# TESTS ON POWER TRANSFORMERS

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***Abstract***: **Power transformers are ma or power system equipment. Their reliability not only affects electric energy availability of the supplied area, but also affects the economical operation of a utility. Determining transformer condition is useful in itself for making short term decisions regarding operation and maintenance. This paper deals with the analysis of maintenance type of transformers, in connection with power transformers testing methods, having in view to establish a methodology to use data acquisition derived from condition monitoring and standard diagnosis for rehabilitation purposes of transformers.**

***Keywords***: *transformer, testing, maintenance, dissolved gas analysis, life of transformer*

## 1. INTRODUCTION

Under new deregulation policies of electric power systems and the growing demand to maintain electric system reliability, significant changes are required in the way a utility operates and cares for its power transformers. It is usually not economically feasible to subject every aging transformer to rigorous inspection and extensive testing. A promising industry strategy for life-cycle management is to set monitoring priorities and to provide strategic maintenances for all transformers.

For determining the most cost-effective alternative for operation or replacement it is necessary to know the operating conditions of transformers which are important inputs to the technical and economic models.

## 2. MAINTENANCE AND TESTING WORKS

Maintenance can be described as the measures adopted to ensure that equipment is kept in a fully serviceable and reliable condition. Of necessity it is therefore mainly a routine involving attention at regular intervals to particular features based on service experience and manufacturers' recommendations. The purpose of a maintenance service is to maintain the equipments functioning for a longer period of time and the reduction of the number of failures. The failures are very expensive and lead to the rise of exploitation costs through:

1. production of losses caused by the interruption of the interruption of the installation functioning or equipments depended on this;
2. supplementary activities connected with investigations, the repairing teams interventions and elimination of fault;
3. losses due to the reduction of the product quality;
4. generation of indirect costs.

For the optimization of the maintenance activities is necessary that those:

- to be efficient (as type, cost and quality);
- to take into account the consequences of some incidents;
- to take into account the history of the installations and of their components, their wear;
- to take into consideration all the elements which contribute to the exploitation of the installation components in the system;
- to use modern methods and procedures of the equipment state diagnosis.

Maintenance program means all the technical and organizational actions which are executed on the installations and their components after given into functioning and which are made for maintaining or resettlement of the capacity to fulfill the functions for which are they were designed.

The works which are made at the transport installations of electric energy are included in the next main maintenance categories as shown in figure 1:

- preventive maintenance;
- predictive maintenance;
- corrective maintenance;
- reliability based maintenance.

The preventive maintenance works are those which are done at predetermined time periods, to prevent the fault of the component elements of the installations or the reduction of the evolution probability in time of some failures.

The main purpose of the preventive maintenance is the prevention of break off and the assurance of doing the life time, in the conditions of the preventive maintenance strategies justified from the technical and economic point of view.

The ideal strategy from the point of view of security in operating is that to predict such a periodic preventive maintenance work, to prevent the occurrence of some failures which would have been produced in the absence of the works or if these works were made at another time.

In the category of preventive maintenance works are included:

- efficient exploitation works which are constituted by the ensemble of activities connected by the installations surveillance, operating regime assurance, maneuvers, receptions and into operation made by the personnel from the power station ;
- the control of the installations to see their technical state and to find out some failures which are going to be remedied;
- technical revise which contains check works, cleaning, adjustment, measuring and assay, with the elimination of some failures, through the replacement of pieces and used subsystems.

The technical revise has the purpose to find out the technical state of installations. In the case, when at the technical revise there are seen failures that cannot be repaired in the appointed time, the equipment or installation becomes unavailable and there are going to be made corrective maintenance works.

Repairing works have the purpose of restoration the initial technical state of the electric installations through the replacement of the defect or used elements.

Repairing works can be classified as it follows:

a) Current repairing works contain the works and operations which are done periodical, in the purpose of assuring the installations operating until the next repair; so the used pieces and subsystems with low reliability are replaced, eliminating the causes of failures found by the previous maintenance works.

b) capital repairing works contain the works done periodically on the fixed means, with the purpose of bringing the installations and their components at the corresponding parameters from the prescriptions.

For these repairing works there are done partially or entire replacement works of the used elements or subsystems and those whose normal life time is inferior to the normal operating life time.

Through predictive maintenance actions are made diagnosis and monitoring of the equipments, in the purpose of finding some incipient faults, for the reduction of the evolution probability in time and to avoid the failures of the equipments.

Corrective maintenance works are made after the detection of the fault, to bring the installations to be capable to fulfill the functions which they were built for.

Reliability based maintenance works are done after the installations modernization, at higher periods of time than those used for the rest of the installations.

Although maintenance and work practices are designed to extend the transformer's life, it is inevitable that the transformer will eventually deteriorate to the point that it fails or it must be replaced.

Transformer testing allows this aging process to be quantified and tracked, to help predict replacement intervals and avoid failures.

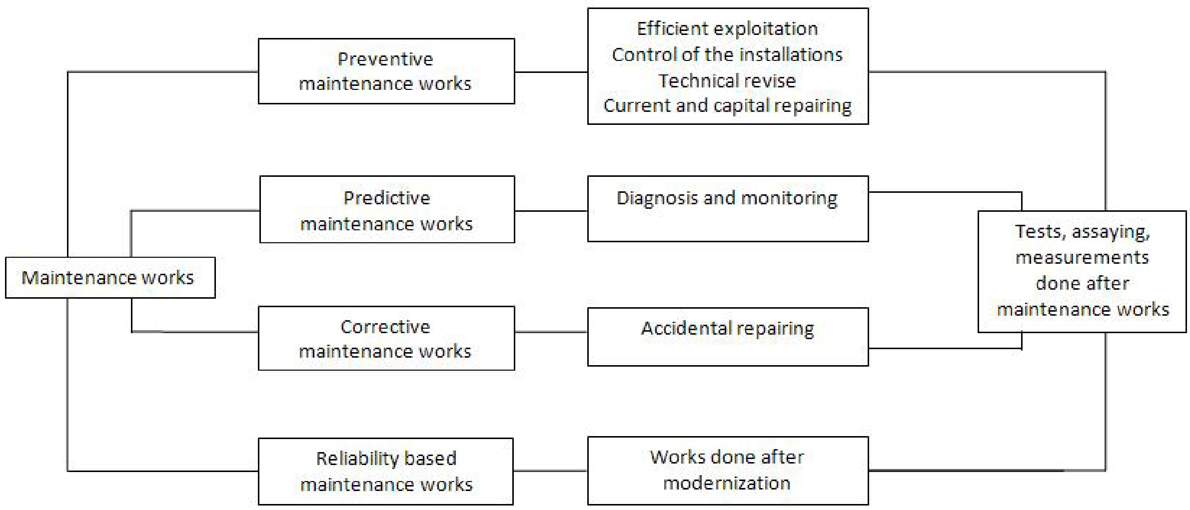


Figure 1: Classification of maintenance works.

## 3. OPERATIONAL CONDITIONS FOR TRANSFORMERS

For monophase and triphase power transformers and autotransformers, with two or three copper or aluminum windings with the insulation from the voltage domain A and C of at least 1kVA rated power for monophase transformer and at least 6.3 kVA or 5 kVA for triphase transformers, destined to function at the frequency of 50 Hz, the main conditions are:

- the temperature of the cooling environment:

a) water cooling: - the maximum entrance temperature: 25°C

b) air cooling: - the maximum temperature: 40°C

- the minimum temperature: -40°C (-35°C) for the transformers assembled outside, (-15°C) for the transformers installed inside,

- the maximum daily average temperature: 30°C,
- the maximum annual average temperature: 20°C,
- the supply voltage has the sinusoidal form,
- concrete symmetrical voltages in case of triphase transformers.

The operating temperatures allowed for the oil transformers are: oil maximum 100°C; windings maximum 105°C; if the temperature of the cooling air surpasses 40°C with until 5°C, the maximum temperatures permitted for oil and windings are reduced with 5°C, and if the surpassing is between 5°C and 10°C, the allowed temperatures for oil and windings are reduced with 10°C.

The level of oil in the transformers, function of the outside environmental temperature, is supervised with the level bottle or other device, which indicates the corresponding levels of some outside temperatures like: -35°C, +15°C, +35°C.

The ultimate deviations admissible to some electric characteristics are:

- the no-load transformation ratio: ±0,5% from the transformation ratio or ±10% of the short circuit voltage in percent, measured at the rated current;
- short circuit voltages: ±10% for the two windings transformers and ±15% for the three windings transformers only for one of the windings and ±10% for the others.

## 4. TESTING METHODS AND ASSET MANAGEMENT OF TRANSFORMERS

The normal practice for testing transformers is to elaborate a set of tests to prove that the transformer is ready for service. The three classes of works tests are referred to as ‘type’, ‘routine’ and ‘special’.

Routine tests consist of:

a) voltage ratio, polarity and phase checked;
b) winding resistance measured;
c) insulation resistance measured;
d) load loss and short-circuit impedance measured;
e) no-load loss and magnetizing current measured;
f) dielectric routine tests;
g) tests on on-load tap changers, where appropriate.

a) Ratio test must be made at rated or lower voltage and rated or higher frequency. The methods which are accepted for the ratio test are the voltmeter method, the comparison method and the ratio bridge. The voltage at the primary and the open-circuit voltage of the secondary winding are measured, with the voltmeter method when the primary winding is excited at rated frequency. The comparison method applies voltage simultaneously to the transformer under test and the open-circuit secondary voltages are measured and compared.

b) With the voltammeter method is measured the direct current resistance of each phase of each winding.

c) The insulation resistance test applies a high-voltage to one winding at a time with the other windings grounded. The leakage current is measured and the insulation resistance is calculated using Ohm’s law.

d) For measuring the load losses and impedance voltage, the transformer must have a specific state. The temperature of the insulating liquid must be stabilized and the difference between the top and bottom oil temperatures shall be less than 5°C. The difference in the winding temperature before and after the test must not exceed 5°C. The two test methods for measuring load losses and impedance voltage are the wattmeter-voltmeter-ammeter method and the impedance bridge method. These tests generally apply a reduced voltage to one set of windings with the other set of windings short-circuited.

| Limit | Diagnostics | Interpretation | Measures |
|---|---|---|---|
| Resistance change to the factory value >5% | 1. Bushings, LTC loose connections.<br>2. Shorted winding turns or open winding circuit | The values tested are compared with the factory tests or with previous values having the same temperature as reference | If DGA test indicates the presence of $C_2H_4$, $C_2H_6$, then a winding resistance test is necessary. |

Table 1: Winding resistance test.

e) The fundamental principle of the no-load loss and magnetizing current test is that normal rated voltage is applied to one winding while the other is left open circuit. The magnetizing current is normally a small percentage of the full-load current.

f) Dielectric routine tests consist of applied-voltage tests and induced-voltage tests in combination with a switching impulse test and a lightning impulse test. With the applied voltage tests a high voltage to all bushings of a winding is applied, one winding at a time, the other windings are grounded. With the induced-voltage tests, a high voltage across a winding is applied; the other windings are open-circuited in order to test the quality of the turn-to-turn insulation. The switching impulse test applies a switching impulse wave between each high-voltage line terminal and ground. The test is successful if there is no sudden collapse of voltage. The lightning impulse test sequence consists of one reduced full wave, two chopped waves and two full waves.

g) With the tap changer fully assembled on the transformer the following test sequences are performed:

- with the transformer un-energized, eight complete cycles of operation are performed;
- with the transformer un-energized and with the auxiliary voltage reduced to 85% of its rated value, one complete cycle of operation is performed;
- with the transformer energized at rated voltage and frequency one complete cycle of operation is performed;
- with one winding short-circuited and rated current in the tapping winding, 10 tap change operations over two tap steps on either side of the middle tapping, or where any reversing switch operates, is performed.

Type tests consist of:

- dielectric type tests,
- a temperature-rise test: the transformer is energized at rated voltage in order to generate core losses. The windings are connected to a loading transformer that simultaneously circulates rated currents through all of the windings in order to develop load losses. It is uneconomic, if not totally impossible to test a large transformer at the maker's works with both full voltage applied and full-load current in the windings, as the total output would have to be supplied and dissipated in some way.

Special tests consist of:

- dielectric special tests;
- determination of capacitances between windings and earth and between windings;
- determination of transient voltage transfer characteristics;
- measurement of zero-sequence impedances on three phase transformers;
- short circuit withstand test;
- determination of sound levels;
- measurement of harmonics in the no-load current;
- measurement of the power taken by the fan and oil pump motors;
- measurement of insulation resistances to earth of the windings and measurement of the loss angle of the insulation system capacitances.

Special tests are only carried out by agreement between purchaser and manufacturer.

## 5. CASE STUDY

Transformer dielectric fluids are refined from petroleum and are very complex mixtures containing hydrocarbons. At high temperatures, some of these molecules break down into hydrogen plus small hydrocarbon molecules such as methane, ethane, acetylene, propane and propylene.

At temperatures below 150°C, transformer oil starts breaking down into methane ($CH_4$) and ethane ($C_2H_6$). At temperatures above 150°C, ethylene ($C_2H_4$) begins to be produced in large quantities while the concentration of ethane decreases. At around 600°C, the ethylene production peaks while the concentration of methane continues to increase. Acetylene ($C_2H_2$) production starts at around 600°C and methane concentration peaks at 1000°C. Hydrogen ($H_2$) production is not significant below 700°C and continues to increase along with acetylene at temperatures above 1400°C. The so-called Rogers ratio method takes the ratios of several key gases into account to develop a code that is supposed to give an indication of what is causing the evolution of gas.

| Ratio | Ratio range | Code |
|---|---|---|
| $CH_4/H_2$ | $\leq 0.1$ | 5 |
| | 0.1-1 | 0 |
| | 1.0-3.0 | 1 |
| | $\geq 3.0$ | 2 |
| $C_2H_6/CH_4$ | $<1.0$ | 0 |
| | $\geq 1.0$ | 1 |
| $C_2H_4/C_2H_6$ | $<1.0$ | 0 |
| | 1.0-3.0 | 1 |
| | $>3.0$ | 2 |
| $C_2H_2/C_2H_4$ | $<0.5$ | 0 |
| | 0.5-3.0 | 1 |
| | $>3.0$ | 2 |

Table 2: Four ratio code.

| $\frac{CH_4}{H_2}$ | $\frac{C_2H_6}{CH_4}$ | $\frac{C_2H_4}{C_2H_6}$ | $\frac{C_2H_2}{C_2H_4}$ | Diagnosis |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | Normal deterioration |
| 5 | 0 | 0 | 0 | Partial discharge |
| 1.2 | 0 | 0 | 0 | Slight overheating below 150°C |
| 1.2 | 1 | 0 | 0 | Overheating 150°C-200°C |
| 0 | 1 | 0 | 0 | Overheating 200°C-300°C |
| 0 | 0 | 1 | 0 | General conductor overheating |
| 1 | 0 | 1 | 0 | Winding circulating currents |
| 1.2 | 0 | 2 | 0 | Core and tank circulating currents, overheated joints |
| 0 | 0 | 0 | 1 | Flashover without power follow through |
| 0 | 0 | 1.2 | 1.2 | Arc with power follow through |
| 0 | 0 | 2 | 2 | Continuous sparking to floating potential |
| 5 | 0 | 0 | 1.2 | Partial discharge with tracking |

Table 3. Diagnosis of transformer faults based on the four-ratio code.

In Table 2 there are shown the codes for the four-ratio method.
A fairly detailed diagnosis of transformer trouble can be derived from various combinations of codes, shown above in Table 3.
The problem with the four-ratio Rogers code is that a code generated from the gas concentrations will often not match any of the "known" diagnoses. So like a rare disease with strange symptoms, many cases of transformer trouble cannot be diagnosed at all using this method.

## . CONCLUSIONS

Although maintenance has the objective to increase the operating time through the reduction of the faults or failures number, this doesn't mean that the objective must be achieved "at any cost", but in the context of finding an optimum solution, which takes into account the rise of the costs due to the enlargement of the maintenance complexity and due to the large number of faults. The life of the transformer usually depends to some extent on how well it is treated. Every transformer that is manufactured undergoes some form of factory testing. For power transformers, these tests are quite extensive and a certain percentage of test failures do occur.
The tests have to accomplish some requirements:
- they should have sensitivity; in other words, it should give an early warning of impeding trouble;
- they should have selectivity; shouldn't give off false positive indications of trouble and should give a clear indication of what is wrong;
- they should be practical; they should not require an unusually high skill level to perform the test or interpret the results;
- they should be nondestructive.

The fundamental purpose of maintenance can be stated as to contribute to the production and profit objectives of the station, by keeping its reliability at the optimum level.
To manage the life of transformers, to reduce failures and to extend the life of the transformer, some tests must be taken.
The tests are carried out to prove that the transformers are ready to operate or to find the faults .
Equipment failures do occur even with the best equipment designs available and using the best utility practices. In order to operate a power system reliably, transformer failures must be anticipated.
Dissolved gas analysis is very important to determine the condition of a transformer, it can identify a problem such

as: deteriorating insulation oil, overheating, partial discharge and arcing.

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