SEMINAR
ELECTRICAL INSULATION
FOR TRANSFORMERS
SESSION 3: Components & Processes

VPI, Degassing & Impregnation
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Vacuum Pressure Impregnation (VPI)

combination of vacuum and subsequent pressure for impregnation process of windings or bars with a fluid insulation material

typical examples of equipments are transformers and high voltage rotating machines
Why Vacuum Pressure Impregnation (VPI) ?

Insulation systems are sensitive to small voids within the insulation system e.g. paper/fluid in high voltage transformers or in solid insulation systems of windings in high voltage rotating machines.
3 steps of the process and its purpose

- **vacuum**
  to eliminate any gas components from solid as well as from fluid insulation material

- **pressure**
  to support the process of impregnation

- **impregnation**
  to impregnate the solid insulation material which means to fill all existing voids of the solid insulation with the fluid insulation material
Step 1: Vacuum

Vacuum is required because gas bubbles in fluid insulation material and voids in solid insulation materials reduce strongly the electrical strength, which means the breakdown voltage of the entire insulation system.

High temperature at low pressure supports the drying of the insulation material.

Therefore, an insulation system for a high voltage transformer should be free of voids or bubbles, should be dry, and the voids in the solid material like paper should be filled with the fluid insulation material.
A void within a solid insulation material can be simulated by a system of two materials with different permittivity.

Regarding the electrical field stress two simplified arrangements should be taken into account depending on the direction of the electrical field and the boundary between the two materials.
Case 1:
Electrical field parallel to the boundary

Electrical field in material 1 is identical with the electrical field in material 2

The two materials represent a parallel connections of 2 capacitors
Case 2: Electrical field rectangular to the boundary

Electrical field in material 1 is different from the electrical field in material 2

\[ \frac{E_1}{E_2} = \frac{\varepsilon_{r2}}{\varepsilon_{r1}} \]

The two materials represent a series connections of 2 capacitors
Humidity or moisture within solid or fluid insulation material reduces also the electrical performance.

Depending on the pressure and the temperature the moisture will be taken out from the solid part of the insulation system.

The moisture distribution within a transformer insulation system of paper and e.g. mineral oil is in such a way that the moisture content in the paper is in the range of a few % and in the mineral oil in the range of some ten ppm (pars per million).
Moisture distribution in an insulation system

Moisture Content in Paper

Moisture Content in Mineral Oil

0 10 20 30 40 50 60 70 80 90 ppm

0 1 2 3 4 5 6 7 8 9 10 11 %

20 °C 30 °C 40 °C 50 °C 60 °C 80 °C 100 °C
Breakdown electrical field strength as function of the relative moisture content

The relative moisture content is the ratio between the absolute moisture and the solubility at a given temperature.
Step 2: Pressure

If the required vacuum is reached the fluid insulation material can penetrate the voids within the solid insulation material and the high pressure supports this process.

The high temperature supports this too because the viscosity of the fluid is lower at higher temperature.
Step 3: Impregnation

During this step the fluid insulation material can fill up all the voids and open area within the solid insulation material.

Then the pressure is increased and the temperature is reduced up to normal environmental conditions and the process of the VPI is terminated.
The main parameters of the VPI are not always required for all types of insulation systems, but there are a few parameters which should be fulfilled in any case for the handling of an insulation systems for high voltage transformers:

- Drying of the insulation material (solid or fluid) at high temperature and low pressure.
- Impregnation of the solid part in order to prevent voids within this part.
There are different procedures to impregnate insulation systems for high voltage equipment:

- atmospheric-dipping-impregnation
- vacuum-impregnation
- vacuum-pressure-impregnation
- combined impregnation and curing equipment
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for solid/liquid insulation system
for power transformers
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for dry type power transformers
There are different process technologies for drying transformer insulation systems:

- convection drying
- oil-spray-process
- vapour-phase-process
- low frequency heating for distribution transformers
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The convection drying of insulating material means the drying with increased temperature and the transfer of moisture via the surface of the system to be dried.

The transformer is heated by heating the Autoclave walls first and then conveying heat from wall to the job is done by air circulation.

This procedure is time consuming, not very efficient and sometimes not sufficient for the required drying process and the limit of the moisture.
There are different process technologies for drying transformer insulation systems:

- convection drying
- oil-spray-process
- vapour-phase-process
- low frequency heating for distribution transformers
The drying with the hot oil spray or the hot oil circulation method in conjunction with vacuum applied to the transformer is very well known and had been practiced for many years.

The main disadvantages of these methods are:

- Limited temperature
- No heating during vacuum phase with the oil circulation method
- Difficulty to get a uniform temperature distribution with the spray method
- Long drying times
- Limited drying quality
There are different process technologies for drying transformer insulation systems:

- convection drying
- oil-spray-process
- vapour-phase-process
- low frequency heating for distribution transformers
The drying process starts with the evacuation and heating of the transformer windings.

After reaching a steady situation solvent vapors are introduced and condense on any cold surface.

When these vapors condense, they give up their latent heat to vaporization, heating the core and coil assembly.

The moisture in the insulation then evaporates, due to either the vacuum-operating condition or in a solution with a condensed solvent.
The advantages of this procedure are

- heating of insulation materials under vacuum; reduced oxygen level minimizes oxidation and thermal aging of cellulose materials, resulting in less loss of life than can be achieved in rapid oven drying or radiation processes

- excellent heating characteristics of vapor condensation process; heat is transferred to all parts of the core and coils uniformly, quickly, and more efficiently than can be achieved with hot air or radiation processes; this further reduces thermal aging and loss of insulation life over other drying processes
The advantages of this procedure are:

- Excellent Cleaning Action; soluble process materials and contaminants are washed off the core and coil assembly prior to oil impregnation in the vapor phase process; this washing action is only possible with the condensing vapors.

- Uniformity of temperature

- Reduction in process time

- Improved quality of dryness of insulation
There are different process technologies for drying transformer insulation systems:

- convection drying
- oil-spray-process
- vapour-phase-process
- low frequency heating for distribution transformers
Source: Practical experience with the drying of power transformers in the field, applying the LFH technology, CIGRE 2004, paper A2-205
Low frequency heating will be used for the following reasons

- to winding will be heated from the conductor
- the required voltage can be lower due to the reduction of the frequency dependent impedance
- the lower voltage reduces the risk of a flashover at low pressure (vacuum)
State-of-the-art computer controlled process monitoring and measuring equipment is used to continuously monitor the currents, voltages and resistances with automatic shut off if a deviation occurs.

The advanced control and measuring system performs extremely accurate temperature determination in the HV and LV windings and automatic verifies the correctness of the input transformer data by comparing measured to calculated values.

The monitoring system allows the ability to trend all of the process parameters as a quality assurance record or for future reference.
Vast improvement in the quality of the transformer insulation is achieved by using the low frequency heating process to dry the cellulose insulation as compared to the conventional transformer insulation drying systems.

The insulation is dried in its own tank and is never exposed to the atmosphere after it is dried.

The windings are heated uniformly throughout the drying process, assuring that the insulation deep in the windings achieve a temperature that promotes moisture removal during the vacuum cycle.
The continuous monitoring of the moisture of the air in the vacuum exhaust during the fine vacuum phase assures that the insulation is dry upon the completion of the process.

The drying process cycle time is reduced by up to 60% compared with the conventional oven and vacuum method.

The automatic computer control system optimized the LFH process by having the controls automatically change the heating current until the desired temperature heat up rate of rise is achieved or the maximum allowed current is reached.
The lowest possible voltage to avoid flash over in the insulation is possible using the low frequency converter.

This allows the heat up of the windings with low frequency current while simultaneously being exposed to a strong vacuum.

The most efficient use of energy to dry the transformer’s insulation.

The low frequency heating process insures a low depolymerisation of the cellulose insulation by removing the majority of the moisture while the winding temperature is 100 °C so that the cellulose insulation is almost dry before been exposed to the higher drying temperatures.
Water extraction as function of the drying process

Source: Practical experience with the drying of power transformers in the field, applying the LFH technology, CIGRE 2004, paper A2-205
Drying time as function of the drying process

- Online oil degassing 200 lt/h average oil temp. 30°C
- Online oil degassing 200 lt/h average oil temp. 50°C
- Online oil degassing 6000 lt/h average oil temp. 30°C
- Online oil degassing 6000 lt/h average oil temp. 50°C
- Hot oil circulation + vacuum cycles
- LFH + oil circulation
- LFH + Hot oil spray
- Vapour phase

Source: Practical experience with the drying of power transformers in the field, applying the LFH technology, CIGRE 2004, paper A2-205
Transformer drying equipment
Transformer drying equipment
Oil purification equipment
Screen shoot of the process parameter for Low Frequency Heating
Screen shoot of the process overview
Conclusions

- The proper drying and impregnation of insulation systems for high voltage transformers are very important.
- The process as well as the temperature and vacuum should be automatically controlled.
- The requirements concerning moisture content and impregnation quality should be reached in a reasonable time.
- The whole procedure, drying, oil purification and impregnation should be very efficient concerning time and costs.