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Testing of the Oil Type Distribution Transformers

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Presenter Information

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Abstract. This paper proposes to present the testing of oil type distribution transformers in order to supply with adequate voltage for all consumers, regardless of the voltage level where they are connected. One of the main challenges of the distribution system operator remains the proper selection of the transformer, application of the modern methods of commissioning and testing them, as a necessity to provide a reliable electrical supply. With the technological advancement, has been achieved to proportionally increase the quality of transformers, contributing to the increase of the efficiency of the power system as a whole. Input data, including construction and operation principles of the transformers are used to create the testing model by discussing and analyzing the cause and consequences of the failures. Finally, based of these findings, the types of testing of transformers and their elements, create a realistic reflection of what needs to be considered when it comes to the testing of these devices. This paper will discuss the techniques and types of testing applied around the world, with special emphasis in Kosovo on testing of oil type transformers. The working methodology for the preparation of this paper is based on the practical knowledge and scientific research about worldwide experiences for the testing of oil power transformers.

Keywords: Oil type transformers, Testing of transformers, Commissioning of transformers, Type of testing.

1 Introduction

Operation tests are intended to check the design features of the equipment against the specified standards. This may include failure tests to assess the extreme capabilities of the equipment.

Commissioning is the last phase of the final project cycle, in which the objective is to verify the performance of the new equipment/systems/processes according to the purpose of the design and demand as well as the level of service of those equipment [1].

The aim of the preventive maintenance is to keep the components from aging and wearing out, or to restore and replace aged or worn components before they fail. Preventive maintenance is scheduled periodically or is performed on some other time table based on the past experience of the component failure modes [2].

The aim of the predictive maintenance, on the other hand, is to detect the aging or wear out in the components so that the preventative maintenance can be performed before the ultimate failure occurs. Predictive maintenance is commonly referred to as testing [2].

These same criteria apply to the testing. There are a number of site tests that are considered as good predictive maintenance practices and which are also useful for diagnosing the transformers' trouble, which should be performed periodically [2].

Transformers are exclusively used in the power systems to transfer the power by electromagnetic induction between the circuits at the same frequency, usually with changed values of the voltage and current [3, 4].

Transformers increase the voltage starting from 110 kV to approximately 1000 kV for long transmission lines with very small losses. Then, they reduce the voltage in the range of 0.4 kV to 34.5 kV for the distribution, and finally electricity can be safely used by the consumers.

If we know the fundamentals of the transformer's theory, design and operation, these principles can be applied for the maintenance, testing and troubleshooting.

A transformer may have a very long life or it may go out of function after its first energizing. The average longevity of a transformer usually depends to some extent on how well it is maintained [3].

Every transformer that is manufactured undergoes some form of factory testing. For power transformers, these tests are quite extensive and 5% of the test failures do occur. Test requirements are spelled out in a number of industry standards and specifications [5, 6].

This paper treats the techniques and types of testing applied around the world, with special emphasis in Kosovo on testing oil type transformers. It has been analyzed classification of faults in the transformers and the testing of oil type distribution transformers.

The paper is structured as follows: Construction and principle of transformers presented in section 2; Classification of faults in the transformers presented in section 3; Testing of oil type transformers presented in section 4 and Conclusions of this paper are summarized in section 5.

2 Construction and operation principles of the transformer

Power transformers are available as single-phase or three-phases [7].

According to the external form of transformers, they are distinguished as:

- Dry transformers, in which the windings are insulated with solid and gaseous materials. Dielectric gas also serves as a coolant, and
- Oil transformers, in which the windings between themselves and other conductive parts are insulated with solid and oily materials. The oil simultaneously serves as a coolant for the coils and for the magnetic circuit.

Like any other device, the transformer consists of its internal and external parts. The main internal parts of the transformer are the windings and the magnetic core. The internal composition of the transformer can also be considered as oil, if the transformer is of oil type.

2.1 Transformer windings

Windings are the most important and at the same time the most delicate parts of the transformer. The winding connected to the power grid is called primary, while the winding connected to the load is called secondary winding. The windings are electrically insulated from each other. The transformer has two or more windings that are electromagnetically connected to each other by means of a common magnetic flux. Transformer windings are usually made with copper conductors and less often with aluminum conductors.

If the number of windings in the secondary N_2 is greater than the number of windings in the primary N_1, $N_2>N_1$ then $u_2>u_1$, $i_2<i_1$ and the transformers are called step-up transformers. If the number of windings in the secondary N_2 is less than the number of windings in the primary N_1, $N_2<N_1$ then $u_2<u_1$, $i_2>i_1$ and the transformers are called step-down transformers (Fig.1).

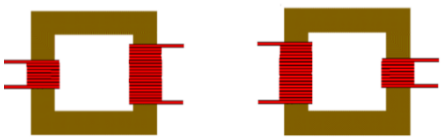

Fig. 1. Winding of step-up and step-down transformers

2.2 Transformer's core

To strengthen the magnetic connection between the windings in most transformers, the windings are placed in the steel core, which represent a closed magnetic circuit.

2.3 Transformer's oil

In oil type transformers, the magnetic cores together with the windings are inserted into the oil-filled boiler. The primary functions of transformer oil are its insulation and cooling. In order for these functions to be properly performed, the oil must have high dielectric strength, thermal conductivity and chemical stability.

2.4 Operation principle of the transformer

The function of the transformer is based on the principle that electricity is efficiently transferred through electromagnetic induction from one circuit to another. From fig. 2, we show that by connecting the primary winding at the voltage u_1 flows the current i_1. As a result of this current, the magnetic flux ϕ_1 is created which due to the very small value of magnetic resistence of the cores is closed mainly inside it. This flow represents the main flow ϕ and the rest of the flow closes through the airspace and is called leakage flow ϕ_{11}. Therefore we have: $\phi_1 = \phi + \phi_{11}$, the same analogy applies to the secondary winding.

This flux as well as the current that creates it, being alternative, induces in the primary and in the secondary winding the corresponding f.e.m:

$$e_1 = -N_1 \frac{d\phi_1}{dt} \quad (1)$$

$$e_2 = -N_2 \frac{d\phi_2}{dt} \quad (2)$$

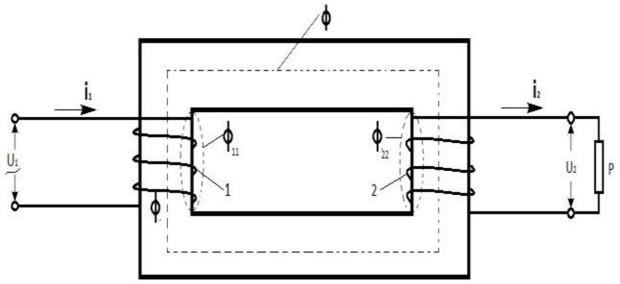

Fig. 2. The operation principle of the transformer

By closing the secondary circuit under the action of e.m.f e_2 in the secondary circuit will flow the current i_2, which shows that the electricity $(e_2 i_2 dt)$ is transmitted through the magnetic field from the primary to the secondary winding. The equations of e.f.m. for primary and secondary confusion are marked:

$$u_1 + e_1 = i_1 r_1 \quad (3)$$

$$e_2 = i_2 R_{load} + i_2 r_2 = u_2 + i_2 r_2 \quad (4)$$

Since the active winding resistances are very small, the above equations will be:

$$u_1 = -e_1 \quad (5)$$

$$u_2 = e_2 \quad (6)$$

$$\frac{u_1}{u_2} = \frac{|e_1|}{|e_2|} = \frac{N_1}{N_2} \quad (7)$$

Since in the power transformers, the current values of voltage and corresponding e.m.f for each current time are practically the same, then the ratio of current values is equal to the ratio of effective values:

$$\frac{U_1}{U_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = k \quad (8)$$

$$\frac{i_1}{i_2} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = \frac{1}{k} \quad (9)$$

Where k represents the ratio between the number of N_1 and N_2.

3 Classification of faults in the power transformers

Faults in the dsitribution transformers can occur:

- Due to the user: Overloaded transformer, one-phase overloaded, unbalanced loads, faults ocured by short circuits in the network, non-periodic maintenance and wrong transformer installation.
- Due to the manufacturer: Wrong design, poor quality of the material used, work performed not according to the technical specifications, improper transport, improper conductor insulation;

Belove are the most common faults during the operation mode.

3.1 Oil leakages

The oil, in addition to serving as an insulating tool, it serves also to transfer the heat generated in the windings and core towards the tank walls and radiators. For this reason it has:

- High dielectric strength
- Low viscosity

If the oil leaks from the transformer tank for any reason, the oil level in the tank will drop. In the worst case, the insulator connections and winding parts will be exposed to the air. This will increase the temperature of the windings. This, in turn, would damage the insulation of the windings. In addition, moisture can penetrate through the leak, and degrade the transformer oil leading to the transformer's overheating.

Oil leakages can occur from many parts of the transformer's tank: radiator arms (Fig.3.a), gaskets (Fig.3.b), bad welds, valves that control the oil flow between the radiator and the main oil tank.

3.2 Improperly fixed bolt connections

In the Fig.3 (c) , there is an example where the maintenance workers made improper connections to the terminals in the distribution transformer. This resulted into overheating of the transformer near the bolts (connections), causing failure.

3.3 Damage of the insulating oil

Insulating oil is gradually damaged by its use. The main cause is the absorption of the moisture inside the oil type transformer. Whenever the humidity doubles in a transformer, the life span of the insulation is halved. Faults due to moisture absorption are the most common causes of the transformer failures. The moisture content in the oil increases, and when the transformer is activated, water begins to migrate to the colder part of the transformer. There is almost twice as much moisture at the bottom than at the top (Fig.3 (d)).

3.4 Failures due to the winding strain and shrinkage of the windings

Transformer failure can occur due to the strain of the several windings of the same phase, which occurs due to the overheating (Fig.3.e).
Shrinkage can cause looseness in the coil mounting, which can result into failure due to the short-circuit forces (Fig.3.f). To overcome such failures, it is recommended to be used good quality insulating bolts.

3.5 Failures from the magnetic circuit damage

When the insulation between the iron rods is damaged, it results into local overheating. Thus, the temperature of the coil rises and its insulation may fail (Fig.3.g).

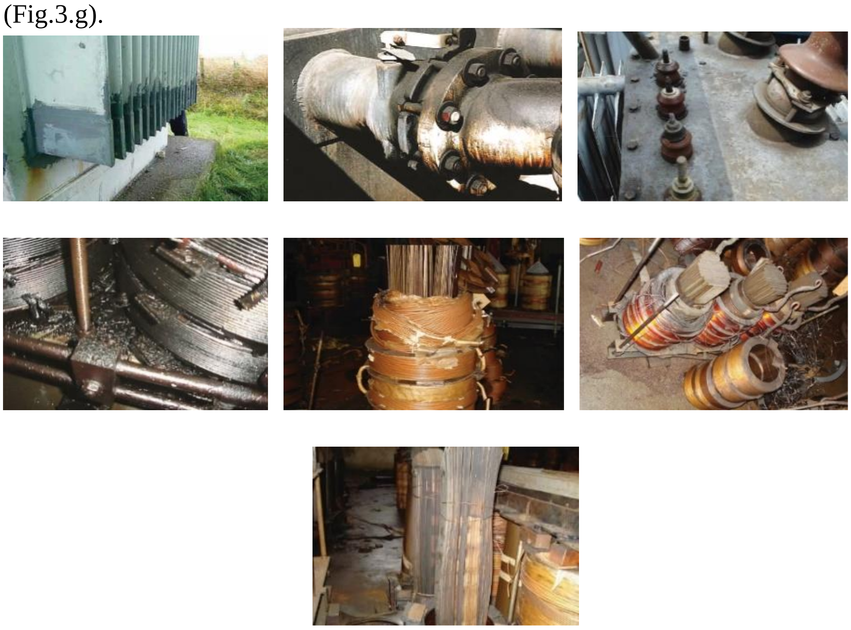

Fig. 3. Failures in the power transformer: (a) Oil leak from the radiator and (b) gaskets; (c) Released connections; (d) Moisture damage to transformer oil; (e) Strengthening the coils; (f) failure due to shrinkage and (g) Failures from magnetic circuit insulation

4 Testing of oil power transformers

To carry out a successful operation of the electrical equipment and apparatus, it is essential to set up an effective maintenance and testing program [8].

The schedule for all required tests and inspections is listed on the Power Transformer Acceptance and Maintenance Checklist.

According to [9] the transformer, tests are divided into: type, routine and special tests.

- Type test includes: Dielectric measurement, temperature rise test, noise level measurement and tap changer tests.
- Routine test includes: Winding resistance measurement, voltage ratio check, phase relationship check, impedance voltage, load loses, no-load loses, high voltage test and on-load tap changer functional test.
- Special test are made at the request of the client or the engineer. It should be appreciated that such test may put a considerable strain on the transformer. The special test actually simulate the conditions that could really occur in the practice.

The requirements for a good test are as follows:

a) The test should have a sensitivity; in other words, it should give an early warning of the impending trouble.
b) The test should have selectivity; in other words, it should not give off false positive indications of the trouble and should give a clear indication of what is wrong.
c) The test should be practical; in other words, it should not require an unusually high skill level to perform the test or interpret the results.
d) The test should be nondestructive.

Below we will address some types of testing.

4.1 Inspection

A transformer maintenance program should be based on the detailed routine inspections. Determining the existing condition of the distribution transformers is an essential step in analyzing the risk of the failure. New transformers should be inspected for the damage during the transport when accepted. All connections that may have been dismantled during transport must be strengthened before being activated.

4.2 Insulation resistance test - *IR*

Insulation resistance tests are performed to determine the insulation resistance from the individual windings with earthing or between individual windings. Insulation resistance tests are usually measured directly with mega Ohm (Fig.4.a) or can be calculated from the measurements of applied voltage and leakage current.

4.3 Winding resistance test

Winding resistance measurements are an important diagnostic tool for assessing the potential transformer damage resulting from the poor design, mounting, handling, adverse environments, overloading, or poor maintenance.

The main reason of this test is to check for the large differences between the windings and open points which may be in the windings. Measuring the resistance of the transformer windings ensures that each circuit is properly connected and tightly tightened.

The winding resistance in the transformers will change due to the loose connections or deteriorated contacts in the tap changer. Regardless of the configuration, resistance measurements are normally done step-by-step and readings are compared with each other to determine if they are acceptable.

Transformer winding resistance measurements are taken by passing a known DC current, through the winding in which the tests are being carried out and by measuring the voltage drop across each terminal.

4.4 Polarization index test - *PI*

Insulation of the system prevents winding defects. The excessive temperature rise dehydrates the air and oxidizes and makes the insulation brittle.

Insulation Resistance (*IR*) and Polarization Index (*PI*) are two universally accepted diagnostic tests for the insulation tests.

PI is a variation of the *IR* test and it is the ratio of *IR* measured after voltage has been applied for 10 minutes (R_{10}) to *IR* measured after one minute (R_1).

$$PI = \frac{R_{10}}{R_1} \tag{10}$$

A low *PI* value indicates that the windings may have been contaminated with dirt or have absorbed moisture.

$$R_1 = \frac{V}{I_t} \tag{11}$$

Where: V is the DC voltage applied and I_t is the current flowing in the circuit.

4.5 Power factor test

Power factor tests are used to measure dielectric losses, which are related to the moisture, dryness or deterioration of the transformer insulation. The power factor testing of a two-winding transformer is performed by activating a nominal voltage (usually 10 kV for winding) in the short connected windings.

The general results of the power factor test on the power transformers reflect the state of the insulation of the winding, tap changer, bushings and oil. Modern oil type power transformers must have $cos\varphi$ of 0.5% or less, at a temperature of 20^0 C.

4.6 Dielectric test

The dielectric strength of the transformer oil is also known as the breakdown voltage (BDV) of the transformer oil. The permability voltage is measured by observing the voltage, between the two electrodes immersed in the oil, separated by a specific gap. A low value of BDV indicates the presence of the moisture content and accompanying substances in the oil. This measurement is taken 3 to 6 times in the same oil sample, and we obtain the average value. BDV is an important transformer oil test, as it is the main indicator of oil health and can be easily performed on site (Fig.4.b).

Dry and pure oil gives BDV results, better than the oil with moisture content and other accompanying impurities. The minimum breakdown voltage of the transformer oil or dielectric resistance of the transformer oil in which this oil can be safely used in the transformer, is considered as 30 kV. Water content in the oil is allowed up to 50 ppm as recommended by IS - 335 (1993).

4.7 PCB Test

Polychlorinated biphenyls (PCBs) were widely produced worldwide between the 1930s and 1980s wich were widely used in many appliances such as at the transformers, capacitors and other electrical appliances because of their useful quality as resistant to fire, where they were used as lubricants and as coolants. Polychlorinated biphenyls (PCBs) were recognized as an environmental pollutant, when they were classified as hazardous waste. Although prohibited by law and severely punished, a large number of transformers contaminated with PCBs are still in service. Unfortunately, still a large number of transformers with PCBs remain which can be a source of pollution in the environment, and it can contain a worth of 500ppm or less.

4.8 Transformation ratio test

Transformation Ratio Tester (TTR) is a device used to measure the transformation ratio between windings (Fig.4.c). Ratio measurements are performed at all tap changer positions and are calculated by dividing the reading induced voltage by the value of the applied voltage.

When transformation of ratio test is performed on the three-phase transformer, the ratio is taken in one phase at the same time as a three-phase TTR until the three-phase ratio measurements are completed. The measured ratio changes must be within 0.5%.

4.9 Testing of the transformer protection components

Transformer components that are routinely tested are:

- Buchholz relay (Fg.4.d);
- Thermometer (Fig.4.e);

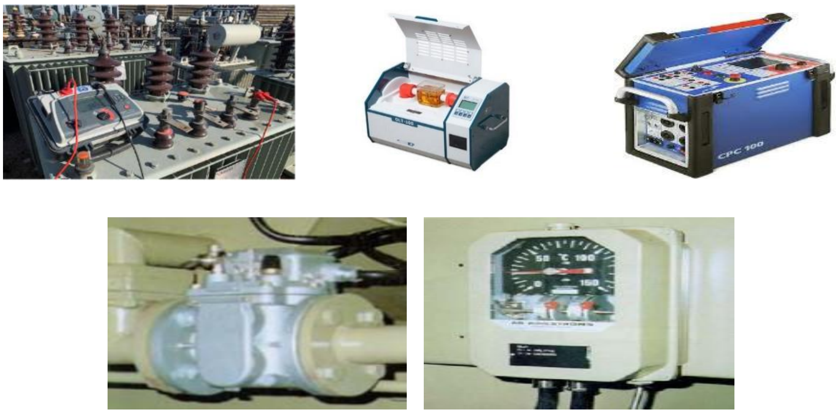

Fig. 4. (a) Insulation resistance test of 10/0.4 [kV] transformer; (b) Equipment for testing the dielectric strength of oil; (c) OMICRON CPC 100; (d) Buchholz relay and (e) Thermometer

Below are some types of the tests performed on a 35/10 kV oil power transformer and the results obtained from these tests are presented in Fig.5.

The tests performed are:

- Insulation resistance test *IR*, performed with the Megger instrument;
- Winding resistance test, measured with Omicron CPC 100 (mΩ);
- Transformation ratio test, performed with Omicron CPC 100 (%)
- Dielectric test - strength of oil (kV/cm) and
- Earthing resistance (Ω).

5 Conclusions

The importance of studying the transformers during their work in the power system is quite great. As key components in the overall operation of the system, early detection of failures would reflect on ensuring the continuity of the power supply.

Based on the chronology of developing testing oil type transformers, it was concluded that commissioning and testing are crucial phases, which provide a guarantee of proper operation and justify the intended service life of this device.

Testing of transformers as preventive measure for possible failures that may occur, guarantee their functionality and ensure that the devices serve the purpose within the foreseen period. Except the type tests performed after the manufaturing of transformers, it can also be realized the site test as a measuremet unit included in the maintenance phase. Inspection is also equally important which contributes greatly to obtaining the records, routine tests and create a safe database.

All type tests treated in this paper, executed into oil power transformers on a periodic basis, are a necessary processes that contribute greatly to the achievement of the goals set by professionals in this field.

35/10 [kV] Transformer Test

Substation - Place	Fushe Kosova Warehouse	**Serial Number**	XXXX	
Power	8 [MVA]	**Connection Group**	Dy 5	
Type	VT 8000/35-10.5	**Production Year**	1981	
Producer	Energoinvest	**Position of TR**	Reserve	
Uk %	6.95 [%]	**Oil / Total Weight**	3.3 [t]	15.3 [t]

Insulation Resistance Test (Test with Megger)

		HV -with ground - R' (GΩ)			LV - with ground - R" (GΩ)		
Measurement Time		**1U-m**	**1V-m**	**1W-m**	**1u-m**	**1v-m**	**1w-m**
1	**15 sec**	1.350	1.600	1.812	1.295	1.548	1.722
2	**60 sec**	2.300	2.600	2.820	2.850	3.470	3.820
3	**R (GΩ) HV-LV (U-u)**	0.909			2.340		
Factor		**High Voltage**			**Low Voltage**		
4	**Rad=R (60 s)/R (15 s)**	1.703	1.625	1.556	2.200	2.241	2.218
5	Insulation quality	Rad.>1.25	Rad.>1.25	Rad.>1.25	Rad.>1.30	Rad.>1.30	Rad.>1.30

Winding Resistance - Omicron CPC 100 or Multimeter (mΩ)

1U-1V	1U-1W	1V-W	2u-2v	2u-2w	2v-2w	2u-2n	2v-2n	2w-2n
1.5	1.5	1.5	0.1	0.1	0.1	0.1	0.1	0.1

Ratio Test - Omicron CPC 100 (%)

1U-1V/2u2n	1U-1W/2v2n	1V-W/2w2n
0.04%	0.02%	0.02%

Oil Dielectric Strength (kV/ cm)

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average (1+2+3+4+5+6)/6
kV	53.30	59.90	75.00	95.40	54.20	59.10	**66.15**

Ground Resistance (Ω)

Point 1	Point 2
0.1 Ω	0.3 Ω

Date: 06.01.2021
Tested by: Team

Fig.5. Tests performed in 35/10 kV oil transformer

References

1. Rao, S.: Testing, Commissioning, Operation and Maintenance of Electrical Equipments, 2004.
2. Power Transformers: Acceptance, O&M, Tests, Inspections. Distribution Department Instructions DDI S-110. Pennsylvania Power & Light Company, Allentown, PA, 1997.
3. John, J., Winders.: Power Transformers Principles and Applications; PPL Electric Utilities Allentown, Pennsylvania, Marcel Dekker's, 1st Edition, 2002.
4. Kulkarni, S. V., Khaparde, S.A.: Transformer Engineering Design and Practice, Marcel Dekker's, 2004.
5. IEEE Std. C57.12.90-1999. IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers. Institute of Electrical and Electronics Engineers, Inc., New York, 1999.
6. IEEE Std. C57.12.00-2000. IEEE Standard General Requirements for Liquid Immersed Distribution, Power, and Regulating Transformers. Institute of Electrical and Electronics Engineers, Inc., New York, 2000.
7. Harlow, J. H.: Electric Power Transformer Engineering, The Electric Power Engineering Hbk, Second Edition, 2003.
8. Gill, P.: Electrical Power Equipment Maintenance and Testing, Taylor & Francis Group, Second Edition, 2009.
9. Baylis, C. R.: Transmission and Distribution Electrical Engineering, Linacre House, Jordan Hill, Oxford OX2 8DP 200 Wheeler Road, Burlington, Second edition, 2003;