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EXTENSION OF THE LIFETIME AND INCREASE OF THE TRANSFORMER OPERATION SAFETY ON THE GRID

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INTRODUCTION

It has been briefly explained the aging mechanism of the oil-paper insulation as well as the influence of the aging products on the acceleration of this process. The new methods of extraction of water, oxygen, peroxide, radicals, acids and all the rest of the pollar molecules from oil-paper insulation.

During the long-term period of monitoring of oil-paper insulation system conditions, we have concluded that, temperature degradation of paper with catalytic acting of metals presented crucial aging factors in the operation biggining on grid. Later phases of aging have shown more and more increasing influence of aging products – oxygen, acids and water. Our experience during the testing of degree of paper polymerization, in transformers opens for repair, shown that the paper was closed to insulation oil, in transformers 15 years old and more, was often in worse condition then paper closed to conductor – copper.

It has been concluded without doubt that accelerates of degradation process are depending on increasing of aging products in insulation system. By removing of these, newly formed molecules, lifetime of transformer could be substantially prolonged, and operation of transformer in service becomes more safe.

We developed new methods for regeneration of oil-paper system. The system operation principle is adsorption of all polarized molecules, by specially designed adsorbents. Reactivation of adsorbents is simple. Adsorbents are absolutely neutral against isolation oil and their application has been patented. Based on the adsorption, we made new plant for complete regeneration of oil-paper insulation. This plant operates on transformer in service (on the grid) and could be used as accelerate aging protection of new transformers (on-line), or for revitalization (removing of all aging products) and restoration of oil-paper insulation.

The operations principles are following:

-By oil recirculation between transformer and tanks with adsorbents, we remove aging products.

-According to Henry's law, we are transfering aging products from paper in to the oil. The process is accelerated by temperature increasing and temperature differences between conductor and oil.

-After saturation of adsorbents, we are doing reactivation with burning (aging products from adsorbents), i.e. with full oxidation to CO_2 and H_2O.

-Due to huge adsorption capacity of our adsorbents, reactivation, by burning aging products, has to be done every three to ten days, depending on insulation system condition. Adsorbents don't change their characteristics even after 300-500 reactivations.

-On new transformers, in on-line mode, replacement of adsorbents it has to be done every six to twelve months, depending on transformer operation regime.

-The old transformers revitalization lasts from 15 to 90 days, depending on the amount and the condition of insulation.

-During the revitalization process, the plant can remove from 10 lit up to 60 lit of water.

-Complete process is closed, automatic operated, enviroment friendly and could be remote controlled and followed. There is no any dangerous for transformer, during plant operation, due to f multiple protections.

Keywords
Oil-Paper–Transformer–Regeneration-Revitalization
Adsorbent – Extention – Ageing -On-line

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1. Degradation and revitalization of oil-cellulose insulation of power transformers

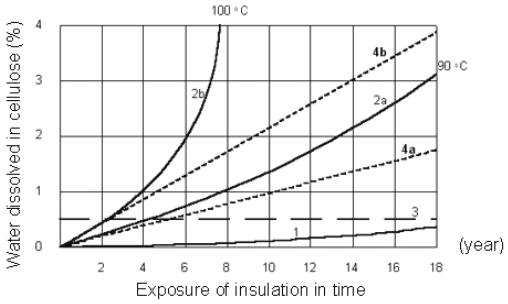
Following for many years aging of isolation and using experience of others and our experience we came to the conclusion that aging of isolation system and safety of operation of transformers in the network depends on several factors, following being most important:

-Thermal degradation (thermal disintegration of paper and oil)

-Oxidation degradation (oxygen which in different form causes oxidation and directly conditions degradation of paper and oil - without it oxidation would not exist).

-Hydrolytic degradation (influence of acids and water, products of oxidation of oil and paper and disintegration of paper)

Our research demonstrated that in transformers, after more than 10 years of operation in electric network, status of paper towards oil is worse than status of paper close to conductor. Therefore, we concluded that if the products of aging are not eliminated on time they are becoming major factor for degradation of isolation.
Graphics are demonstrating quantity of H_2O produced by decomposition of polymerized molecules of cellulose at constant temperatures of oil between 90°C and 100°C, at that, curves 2a and 2b present status when products of aging are not eliminated, and curves 4a and 4b when they are totally eliminated. Curve 1 shows amount of water from atmosphere, and curve 3 shows remaining water, which was not removed during the production of transformer.



On the basis of these phenomena we concluded that thermal destruction during catalytic action of metal represents primary cause for aging of relatively new transformers, while in the later period this role overtakes acting of products of aging, oxygen, acids, water. In this way, the process accelerates with the time and presence of polarized molecules itself increases the possibility for breakdowns. According to the above mention, we focused our research and we came to the very efficient system for simple elimination of polar molecules, i.e. the cited products of aging. Principle of system operation is adsorption of all polarized molecules, by specially designed adsorbents while implementation has been patented in 19 countries.

Advantages of our method as compared to with other state of the art techniques are: efficiency and reactivate possibility of our adsorbents, simplicity of construction, effect on complete system of oil - paper isolation, much lower price, simplicity of maintenance, adaptability to actual needs (modular type) and obtained results. Solution of this problem consists of permanent elimination of all polarized molecules out of isolation oils, and with it, by Henry's law out of transformer's paper isolation. Elimination of these molecules is performed by adsorption. The capacity of these adsorbents is several times more efficient than the capacity of the other adsorbents that are in use.

2. Ageing products removal by adsorbent treatment of insulating oil

The selection of adsorbent for rehabilitation of paper-oil insulation has been made after detailed laboratory tests. Old oil have been adsorbent-treated with the following ensuing results:
- Our adsorbents act at temperatures in the range from 0^0C up to 120^0C.
- Relatively small adsorbent quantities are highly efficient in eliminating
- Products developed in oil due to the ageing process.
- High capacity and activity of the adsorbent do not diminish even after several hundred reactivation repetitions.
- After adsorption, no harmful effect affecting the oil characteristics is being produced.

Table 1. gives summary of test results using adsorbents:

Table 1.

Sample	Dielectric Strength	Naturalization Value	Interfacial Tension at 20°C	Dielectric Dissipation Factor(tg δ) at 90°C
	kV/cm	mg KOH/g of oil	mN/m	x 10^{-3}
S_1	**140**	**0,036**	**31,96**	**5,90**
2 %	>250	0.017	44.31	0.50
3 %	>250	0.012	45.56	0.20
S_2	**120**	**0.130**	**21.54**	**8.00**
6.25 %	>250	0.020	34.23	4.40
S_3	**85**	**0.043**	**25.05**	**8.30**
3.125 %	>250	0.014	44.06	1.90
6.25 %	>250	0.009	45.01	1.40
S_4	**220**	**0.03**	**31.60**	**86.00**
3.00 %*	>250	0.015	38.62	24.00
4.00 %*	>250	0.005	42.91	18.30

- S_N – sample of oil before regeneration
- Percentage data represent the ratio of used adsorbent compared with the processed isolation oil.

* Contact time between the adsorbent and oil was 3 times shorter than in the other cases (the adsorbent capacity was not completely used)

It should be noted, that the oil colour was slightly changed while highly volatile aromatic agents and natural inhibitors mainly remained in oil. We came to this conclusion after IR analysis of the graphs.

By testing influences of adsorbents A_1, A_3 and A_3 on transformer oils, we reached the conclusion what elements of oil are effected by each absorbent and with what intensity.

IR spectrum shows that adsorbent A_1 removes products of oxidization and pollution (acids, esters, lactases, aldehydes, ketones, etc) what can be seen in the spectrum from 1800 cm^{-1} to 1650 cm^{-1}, while it only slightly changes peaks in the spectrum from 3720 cm^{-1} to 3600 cm^{-1} (presence of oxidation inhibitors).

Besides inhibitors, this adsorbent has less effect on color of the oil, as well as on aromatic structure.
Adsorbents A_2 and A_3, apart from other , effect part of the spectrum 3720 cm^{-1} – 3600 cm^{-1}, and adsorbent A_3 extremely efficiently discolors dark isolation oil.

By analyzing results of large number of testing absorbent effects on oil of different structure and 'pollution' we found corresponding granular mixtures. We choose mixture of adsorbents by of transformer isolation, which needs elaboration. Isolation of each transformer can be set in desired condition by four mixture combinations regardless of pollution percentage and used inhibitor (organic or additional inhibitors).

Table 2.

Sample	Dielectric Strength	Naturalization Value	Interfacial Tension at 20°C	tg δ at 90°C
	kV/cm	mg KOH/g of oil	mN/m	x 10^{-3}
sample (S_5)	**220**	**0,07**	**24,7**	**48,5**
(A_1) 4%; (A_2) 3%;	310	0,008	45,5	1,6
sample (S_6)	**190**	**0,07**	**23,01**	**57,2**
(A_1) 3%; (A_2) 3%;	290	0,01	40,4	1,8

As shown, the ensuing results are highly favourable and a very small quantity of adsorbent was used as compared to the quantity of treated oil. Both natural adsorbents contributed considerably to alteration of oil colour.

Extended contact of oil with adsorbent (percolation) results in completely colourless oil, `white oil` (transparent oil).

Some oil samples were subjected to inductive period tests after having been treated by means of adsorption and 0.3% inhibition. Time obtained varied from 170 h – 240 h.

These tests proved that transformer oil can be transformed into new oil using a simple and cost effective process, which then is used for solid insulation cleaning after a period of 20 to 30 days.

Eventually, there is no need to replace existing oil with new oil quantities since the adsorption decelerates paper insulation ageing process, and additionally purifies it by removing ageing products and regenerates the oil in a way to match the quality found in new, unused oil.

3. Insulating oil drying by adsorption

Adsorbent selection for humidity removal from insulating oil was also made after extensive laboratory tests. Humidity removal adsorbent is working efficiently at oil temperatures ranging from – 10^0C to + 50^0C. Due to highly intensive effect of the adsorbent, we have built small hand devices having 600 lit/h to 2400 lit/h flow capacity.

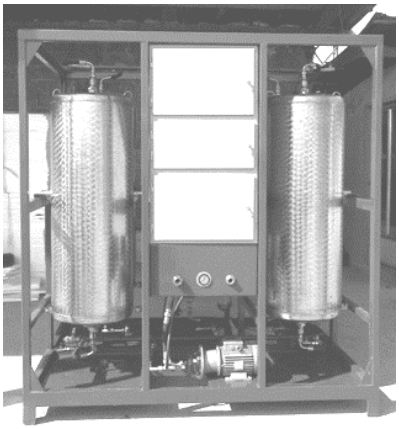
Adsorbent refill is very simple and requires only cartridge replacement. Depending on the type, a single cartridge, without replacement, suffices for 100 t to 400 t of insulating oil drying. It is possible to reactivate this adsorbent several hundred times.

During oil drying, the process does not adversely affect physical and chemical oil properties. Also, no inhibitor adsorption occurs.

oil characteristics	oil parameters before	oil parameters after first passage	oil parameters after second passage	oil parameters after third passage
water (ppm)	100	< 20	< 7	< 3
dielectric strength (kV/cm)	45 - 80	180 - 200	250 - 300	> 300

FIELD EXAMPLES

Used of selected adsorbents enabled us to provide new solutions of equipment and transformer maintenance and life extension techniques. This equipment is both easy to handle and maintenance friendly. They are automatically operated and provide complete transformer protection during insulating oil treatment while the transformer is in operation. Distance check-up and monitoring of the process is possible. If this technique is applied to old transformers, adsorbent reactivation is carried out on a weekly basis, i.e. every 5-7 days. If applied to new transformers, with insulation being in good condition, the treatment goes on uninterrupted with reactivation taking place every 6-12 months depending on the transformer rating and operating state. This enables not only to constantly maintain important transformers in satisfactory condition but also to considerably extend the transformer life expectancy. Transformer operation reliability is also upgraded.
These machines are 2 x 1,8 x 2,0 m dimensioned having 1400 kg.



Use of selected adsorbents enabled us to provide new solutions of equipment and transformer maintenance techniques. In support of this, here are some practical field examples:

a) 400 MVA transformer 37 years in operation in TPP Isalnita, Craiova, Romania. The transformer oil content is 57 tons.

Oil-spray method was used for drying prior to oil replacement. After energizing and heating, ageing products developed in solid insulation reached oil affecting tangens delta to rise to 89,0 x 10^{-3}.Oil characteristics are shown in Table 1, under S_4.

According to Romanian regulations, this unit should not have been put into operation. All conventional methods applied failed in yielding satisfactory results.

At the owner`s request, new method was applied and oil tang δ value was brought down to 6,7 x 10^{-3}. Oil treatment duration was 25 days.
The oil was uninhibited and after testing, at the Purchaser`s request no inhibiting agent was added, as it was concluded that no such measure was necessary.

b) 200 MVA transformer with 56 tons oil content in ARAD substation, Romania.

Dielectric dissipation factor was tanδ = 62 x 10^{-3}. The transformer owner requested for the transformer to have the following characteristics after testing:

Dielectric strength:	≥ 280 kV/cm
Oxygen content:	≤ 0.2 %
tg δ at 90^{0}C:	≤ 14 x 10^{-3}
Acid number:	≤ 0.02 mg KOH/g oil
Interfacial tension (20^{0}C):	≥ 38 mN/m

After 30 days application of our adsorbent all requirement were met. The treatment was carried out with two adsorbents applied to inhibited oil with 0.3% inhibiting agent addition.The results after treatment:

Dielectric strength:	= 320 kV/cm
Oxygen content:	= 0.1 %
tg δ at 90^{0}C:	= 4.7 x 10^{-3}
Acid number:	= 0,005 mg KOH/g oil
Interfacial tension at 20^{0}C:	= 44 mN/m

Examples of insulating oil drying process:

-A transformer 150 MVA-220/115/10.5 kV in s/s 400/220/110 kV Novi Sad 3, was damaged during air raids. After repair, the transformer was filled with oil. After dielectric strength tests, the value obtained was 154 kV/cm. Over the next three days the oil was recirculated for drying using a 1200 lit/h hand device in order to remove humidity and air, resulting in oil dielectric breakdown increase to 296 kV/cm.

-A transformer 150 MVA-220/115/10.5 kV in s/s Beograd 5 showing oil dielectric strength to be 220 kV/cm resulted in over 300kV/cm dielectric strength after 24h drying process using hand device having 2400 lit/h flow rate.

-A transformer 31.5MVA-110/21/10.5kV in s/s Kaludjerica was partly discharged due to repair. Some eight (8) tons of oil refill was required. Filling of transformer with oil from barrels was performed using hand device having 600lit/h flow rate. Oil dielectric strength was 90-110 kV/cm. After completion of filling (in two working days), and the hand device was mounted in order to enable additional oil drying through recirculation. After 10 h recirculation, oil dielectric strength reached 260kV/cm.

CONCLUSION

Introducing adsoption as a basic technique for keeping power transformer insulating oil in good condition eliminated the need of replacing old oil with new oil. In addition, it is worthwhile noting that this technique helps removing ageing products and humidity from solid insulation . Costly and complex oil drying procedures are imperative only in cases if extremely humid insulation. We would like to suggest introducing this technique to become staple practice in periodic transformer treatment due to its low cost and simplicity not to mention additional benefits such as the fact that it eliminates the need for either disruption of transformer operation or increased labour requirements. In cases of new important transformers being located in hostile environment, the adsoption equipment may be placed to become integral part of the tarnsformer itself thus enabling permanent transformer maintenance. Periodic adsorbent reactivation is simple and cost effective.

Easy to handle hand equipment for transformer insulating oil humidity treatment has been efficiently used on site by field staff and may be considered as indispensable tool for on site handling of insulating oil.

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