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CHEMICAL REGENERATION OF TRANFORMER OILS BY APPLYING DRY NITROGEN FOR FILLING OF TRANSFORMERS

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INTRODUCTION

Crude oil has remained intact in underground deposits for millions of years. This indicates that the molecular constituents of crude oil are chemically stable in absence of oxygen. The implication is that under ideal conditions oil used in sealed equipment should last forever. Oxygen free environments are very difficult to maintain in electrical equipment which is subject to moisture and air intrusion. Impurities that originate from materials used in construction of the equipment can also mix and/or react with the oil. Oil degradation occurs because of these impurities. Oil properties, such as dielectric strength, can be affected even by non-reactive impurities such as carbon or cellulose particles. Oil must therefore be periodically tested to ascertain wheather or not chemical degradation or impurities have impact on oil quality (1,2).
Long term analysis and investigation of oil during its exploitation has proven to be necessary for the control and monitoring of transformer condition and prediction of its future performance.
The investigation of chemical, physical and electrical characteristics on regular bases (according to IEC regulations) has great significance for prolongation of transfomer life, since with the result of these analysis the regeneration of oil could be applied.
In this paper the method for adsorption of oil for transformers that can't stand high vacuum has been explained and proven to work. The chemical regeneration has been applied for three power transformers that have been filled with dry nitrogen after the oil has been taken out of tank. With this modification the possisiblity for regeneration of transformer oils in transformers that cannot stand high vacuum has been achieved.

These methods are based on the long term experience of two expert teams from the Institute *Nikola Tesla* and Power Transmission Company *Elektroistok* in the field of chemical regeneration of insulating oils in 110, 220 and 400 kV power transformers. Consequently, more than 200 transformers were subjected to the aforementioned investigation procedure, which has contributed to the high quality of transformer insulation throughout the Power system of Serbia and Montenegro.

THE CHEMICAL REGENERATION OF TRANSFORMER OILS PERFORMED IN FIELD

The chemical regeneration of transformer oils can be done by using the percolation method. In practice with the special equipment [3], the regeneration can be done in two ways (3).
The first way of chemical regeneration includes regenerative cleaning of windings and usually is performed without oil removal.
The second way consists of cleaning the oil and windings seperately, with the removal of oil out of the transformer tank.
Both ways described above consist of several phases.

The first regenerative way, schematically shown in Fig. 1, includes:
I phase: drying of oil in transformer,
II phase: chemical regeneration of oil and regenerative cleaning of windings, performed at the same time,
III phase: addition of inhibitor to the oil.

This way is used for the transformers that cannot stand high vacuum. The advantage of this way is that it requires less equipment then the second way (only the VH 120 equipment and an additional filter press).

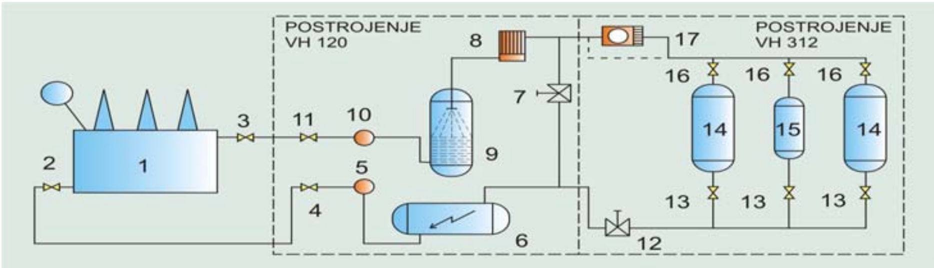


Fig. 1. Regenerative process performed without oil removal (3)

Numbers in Fig. 1 represent: 1) transformer, 2) exhaust valve, 3) delivery valve, 4) entrance valve, 5) gear pump, 6) oil heaters, 7) ”by-pass” valve, 8) fine filter, 9) chamber for degassing, 10) centrifugal pump, 11) exit valve, 12) regulative valve, 13) entering valve, 14) chambers with adsorbent, 15) chambers with inhibitor, 16) exit valve, 17) filter press, 18) cross duct.

The second regenerative way, schematically shown in Fig. 2, includes:
I phase: drying of oil and warming up of transformer ,
II phase: emptying of transformer in a special tank with the chemical regeneration of oil and vacuuming of transformer, at the same time,
III phase: filling up the transformer with the clean regenerated oil,
IV phase: cleaning up of windings with the clean oil,
V phase: emptying of transformer (second time) and chemical regeneration of oil with the very small amount of inhibitor,
VI phase: filling up the transformer with the clean regenerated, freshly inhibited oil,
VII phase: addition of inhibitor to the oil directly in transformer.
This process is used for the transformers that can stand high vacuum, no matter how high the vacuum is, no matter what is the oil content or the percent of adsorbense necessary. The disatvantage of this process is that it needs an extra tank which can take the whole amount of oil.

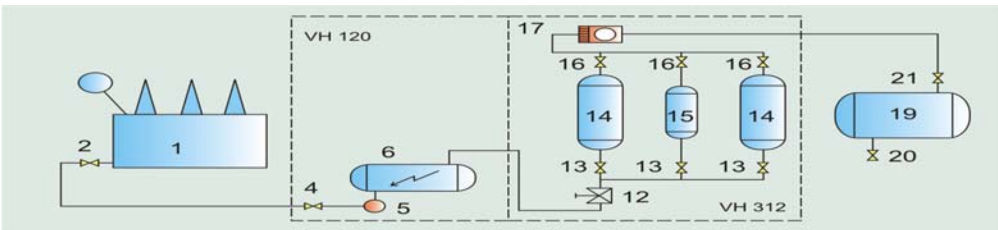


Fig. 2. The regenerative way performed with oil removal (3)

Numbers in Fig. 2 represent: 1) transformer, 2) exhaust valve, 3) delivery valve, 4) entrance valve, 5) gear pump, 6) oil heaters, 7)”by-pass” valve, 8) fine filter, 9) chamber for degassing, 10) centrifugal pump, 11) exit valve, 12) regulative valve, 13) entering valve, 14) chambers with adsorbent, 15) chambers with inhibitor, 16) exit valve, 17) filter press, 19) tank, 20) exhaust valve, 21) delivery valve.

In this work, second way of the regenerative process, witch has been modified, is presented. This modified regenerative process has been applied in the same manner as the second way with a small change. The process has been performed without the use of vacuum. The alternative for vacuum is dry nitrogen that the trasformer has been filled with. The advantage of this method is its applicability to transformers that cannot stand high vacuum.

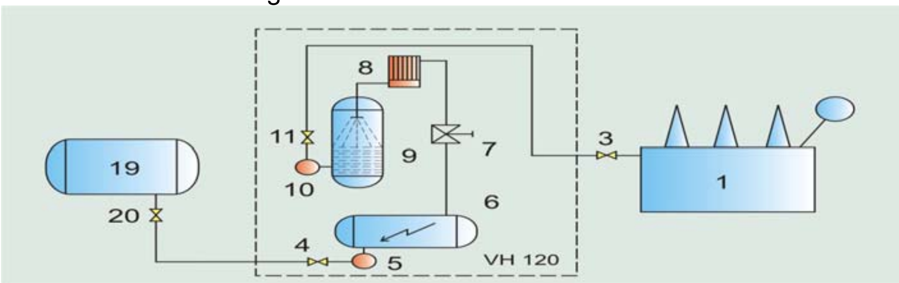


Fig. 3. The regenerative process performed with oil removal (3)

Numbers in Fig. 3 represent: 1) transformer, 3) delivery valve, 4) entrance valve, 5) gear pump, 6) oil heaters, 7) "by-pass" valve, 8) fine filter, 9) chamber for degassing, 10) centrifugal pump, 11) exit valve, 19) tank, 20) exhaust valve.

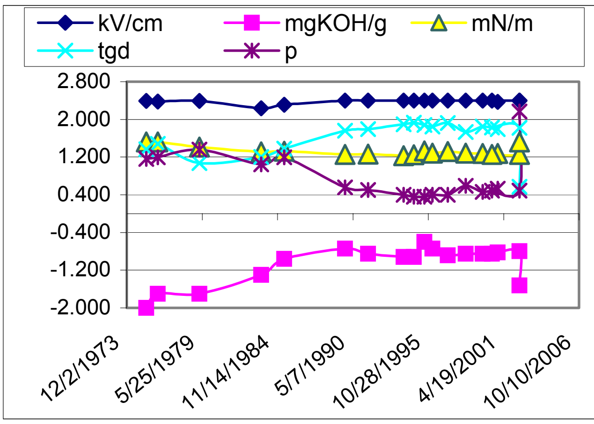
RECOMMENDED IN-FIELD CHEMICAL REGENERATION

In this paper the results obtained for the regeneration of 110 kV transformers with the use of dry nitrogen are shown. Three case studies are thoroughly investigated and analysed.

CASE STUDIES

Case 1

First, transformer from 110 kV network, in use since 1971, with 28 t of oil has been analysed. Due to its long exploitation and changes of oil characteristics (Fig. 4), oil needs to be regenerated. With ageing and with the other degradation processes (higher temperature, oxidation, dissipation of constructive metals in the oil, higher water content, degradation of cellulose) some characteristics, such as dissipation factor and acidity, get higher (4). Both changes are undesirable, since oil is suppose to be isolating medium, with low dissipation factor and low acidity. In Fig. 4 it is obvious that dissipation factor and acidity are getting higher as ageing progressing. Some other measurements, such as the measurement of resistivity, interfacial tension and breakdown voltage have been the highest when oil was new, at the beginning of exploitation. During the exploitation these values have been deteriorated and their measured values have been lower.
As it shown in Table 1 all aforementioned quantities have values out of normal range, above values approved by IEC 60 422. After the regeneration under "dry nitrogen" all the measured characteristics improved and the oil itself is in good condition for re-use and exploitation.

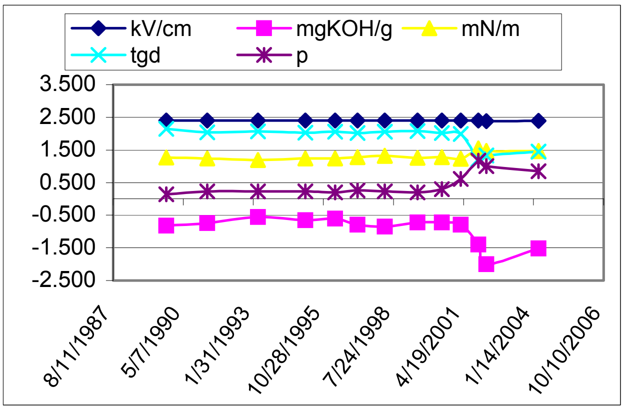


Year	kV /cm	mg KOH/g	σ mN/m	tgd * 10^3	ρ GWm	class of oil
1979	>245	0.02	25.80	11.8	22.8	I
1983	171	0.05	20.35	16.0	11.2	I
1985	206	0.11	21.18	23.8	15.8	I
1989	>250	0.18	18.12	57.9	3.6	III
1995	250	0.25	21.46	76.4	2.3	III
1997	>250	0.13	20.94	83.4	2.5	III
1998	>250	0.14	19.22	54.4	3.9	IV
2000	237	0.15	19.00	62.1	3.4	IV

Fig. 4. Change of transformer oil characteristics during exploitation

Case 2

The second transformer being studied is also from 110 kV network, in operation since 1971, with 21.2 t of oil. Due to its long exploitation and changes of oil characteristics (Fig. 5), oil needs to be changed or regenerated. As it shown in Fig. 5 all measured and considered values are in critical range, above the values approved by IEC 60 422 (see Table 1). Since the transformer has been in III class of oil, after frequent controls, oil has been subject to regeneration. Solid insulation has been aged, according to 2-furfural (2-FAL) content in oil. The measured value has been 1.33 ppm. It is considered to be very high. According to this value the cellulose has very low mechanical strength. In such case it is very important to predict the life expectancy of transformer. The analysis of 2-FAL content in oil is in this case the main diagnostic tool for oil regeneration or for strict control of oil. The decision has been to apply the propsed "dry nitrogen" method. The results after regeneration of oil are shown in Table 2. It is shown that measured characteristics are improved. The oil has become of I class and it turns out to be good for further use and exploitation.

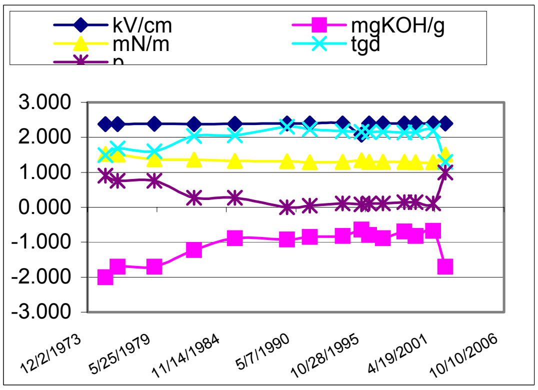


Year	kV/cm	N.b KOH/g	σ mN/m	tgδ * 10^3	ρ GWm	class of oil
1991	>250	0.18	17.57	109.4	1.7	III
1993	>250	0.28	15.43	116.4	1.7	III
1996	>250	0.25	17.24	115.1	1.6	III
1997	>250	0.14	20.97	113.0	1.7	III
1999	>250	0.19	18.20	118.5	1.6	III
2000	>250	0.19	19.00	103.9	2.0	III
2001	>250	0.04	35.00	16.3	15.0	reg
2002	241	0.01	29.00	21.4	10.2	I
2004	243	0.03	29	28	7.1	I

Fig. 5 Change of transformer oil characteristics during exploitation

Case 3

This is a case of transformer that is similar to the two previously examined transformers. It is a transformer from 110 kV network, in operation since 1975, 21.2 t of oil in total. Results of dissolved gas analysis (DGA), during its exploitation have been indicating that there were no electrical or thermal faults. Transformer is in good condition according to the DGA analysis. On the other hand, paper and oil insulation have been in poor condition. According to High Performance Liquid Chromatography (HPLC) analysis paper insulation has been degraded. The 2-FAL content measured in oil has been 0.68 ppm which is considered to be high, which indicates the poor state of cellulose isolation. In case the transformer has important role in network operation, it is quite important to predict the remaining life. The analysis of 2-FAL content in oil, is in this case, the main diagnostic tool for decision making how to deal with the transformer oil (to regenerate or to apply more strict and frequent control). In this case the decision was to improve the state of oil by "dry nitrogen" regeneration. The results after regeneration have shown significant improvements, having in mind all measured characteristics. Therefore, in this case the oil can be exploited and the lifetime of transformer, from isolation point of view, is extended.



Year	kV/cm	N.b. KOH/g	σ mN/m	tgδ * 10^3	ρ GWm	class of oil
1975	240	0.00	33.70	30.7	8.0	I
1979	>245	0.02	23.70	39.6	5.7	I
1982	>240	0.06	23.20	109.0	1.9	III
1989	>250	0.12	20.61	203.5	1.0	III
1995	118	0.23	22.06	144.0	1.2	IV
1997	>250	0.13	19.72	143.6	1.3	IV
2001	>250	0.21	19.30	155.0	1.3	IV
2002	250	0.02	32	19.7	9.9	I*

Figure 6 Change of transformer oil characteristics during exploitation

In Table 1 a state of oil characteristics for three studied transformers is presented. All three analysed transformers had poor oil condition, especially oil sample labelled as B, which had extremely high values of dissipation factor and oil acidity and low values of interfacial tension and specific resistivity. Also, the other two oil samples have been in not very good condition. For oil sample B the deciding point for regeneration was very high concentration of 2-FAL, which is an indicator of solid isolation degradation. For the third sample considering the economic aspect, it was suggested that the regeneration should take place. The transformer operational staff has been aware of the benefits after regeneration, so it has been taken before the deadline (absolute degradation of oil). In any case, all the regenerations have been properly done comparing the results before and after oil regeneration.

Table 1. Characteristics of oil samples before and after regeneration with dry nitrogen

Sample	**Nb,** mgKOH/g o	σ mN/m	**tgδ** * 1000, ‰	ρ GΩm	**2-FFA,** ppm	**IEC 61125 B** IP,h	**IEC 61125 C**	
							TA, mgKOH/g	**sludge,** %m/m
A	0.16	18	65.9	3.1	0.29	/		
10%rege.	0.05	25	/	/	/	/	/	/
20%rege.	0.03	33	3.7	146.1	/	~ 70	1.67	0.73
B	0.19	18	118.5	1.6	1.33	/	/	/
10%rege.	0.16	26	38.2	7.1	/	/	/	/
20%rege.	0.09	29	16.0	27.1	/	/		
C	0.21	19	155	1.3	0.68	/	/	/
10%rege.	0.09	24	/	/	/	/	/	/
20%rege.	0.04	30	9.5	30.6	/	~48	1.85	0.91

Legend: $\mathbf{N_b}$ - acidity of oil; σ - interfacial tension, **tgδ** - dielectric dissipation factor of oil; ρ - specific electrical resistivity, **2 – FFA** - content of 2 - furaldehyde in oil, **IP** - induction period, **TA** - total acidity, **sludge** – in oil after regeneration, according to IEC 61 125C..

In Table 1. the results after the regenerative process for each transformer oil have been presented. The results are significantly improved and the oil quality is equal to the oil characteristics of I class. So, the proposed oil regeneration process can be recommended as an efficient and economical process.

CHEMICAL REGEGERATION UNDER HIGH VACUUM CONDITION

As it was mentioned before, that there is another method for chemical regeneration of transformer oil. This method is used for the transformers that can stand high vacuum. Three representive cases, given in Table 2, show the oil characteristics, before and after the chemical regeneration. It is shown that almost all measured values (except the value of dielectric strength) are in critical range. High acid number and dielectric dissipation of oil, specially in case 1, make the insulating system less safe for further use. Since the oil was classified in III and IV classes, the oil regeneration was recommended to the end user.

Table 2. Characteristics of oil samples before and after chemical regeneration under high vacuum

Sample of regeneration		$\mathbf{N_b}$ mg KOH/g	**σ** mN/m	**tgδ** *1000‰	**ρ** GΩm	class of oil IEC60422
T-1	before	0.31	16.14	228.4	1.2	IV
	after	0.07	31.41	16.8	28.5	*
T-2	before	0.17	18.16	59.2	4.4	III
	after	0.03	32.41	11.9	35.6	*
T-3	before	0.19	18.02	50.6	4.8	III
	after	0.06	31.69	13.8	2.9	*

After successfully applied procedure, all measured characteristics in three samples where equal to the characteristics of I class of oil. Figures 7, 8 and 9 clearly show that oils retain a very good characteristics many years after regeneration.

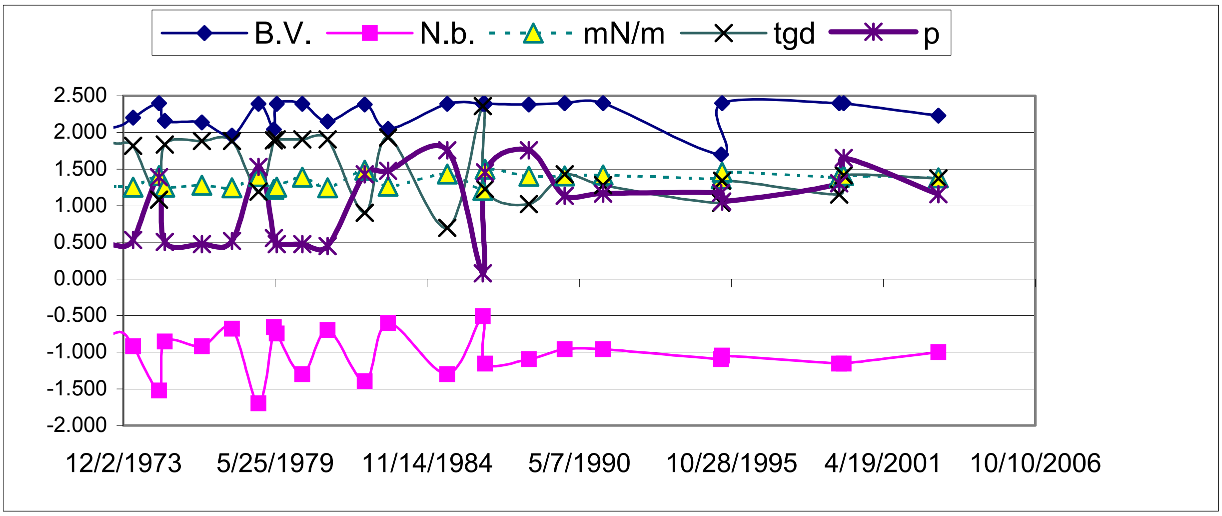


Figure 7. Change of transformer oil characteristics during exploitation (case T-1)

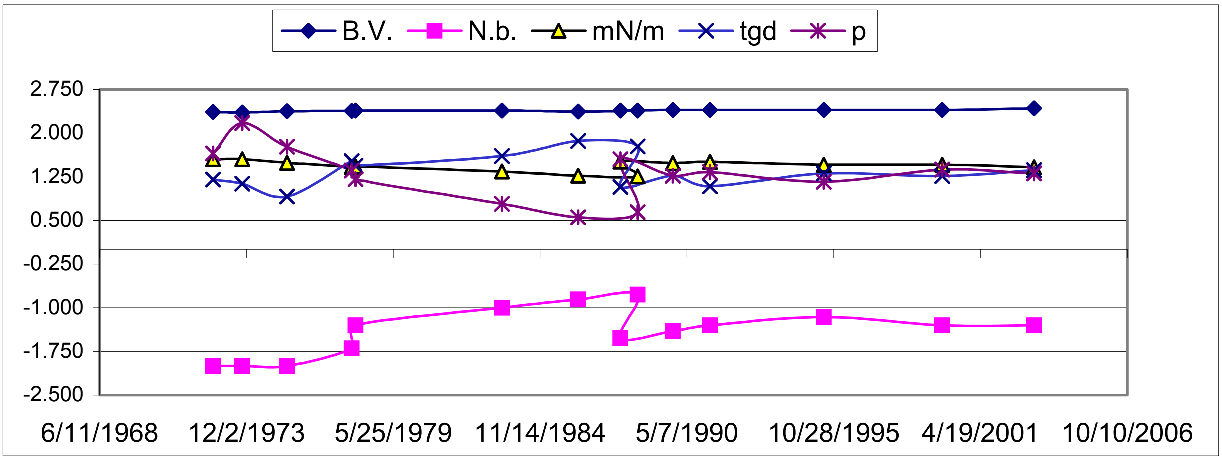


Figure 8. Change of transformer oil characteristics during exploitation (case T-2)

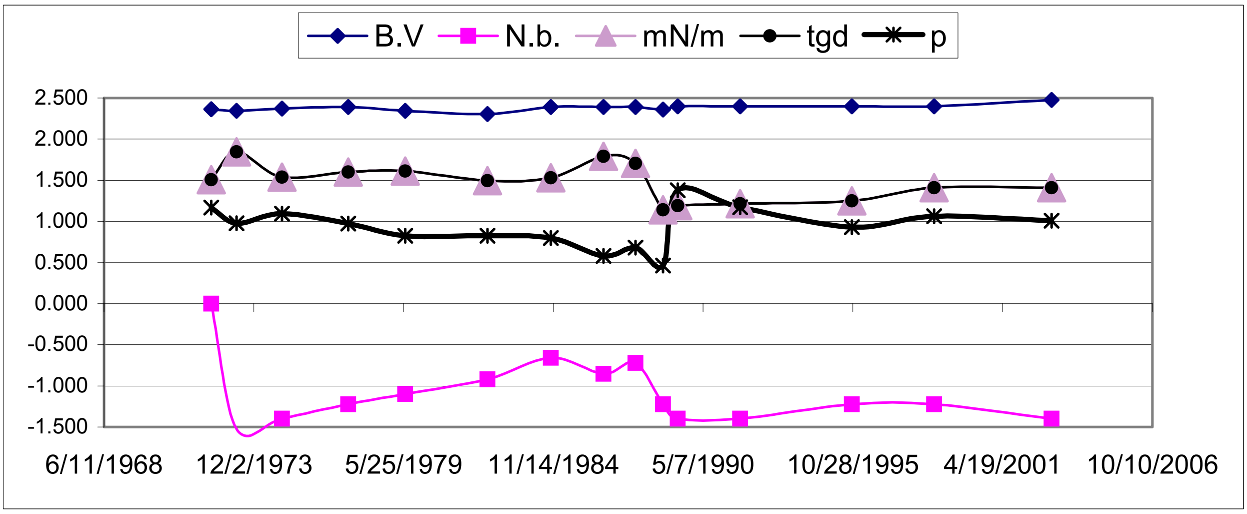


Figure 9. Change of transformer oil characteristics during exploitation (case T-3)

CONCLUSION

In this paper, the modified way for regeneration of transformer oils, which cannot stand high vacuum, has been presented and proven as an efficient and economical process. The results presented are taken from chemical regenerations, which have been applied on three power transformers. With this modification (with the use of dry nitrogen, instead of high vacuum) the possibility for regeneration of oils in transformers that cannot stand high vacuum has been achieved. In purpose to prove this method's efficiency, results of oils characteristics where compared with characteristics of chemically regenerated oils under high vacuum condition. Since there is no significant difference between final results, even after significant period of time, conclusion is that both processes with and without vacuum are recommended and proven to work. The aim of this study is to point out that the oil in power transformers can successfully be regenerated of being replaced.

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