantitative assessment of the technical state of transformers is proposed to be performed on a set of diagnostic parameters, presented as an integral criterion, formed by an artificial neural network using software.

4. The proposed solution

As a solution of the problem of ensuring the reliability of power oil transformers, it is proposed to pay attention to the existing maintenance and repair systems, as well as a general assessment of the reliability of power oil transformers of distribution and substations. Given there is the cost of repairing transformers, it is more reasonable to carry out major repairs more justifiably and as rarely as possible. To solve this problem, it is proposed to apply the theory of fuzzy sets [2] for estimating the state of the transformer, in the Matlab program.

In the program, input parameters of the equipment are entered, they can include resistance of windings to a direct current, insulation resistance of a transformer, an absorption coefficient. Figure 2 shows the Matlab program window.
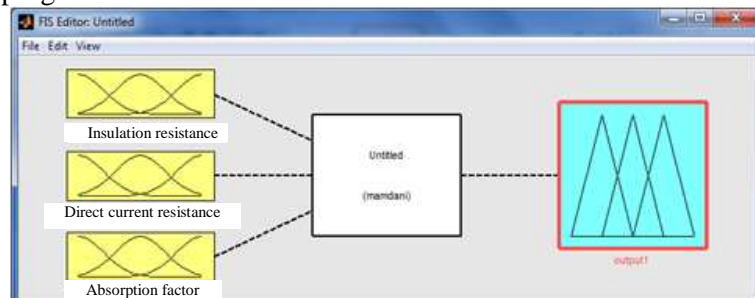

Figure 2. The Matlab program window

The program allows one to enter the input data (linguistic variables) and change them, depending on the characteristics of the equipment being examined, and also to obtain data on the state of the equipment (Figure 3).
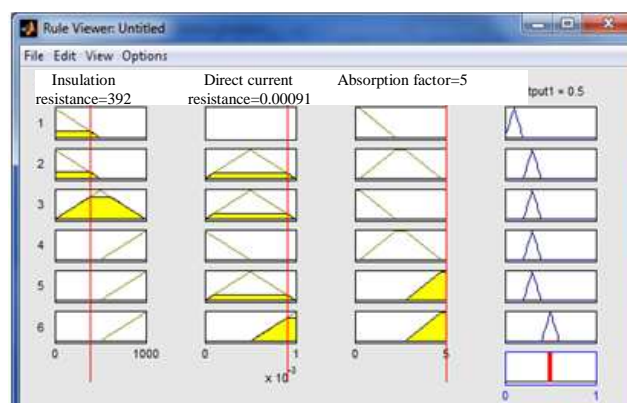

Figure 3. Input parameters and equipment status data

A software package was developed based on the Resurs-UF2 (M) power meter, a notebook and special software which allows for quick diagnostics of the technical condition of the equipment

connected to the SCADA system of the enterprise via the OPC server.

The software complex identifies the technical condition and predicts the resource of trouble-free operation of the equipment based on the set of parameters generated by the transformer of the higher harmonic components of currents and voltages based on the method of artificial neural networks. For the training of an artificial neural network, the theory of experiment planning is applied, which makes it possible to formulate the necessary database for training with a substantial decrease in the number of training experiments [2].

The conditions for ensuring the reliability of detecting diagnostic parameters against background noise and noise for determining the technical state and predicting the service life of the equipment use the parameters of the first ten harmonic components of the phase currents and voltages - the coefficients of harmonic current components KIn, harmonic stress coefficients KUn, which are practically the effective values of the harmonic components , normalized to the effective value of the first harmonic, and the values brought to period phase shift angles φui (n) between the respective harmonic components of phase currents and voltages.

The set of normalized values of diagnostic parameters is analyzed by a neural network. The network gives the result - the code of possible defect D and compares it with the data of the diagnostic dictionary [2].

$$D = f(K_{In}, K_{Un}, \varphi_{ui(n)}) = f(w_{I1} K_{I1} + w_{I2} K_{I2} + w_{I3} K_{I3} + \cdots + w_{I10} K_{I10} + w_{U1} K_{U1} +$$
$$+w_{U2} K_{U2} + w_{U3} K_{U3} + \cdots + w_{U10} K_{U10} + w_{\varphi 1} \varphi_{ui(1)} + w_{\varphi 2} \varphi_{ui(2)} + \qquad (1)$$
$$+w_{\varphi 3} \varphi_{ui(3)} + \cdots + w_{\varphi 10} \varphi_{ui(10)}),$$

where w is the weighting coefficients of the neural network for the corresponding diagnostic parameters.

For each type of test (measurement), the program calculates the membership function, which lies in the range from 0 to 1. Then the program, processing these data, outputs the output parameter. Output parameters determine the degree of efficiency according to the Bayesian table on the scale: D-1 is operational, D-2 is operable, but with small deviations, D-3 is inoperable, repairable, D-4 is inoperable.

An important advantage of the developed software package is that it allows one to diagnose operating equipment, as well as to conduct remote monitoring.

5. Conclusion
Thus, the use of fuzzy logic allows an integral assessment of the state of electrical equipment, which is not unimportant in the planning of equipment repairs. The developed software package allows one to detect defects on working electrical equipment at an early stage of their development, which not only prevents a sudden stoppage of production as a result of the accident, but also significantly reduces the cost of repairing equipment and prolongs its service life.

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