Revitalizing of power transformer insulation

During the service of power transformers, complex physical and electro-chemical reactions occur, which lead to the degradation of dielectric properties of the insulation system and mechanical characteristics of solid insulation, what is described by the term ageing.

Depending on the degradation degree of insulation parameters, the following processes are progressively used in practice:

The reclaiming is the process which removes water and solid particles by chemical means and it reduces their quantity at an acceptable level.

The regeneration is, according to the international standard IEC 60422, the process which removes the accelerators and ageing products by chemical agents or absorbers.

The revitalizing of insulation system of a transformer is the technological process which removes the ageing accelerators: water, oxygen and ageing products as: acids, gases, sediments, colloidal particles etc. and which improves the general condition of the insulation, bringing it at a previous condition, while the obtained characteristics allow the safe operation of the transformer and increase the lifetime, what is equivalent to the ageing slowing.

The revitalizing includes the oil regeneration, the cleaning and the drying of solid insulation

By eliminating the polar molecules, the acid sediments (slime) on the solid insulation surface, on the walls of transformer vessel and cooling system and by removing agglomerated macroparticles, the effects of the cooling increase, significantly reducing the operating temperature and the ageing slows. By removing from the oil of peroxid compounds and free radicals necessary for formation of alcohols, aldehydes, acids in the oil, the progressive formation of the chain of new free radicals is obstructed, what leads to a higher oxydation stability. By removing the acids and water from the insulation, the formation of hydrolisis products decreases and the desintegration of solid insulation is hindered.

A simple change of entire quantity of insulating oil, as a revitalizing measure in a single stage is not a too high gain because the solid insulation was not washed. What remains from the sediments dissolves in the new oil, leading to the quick deterioration of its initial properties. A little better method needs the transformer emptying and washing with hot oil (pulverization with oil) for removing the sediments and drying the insulation. This method does not assure the deep drying and paper purification. The effect is superficial. It is also very costly because the washing needs a very big quantity of new oil.

The worldwide experiences emphasized that the success of revitalizing depends in great part on the supplementary measures which should be taken within the proposed measure. The choosing of the method must be done only after the experts with different specializations finished the research on the insulating systems and failures during the service. The chosen method of revitalizing will be more efficient in the case of a well maintened transformer, which was protected against the humidity, dust and other contaminants, that is more cheaper than a deep subsequent drying. During the revitalizing process the transformer must be protected against the previously mentioned contaminants, especially against those coming from air penetration in the windings. The revitalizing must include the entire insulating system, namely the elimination of acid sediments on the active part and it is necessary to pay a special attention to this fact. With these revitalizing measures, the operating characteristics keep stable for a long period of time.

For revitalizing the paper-oil complex insulation, many off-line and on-line methods became very known worldwide.

In the case of off-line methods it is necessary to put out of operation the transformer and to apply the revitalizing processes both on-site and off-site in certain conditions, respectively in a specialized workshop. These processes are not only expensive but sometimes they need an extremely complicated logistics on the one hand and the putting out of operation of the transformer during long enough periods, sometimes of approximately 60 up to 90 days, on the other hand.

Worldwide the revitalizing of the paper-oil complex insulation by on-line treatment methods began to be used more and more largely. These methods besides the fact they are much less expensive, they do not necessitate the putting out of operation of the transformer not even when the installation is connected to the transformer. In addition the installation does not need to be monitored by the personnel of the station or power station because it provides the permanent recording of monitored parameters, the data being transmitted on-line to a control center or periodically discharged on a lap-top.

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ICMET Craiova successfully used the revitalizing installation of the paper-oil insulation system of the power transformers – VIMAP R2000.

The revitalizing installation of the paper – oil insulation system of power transformers – VIMAP R2000

The lifetime of the transformer is, in fact, the lifetime of paper – oil insulation system.

The most often the insulation system of the transformer consists of the liquid insulation (transformer oil) and the solid insulation (cellulose/paper).

The insulating oil assures approximately 80% from the transformer insulation.

The most part of breakdowns (approximately 85%) are produced because of the deficiencies of the insulation system.

The degradation of the insulation system depends on some factors, the most important being:

- *The thermal degradation* (the thermal degradation of the paper and oil);

-*The degradation by oxidation* (the oxygen causes the degradation of paper and oil – without oxygen there is not ageing.

- *The hydrolytic degradation* (the influence of acids and water, the oxydation products of the oil and paper disintegrate the paper).

The removing of water, oxygen and acids, as well of all the other ageing products considerably prolongs the lifetime of the transformer and increases the reliability of the network.

The use of the VIMAP R2000 technological process removes, by the absorption method, all the polar molecules – products of the insulation paper ageing.

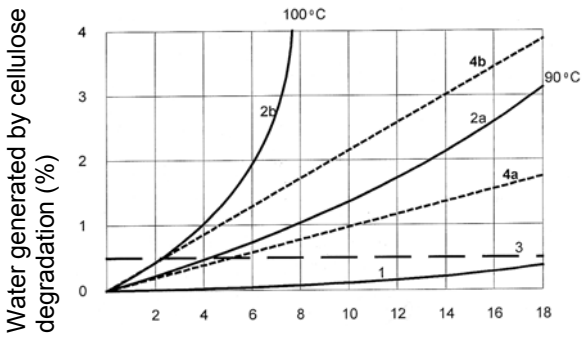
The dispersion of polar molecules between the oil and the paper is constant.

The removing of ageing products from the oil initiates the transition process of these polar molecules from the paper to the oil (so that their ratio remains constant, according to the Henry' law).

Each paper – oil insulation system of power transformers can be purified by removing the ageing products – it can be revitalized during a period of 15-45 days by the VIMAP R2000 method.

The description of the procedure

The ageing products of paper and oil are polar molecules which aggressively act and accelerate the degradation of paper – oil insulation system. In accordance with our experience it can be said that at the transformers having more than 10 years of operation in the electrical network the condition of the paper against the oil and of the paper against the conductor is much worse. We arrived at the conclusion that as long as the degradation products are not removed, they become a factor of continuous degradation of the insulation. On the other hand, as polar molecules, they significantly increase the risk of definitive defaults in the transformer insulation.



The curve 1 from the above diagram represents the water quantity from the atmosphere and the curve 3 represents the water quantity which remains in the transformer after the treatment. The other curves represent the water quantity removed by the depolymerization of the cellulose at certain temperatures of the oil (the curves 2a, 2b) and the degradation products of oil and paper, according to the curves 4a and 4b.

To prolong the lifetime and the safety of the transformer in the network, by VIMAP R 2000 process and VIMAP R2000 installation the ageing products are removed from the oil and the paper insulation and the oil and the cellulose are also dehydrated, bringing the quantity of water from the paper to the values presented in the above diagram (the curve 3).

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The regeneration process is carried out by electroinsulating oil recirculation from the transformer tank through the reservoirs with absorbent. This process lasts between 10 and 30 days, enough for the cleaned oil can extract the polar molecules from the solid insulation, according to the Henri's law. During all the process the transformer can be connected to the network or it can be heated by the process of supply with reduced voltage on HV (high voltage) having LV (low voltage) in short-circuit until the temperature of oil reaches maximum 40^0C.

The absorber used for dehydrating and removing the polarized molecules is completely neutral against the electroinsulating oil and it has an extremely high absorption capacity so that with the VIMAP R2000 installation which has 5 reservoirs with absorber a quantity of transformer oil of 20-60 tons can be treated. The replacement of the absorber from reservoirs is done extremely rapidly and easily of approx. 2 or 3 times depending on the quantity of treated oil.

The installation is connected to the transformer according to the Figure 1.

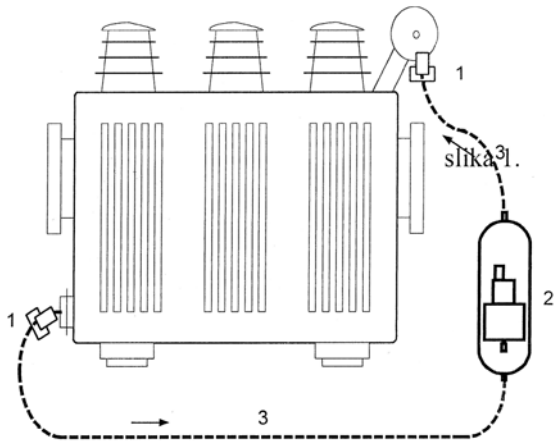

Fig. 1.

1. Connecting elements to the emptying valve of the transformer and to the filling valve of the conservator
2. The installation with absorber
3. Elastic metal-clad hoses

The basic diagram of the installation is presented in the Fig. 2

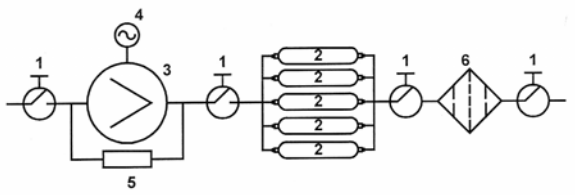

Fig. 2

In the Figure 2 there is:

1. Valve;
2. Reservoirs with absorber (5 x 230 kg) and elements of fast connection-disconnection;
3. Pump with a capacity of 20 l/min or 40l/min;
4. Motor (3 x 380 V or 1 x 220 V, 2 kW);
5. Safety valve;
6. Selective filter.

The installation is safe and it is foreseen with the following protections:

1. Pressure limitation
   - safety valve which connects the inlet and the outlet of the pump
   - contactor which disconnects the motor at adjusted voltage exceeding

2. Protection against the oil leakages
   - differential pressure valves

3. Protection against the fire
   - all the installation is built in protection against explosion

4. Ecological protection
   - the absorber and the oil are completely insulated from the environment. The connection of the installation to the transformer, the replacement of the absorber in the installation are carried out without the contact with the outside.

5. Protection against the air penetration in the transformer
   - the oil from the transformer is drawn out through the emptying valve and it is introduced in the oil conservator therefore the air cannot arrive in the transformer inside even at the beginning of recirculation.

All the deep regeneration technology of the insulation of power transformers is patented and it has in Romania the patent number: 97-00252.

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Guaranteed results

If there are not sediments and free water, by the VIMAP R2000 process the following results are guaranteed (CEI 60296):

The oil characteristics	The unit of measurement	Habitual treatment	Special treatment
Dielectric loss factor, tan δ (90^0C)		< 0.010	< 0.005
Neutralization number	mg KOH/g of oil	< 0.03	< 0.01
Interfacial tension (20^0C)	mN/mm	> 35	> 40
Dielectric strength	kV/cm	> 300	> 300
Water content (20^0C)	ppm	< 10	< 5
Macroparticles*	No.	< 10 000	< 5 000
Oxidation stability**	h	> 120	> 160

* > 5 microns in 100 ml of oil
** For the oils containing inhibitors, the sample is taken at the outlet opening of the engine.

Water content from the insulating paper:
- from 1,0 % it decreases to < 0.5 %
- from 2,5 % it decreases to < 1.5 %
- from 3,5 % it decreases to < 2.0 %

Advantages

a) The most important is that the oil must not be replaced, this fact leading to a reduced cost of the revitalization.

By oil replacement there is no gain because the paper remains „polluted" by the ageing products.

According to Henry's law, the polar molecules in the paper will penetrate again in the new oil. Washing the inside of the transformer it obtains a very superficial effect because the film of washing oil can penetrate only up to maximum 60% from the internal surface of the transformer (depending on the transformer construction). Also, approximately 10% from the oil volume remains „prisoner" in the insulating paper. This remaining oil contains polar molecules which can considerably affect the quality of new oil. By oil replacing the sediment in the cooling elements and between the windings is not removed. The remaining deposition will dissolve in the new oil and it will activate again the oxidation process.

b) It eliminates the complicated procedure of oil replacing (the emptying, the transport, the engagement of transport facilities – vehicles, personnel).

c) The oil for active part washing is not necessary.

d) It is not necessary to vacuum the transformer.

e) There are no risks of accidental pollution with the transport and the oil aeration.

After the transformer revitalizing by the VIMAP R2000 method, the purified oil has the quality of a new oil, non-used, and the paper remains completely clean and dry.

Technical data

- The volume flow rate 2400l/hour
- Electric energy consumption (depending on the ambient temperature) 3-4 kW

References

The 400 MVA transformer being in operation for 37 years at CET Isalnita, Craiova.
The transformer oil content is of 57 tons.
For the first time it was used the oil-spray method for drying before the oil replacing. After the putting again into operation the transformer, the ageing products remained in the solid insulation arrive to the oil, affecting tan δ and making it to reach the value of 89.0×10^{-3}.
The conventional applied methods failed to lead to satisfactory results.
At owner' request the new method was applied and the value of tanδ for the oil decreased at 6.7×10^{-3}. The treatment period of the oil was of 25 days.
The oil had not inhibitors and, after the treatment, at client' request, it was not added any inhibiting agent so that it was drawn the conclusion that a such measure is not necessary.

Results after the treatment:

- tan δ 6.7×10^{-3}
- neutralization number 0.017 mgKOH/g of oil
- dielectric strength 260 kV/cm

Results after 12 months:

- tan δ 16.3×10^{-3}
- neutralization number 0.019 mgKOH/g of oil
- dielectric strength 260 kV/cm

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Options:

- VIMAP R2000 can be placed in the container – without trailer or on the trailer.
- The reactivation of absorber can be automatic or half-automatic.
- In case of half-automatic reactivation of the absorber, a reactivating unit can accompany some revitalizing units.
- Chamber for oil degassing.

Fig. 3 *VIMAP R2000 installation in operation*

The application of this process for insulation revitalizing, in Romania

Characteristics	Measure unit	CET ISALNIȚA 400 MVA		S.T. 400/220/110kV Arad, 200 MVA		CET PAROŞENI 180 MVA		CET PAROŞENI 25 MVA	
		Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
Oil									
Water content	ppm	/	/	**24**	**3**	**2.9**	**2.0**	**9.78**	**2.7**
Dielectric strength	kV/cm	**230**	**>260**	**220**	**320**	**240**	**260**	**240**	**280**
IFT	mN/m	/	/	/	**44**	**30.83**	**40**	**32.5**	**40**
Neutralization number	mgKOH/g	/	**0.017**	/	**0.02**	**0.015**	**0.012**	**0.01**	**0.009**
tg δ for the oil (90°C)		**0.089**	**0,0067**	**0,055**	**0,007**	**0,006**	**0,003**	**0,032**	**0,00495**
Particles	NAS 1638	/	/	**33931**	**6838**	**13329**	**4420**	**26630**	**7380**
Solid insulation									
Water content (Wh_{20})	%	/	/	/	/	**2.22**	**0.65**	**4.3**	**1.38**
Insulation system									
R_{60} (HV-LV) 20°C	MΩ	/	/	**1163**	**4028**	**3840**	**13000**	**2300**	**12000**
R_{60} (HV-m) 20°C	MΩ	/	/	**928**	**3111**	**2940**	**9600**	**60**	**4000**
R_{60} (LV-m) 20°C	MΩ	/	/	**716**	**3375**	**2240**	**6850**	**2200**	**12000**
tg δ (HV) 20°C	%	/	/	/	**0.522**	**0.50**	**0.26**	**0.76**	**0.35**
tg δ (LV) 20°C	%	/	/	/	**0.799**	**0.55**	**0.28**	**1.1**	**0.50**

The transformer oil regeneration is an important instrument of preventive maintenance and therefore the transformer oil must be treated before it reaches the deteriorating levels about that it knows they cause the failure of transformer insulation. If it follows a maintenance program of the oil, the humidity and sludge accumulation in the solid insulation of the transformer can be prevented.

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