

Picture 1.



OIL-INSULATED POWER TRANSFORMERS

The significance of maintenance and automation in preventing transformer damages

The average age of Nordic and other European countries' power transformers will significantly increase during the next few years and decades. The life span of oil-insulated transformers can be continued significantly through competent monitoring.

The history of oil-insulated transformers dates back 100 years. Over the years, alternative types of transformers have been developed, but it seems that the life span of oil-insulated transformers will continue well into the future.

Power transformers with an upper voltage of more than 100 kV, are necessary for the undisturbed operations of

a developed society. In electricity generation plants, power transformers transform the voltage of the generator to a higher level for the transmission of electricity in the main grid. The voltage of the main grid must again be transformed to a lower voltage, so that the electrical energy can be utilized in numerous purposes.

Nowadays we know how oil-insulated power transformers, which can contain many tens of cubic metres of oil as insulator and coolant, can be safely located from a fire risk point of view. They are also often equipped with an automatic fire extinguishing system. This prevents the fire from spreading outside the transformer area, even though the transformer itself will probably be destroyed in the fire. In these cases, an oil-insulated high voltage transformer can be considered as a competitive choice instead of more fire safe but more expensive alternatives. Anyhow, damages that are limited purely to the transformers are so expensive that they must be prevented through the help of proactive maintenance and modern automation.

In 2003, the International Association of Engineering Insurers (IMIA) presented a research, which contained an analysis of transformer failures, which have occurred in IMIA member countries. During the period 1997 – 2001 a total of 94 failures occurred. The total amount of property damage was €150 million, i.e. an average amount of €1.6million/damage. The total value of the losses resulting from business interruption was €114 million, i.e. an average of €1.2 million per loss. One business interruption loss resulting from the destruction of a power plant's transformer totalled €80 million. This single loss increases the average value of a loss resulting from business interruption almost fourfold.

The impact of transformer's age on failure probability

The 94 failures included in the previously mentioned IMIA research have been divided in Table 1 below according to age. 26 of the failures occurred in transformers that were more than 20 years old. 35 of the damages occurred in transformers the ages of which are unknown. Presumably most of these transformers were extremely old as even their year of manufacture was not known. IMIA's previous research from 1996 and other research carried out in this sector provide similar results. The failure probability of trans-

formers which are more than 20 years old clearly increases.

Table 1.
Division of failures according to age of transformers 1997-2001
(IMIA clarification 2003)

Age at time of failure	Number of failures
0–5 years	9
6–10 years	6
11–15 years	9
16–20 years	9
21–25 years	10
Over 25 years	16
Age unknown	35

An oil transformer is made up of a steel tank, which includes windings and the transformer's iron core. During the manufacturing phase, the windings are covered with insulation paper and electrical insulating board. The steel tank is full of transformer oil and it impregnates the insulation paper, during which time the combination of paper and oil and the electrical insulating board form a necessary electrical insulation. To ensure that the transformer can operate without failure for at least 30 years and that the life expectancy of the transformer can be correctly estimated the properties of the transformer oil and insulating paper must be kept at a specific level.

During the normal use of a transformer, oil and insulation paper becomes old and at some phase they are no longer able to fulfil their tasks concerning electrical and mechanical strength. The damage data-bases provide clear observations that transformer damages often arise due to defects in insulation that originate in the interior of the transformer. It is therefore necessary to monitor the ageing phenomena so that reliable information concerning potential faults can be obtained during the earliest phase possible. The most reliable method for obtaining this information is to take oil samples from the transformer oil and carry out a so called Dissolved Gas Analysis (DGA). Certain gases are formed in transformer oil as a result of the transformer's age but they are also formed as a result of different over-loading situations, partial discharges and electric arc phenomena, etc. Normally the first signs of a potential fault occurring are; increases in the levels of hydrogen (H₂) and carbon monoxide (CO). When an extensive gas anal-



ysis is carried out the following are also examined; the oxygen- (O₂) content, nitrogen- (N₂) content, methane- (CH₄) content, ethane- (C₂H₆) content, ethylene- (C₂H₄) content, acetylene- (C₂H₂) and the carbon dioxide- (CO₂) content.

Frequency of Dissolved Gas Analysis and interpretation of results

A Dissolved Gas Analysis that is carried out in a laboratory should be carried out at least once a year and the received results should be compared with the previous results, so that slowly developing defects can also be discovered. It would be beneficial for the buyer of a new transformer to take samples more frequently during the guarantee period (i.e. before commissioning and at intervals of 1 month, 3 months and 6 months after commissioning and at the end of the guarantee period).

A DGA should also be carried out in smaller distribution transformers if they are located in critical places. In such circumstances, it is also possible to use a portable analyser and if the received result is not completely "clean" then a more extensive analysis should be carried out in the laboratory.

The interpretation of the gas analysis results is based on the 1999 IEC standard 60599. On the basis of fault types, the most typical gases found from the gas analysis results of oil samples in different fault circumstances are:



Picture 2.
The temperatures created in an electric arc are extremely high (3 000 °C) and can evaporate e.g. metal parts which as the result of the created heat ignite combustible materials.

Protection relays should be tested at least every 3 years, to ensure their operation during a disturbance. If the automated protection does not operate during a disturbance, the result can be a breakdown of and/or a fire in the transformer and other equipment. The destruction of equipment and the fire caused can spread extensively in the electrical network, if the electric arc, which is created as the result of the short-circuit is able to propagate due to the failure of the protection equipment in different parts of the electrical sub-station (Picture 1). The temperatures created in an electric arc are extremely high (3 000 °C) and can evaporate e.g. metal parts (Picture 2) which as the result of the created heat ignite combustible materials. Damage can also occur to the property of electrical users if it has been connected to the electrical network. The failure of automated protection always significantly increases the probability of serious personal injuries.

Fault type	Typical gas
Partial discharges	Hydrogen
Electric arc	Acetylene
Thermal fault(warming up of a coupling or other such similar item)	Hydrogen carbons, such as methane, ethene, ethane
Disintegration of insulation paper	Carbon monoxide, carbon dioxide, furfuraldehyde

During recent years, continuously operating gas analysers have come onto the market. These have been installed in the main power transformers of higher voltage transmission lines and in the transformers of generators in large power plants, where special attention has been paid to the prevention of damage to transformers.

Automated Protection of Power Transformers

Power transformers normally have specific measurement limits and relays, which will provide an alarm in potential disturbance situations and also provide the possibility of disconnecting the transformers from the network. These protection measurements are e.g.

- over-voltage
- over current
- differential current
- oil temperature
- gas detector i.e. Buchholz relay

Major Overhaul of power transformers

The reliability of power transformers can be improved and their life-span can be lengthened through the carrying out of major overhaul, when a transformer has reached the age of 15–25 years. It is possible to restore the original level of the transformer's short-circuit strength by tightening the windings, which become loose during operation and by tightening other active parts of supporting structures. Damage which the iron core and windings have possibly suffered from during use should be repaired and the conductor joints of the internal circuitry should be checked.

Dampness from the surrounding environment will always get into the transformer if it is not a hermetic model. The volume of transformer oil varies as a result of variations in temperature and as a result of the transformer “breathing open-air in and out”. The dampness in the air dissolves in the transformer oil and it is carried along with the oil to the insulation paper. The damp cellulose of the insulation paper begins to disintegrate as a result of the dampness. By

Measures for the risk management of power transformers

- 1) Provide for the safety of personnel by ensuring that only the necessary personnel in the electrical branch have access to the electrical rooms.
- 2) Plan the location of the transformer and its distances from other structures in such a way that any potential fire will be limited to the transformer itself. If this is not possible, then the construction of the transformer area must be fire resistant.
- 3) The point of departure must be that the transformer is always protected by an automatic fire-extinguishing system.
- 4) Carry out regular examinations of the transformer area many times during the year and ensure the tidiness of the transformer area, check for possible leaks and other hazardous factors caused by the surrounding environment (such as vegetation and animals) and check factors which are connected to the temperature and dehumidification of the transformer.
- 5) Carry out a high level Dissolved Gas Analysis (DGA) once a year and compare the results with previous corresponding information.
- 6) Test the protective relays at least once every three years.
- 7) Carry out major overhaul on the transformer well in advance if you are not planning to renew the transformer.
- 8) Consider other alternatives to traditional oil transformers, such as the use of more fire safe special oil transformers or dry transformers for improving fire safety.

drying the insulation paper during major overhaul this phenomenon can be significantly retarded.

The transformer's oil becomes dirty during use and its properties are weakened. That is why during basic maintenance vacuum treatment and filtering are carried out on the oil so that the ageing of the oil will be retarded and its cooling ability is improved. In addition, during a major overhaul, the bushings will be checked, seals will be renewed, the protection equipment will be overhauled and the transformer's protection will be supplemented etc. The implemented measures should be documented for following-up the serviced transformer in the future. •

VILLE VALTA
ville.valta@if.fi

