

THE OIL-PAPER INSULATION RELIABILITY ESTIMATION OF 420 kV TRANSFORMER CONCERNING THERMAL STRESSES DURING EXPLOITATION CONDITIONS

by

**Safaa Ismail AL-MUSAWI^a, Zoran M. LAZAREVIĆ^a, Radovan R. RADOSAVLJEVIĆ^a,
Zijad M. BAJRAMOVIĆ^b, and Predrag V. OSMOKROVIĆ^{c*}**

^a Faculty of Electrical Engineering, University of Belgrade, Belgrade, Serbia

^b Faculty of Electrical Engineering, University of Sarajevo, Bosnia and Herzegovina

^c State University of Novi Pazar, Novi Pazar, Serbia

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The calculating of reached ageing based on the history of loading according of International Electrotechnical Commission standard algorithm is the first task. In order to verify the obtained results, measurements of polymerization index were made on 28 paper samples taken directly from low voltage terminals (winding ends) and bus connections of the transformer under test rated 380 MVA, 2×15,75 kV/420 kV. The complete procedure of paper sample locations and taking off is described, thereby providing a manner of how this should be done, determined by specific conditions of the transformer under test. Furthermore, the determination of limit viscosity and using its relationship function with polymerization index are explained together. Comparison is made with those of liquid chromatography of oil. The results of particle sort and size analysis are shown. Finally, an estimation of the transformer life remainder is made, which is of paramount importance when defining the steps that have to be made either in revitalization process or in transformer replacement planning.

Key words: generator transformer, thermal stress, solid insulation, ageing, life estimation, polymerization index

Introduction

Good estimation of transformer life remainder depends strongly on its definition. Although the CIGRE Working group 12.09 [1] recognizes: technical, strategic, and economical end of the life, transformers are seldom replaced for non-technical reasons – even in highly developed countries – but mainly in the case when the insulating properties of its oil-paper system is significantly weakened. This system is exposed to thermal, electrical, electro-chemical, and mechanical stresses, that all cause the ageing of the system, thereby producing many products – water, oxygen, particles, and especially acids in the oil. The ageing process develops in three simultaneous modes, caused by temperature and the presence of following agents: pyrolysis, hydrolysis, and oxidation. Pyrolysis is predominant at temperatures above 110-120 °C, due to its need for activating energy which is larger than 1.2 to 1.4 times of that for hydrolysis, which prevails at lower temperatures. Reaction with water occurs mainly by acting of acids, obtained through oil oxidation, which contains a necessary hydrogen atom. Within this complex interact-

* Corresponding author; e-mail: opredrag@verat.net

ing system, the disconnection of cellulose fibers – chain of glucose molecules – occurs, which results in the separation of CO, CO₂, water, and in the forming of polarized groups of unstable laevoglucose-glucose anhydride, and later the furan derivatives are formed. The water content in the paper depends on the temperature and exceeds significantly that in the oil, which accelerates the degrading process. Furan acids are poorly soluble in mineral oils, usually resulting in its depositing at the outer surface of the paper. The main part of the furan derivatives is concentrated in the paper, but a part of them penetrates into oil, which is especially the case with furfuraldehydes – 2-FAL [2, 3]. The oxidation depends mainly on the nature of the oxidant, its structure and pH-value. Hydroxyl groups, present in the cellulose, oxidize, generating water, CO and CO₂ [5]. Tests have shown that low water content reduces strongly the effect of oxygen dissolved onto the carbon-monoxide generation, even at elevated temperatures, which hardly affects the forming of carbon oxide. The presence of dissolved oxygen and high water content also affects the forming of carbon oxides and furan derivatives rather strongly.

For monitoring the transformer situation, following methods have been developed: gaseous and liquid chromatography (DGA and HPLC) of oil; as to the solid insulation, the measurement of the polymerization index (DP index) is the most important test, but recently some new methods are still in development, as: measurement of the polarization and depolarization currents (PDC), photo-electronic spectroscopy in the X-ray domain (XPS) or sub-infrared domain (NIR, FTIR) measurement of the reverse voltage (RVM) [4-7].

The DP method, based on finding the average number of glucose molecules in the cellulose chain, is most reliable. The DP value of the new insulation is in the range 1000 to 1400, and that of the degraded about 200. The advantage of the method lies in the fact that the dissembling of cellulose macro molecules is quantitatively measured as an irreversible process, which is followed – at the beginning slower and afterwards faster – by a decrease of dielectric strength: it falls up to about 50% of its initial value, at DP = 400-300 and up to 20% at DP = 200 [8]. The main disadvantage of this method is its rate of being invasive, because it is necessary to take probes of solid insulation of the transformer *in situ*. The pretty good solution of this problem is partly pouring off the oil and taking probes from the low voltage (LV) terminals when the regular periodical inspection and maintenance are undertaken [9]. DP measurement of probes are made mostly by using the standard viscosity metric method (IEC 60450), measuring the average poly-molecular mass. Recently, a new method has appeared, *i. e.* the gel permeability chromatography (GPC), adding the distribution to the molecular mass. In this way, the difference of cellulose and poly-cellulose fiber degradations may be found [10].

This paper shows the results of DP measurements of probes taken from one generator transformer (GT), in order to form a basis for estimation of the life remainder, as well as for the relationship with measurements made on oil probes by liquid chromatography.

Taking probes from GT paper insulation

It is necessary to take rather numerous specimens of insulation probes from various locations. The reason is that fact that temperature rise, degree of exposing to electric, chemical and mechanical influences, including also the oil flow, differ very much from place to place. The locations are to be chosen in accordance with the supposed highest degree of degradation, which leads to the serious problem – the transformer must be opened. It is, of course, best when such undertaking may be done in the factory during a detailed repair, and so, the results obtained may be used to make the decision to replace the winding insulation. With the transformer *in situ*, taking probes is best to do together with other maintenance work when the cover or the bell shaped lid of the tank is taken off, and the oil is poured out partially. Unfortunately, this

occurs very rarely in the praxis, and it is subject to weather conditions, because the insulation can be exposing to moisture. Before opening it is advisable to make the transformer warmer in respect to the ambient air, in order to avoid moisture condensation. Practically speaking, in most cases, it may be impossible to take the probes exactly from wanted locations. In such cases the oil is partly poured off, bushings or their covers are taken off, and probes from upper winding parts, *i. e.* from accessible bus bar connection at winding entrance, where the winding is warmest, are taken. It must be born in mind that the results of DP measurements at these locations can be worse, *i. e.* more dangerous for the insulation, than expected, because it is possible that bus bar connection may be subject to overheating due to either enormous flux leakage, or weak oil flow, or loosened bus bar connections. As this probe taking is an invasive procedure, a later new patching of insulation is unavoidable.

The insulating paper probes had been taken from inner bus bar connections of all primary LV windings, directly at the cap of entrance bushing (X1, Y1, Z1, X2, Y2, Z2), because they are thermally critical locations, being situated at the top where the oil flow is poor, and probably having poor connections. Three probes had been taken from each of this locations, *i. e.* the outer paper layer (O), intermediate layer (M) and inner layer, situated directly close

to the bus bars (I), making totally 18 probes (figs. 1 and 2). In order to obtain the state are as close to the primary winding as possible, the bus bar connection of the middle phase of the second primary LV winding Y2 had been chosen, because it is situated completely in the upper half of the transformer. As this phase winding is situated in the middle of the upper transformer part, it is expected that its insulation is most critical from the thermal point of view. Four probes had been taken (layers O, M, I and II) from the Y2 bus bar connection, marked with OT2 (output bus bar 2), which is situated in the upper part of the transformer, and which had been visually stated as mostly exposed, having a most darkened color and most damaged paper. Also, five probes (layers OO, O, M, I, II) at the location OT2W (connection of the winding with bus bar 2) in direct contact of the bus bar with the Y2 winding terminal had been taken.

Before the beginning of probe takings, a part of 12 ton oil had been removed, one part into the conservator and second part into two tanks, prepared in advance, and refined by the prescribed procedure. Totally, 27 probes of insulating

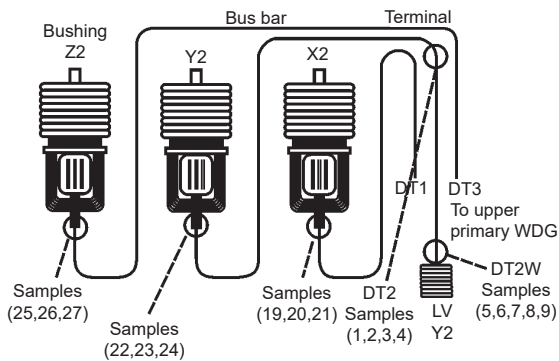


Figure 1. Locations of taking paper probes for measurement of DP index of the upper part of the winding

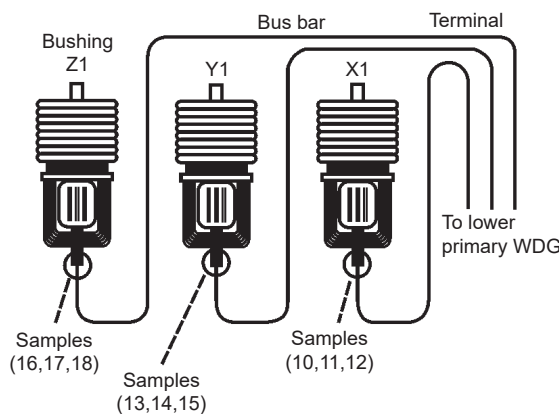


Figure 2. Location of taking paper probes for measurements of DP index of the lower part of the winding

Totally, 27 probes of insulating

paper together with their own oil had been taken. After probe taking, a special procedure for patching, *i. e.* new insulating of all spots wherefrom probes had been taken, was carried out, utilizing the paper of new generation. In order to get a basis for comparison, DP ν of the probe of the new paper was also measured, so that the total number of probes treated was 28.

The measuring method and results of measurements

Viscous indices – degree of polymerization (DP) – have been established by the standard viscous metric method in freshly prepared dissolvent – cupri-etilen diamin (CED or Cuen). In order to determine the (limit) viscosity (ν), necessary to calculate the values of polymerization index DP, the Ubelode's capillary viscosity meter was used; measurements have been carried out at the temperature 25 °C in the water bath.

In order to obtain the characteristics by the viscous metric method, it was necessary to free the probes from oil. This was done by extracting the probes by means of toluol and chloroform. After that, probes were washed with ethanol, and dried in the vacuum drying apparatus (at low temperatures) up to the constant mass. Although drying at higher temperatures is prescribed by the procedure, it was not appropriate, because the tested paper may be damaged subsequently, especially because the paper insulation was relatively old. Probes, having passed the described procedure, were dissolved in a prepared dissolvent – CED. At first, specific viscosity ν_{sp} (in accordance with the viscosity of the material to be dissolved and the dissolvent) for a number of various concentration of polymers (cellulose) were measured, in order to obtain the values of specific limit viscosity number ν by means of the linear extrapolation.

There are many relationship functions between DP values and viscosity ν , as *e. g.* IEC, ASTM, SCAN-C15:62, Evans [11], Marx [12] *etc.*, which are presented in tab. 1. In this paper,

Table 1. Functions correlating DP and ν

ASTM	SCAN – C15:62	Evans [11]	Marx [12]	IEC 60450
DP = 1.9 ν	DP ^{0.905} = 0.75 ν	DP ^{0.9} = 1.65 ν	DP ^{0.9} = 1,22 ν	$\nu = K \cdot DP^a$

Table 2. Limit viscosity and DP index for probes taken from GT

Probe	Location/layer	DP ν	Probe	Location/layer	DP ν
1	OT2 Inner (close to Cu) II	164	15	Y1 Outer O	387
2	OT2 Inner I	302	16	Z1 Inner I	224
3	OT2 Middle M	360	17	Z1 Middle M	471
4	OT2 Outer O	494	18	Z1 Outer O	439
5	OT2W Inner (close to Cu) II	206	19	X2 Inner I	243
6	OT2W Inner I	319	20	X2 Middle M	542
7	OT2W Middle M	402	21	X2 Outer O	449
8	OT2W Outer O	444	22	Y2 Inner I	348
9	OT2W Quite outer OO	519	23	Y2 Middle M	422
10	X1 Inner I	294	24	Y2 Outer O	481
11	X1 Middle M	357	25	Z2 Inner I	208
12	X1 Outer O	418	26	Z2 Middle M	276
13	Y1 Inner I	375	27	Z2 Outer O	290
14	Y1 Middle M	441	28	Paper of new generation (NI)	1235 (1100)

calculation applied was the Marx's relationship, as it covers all DP's in the literature – ranging from new, up to totally degraded insulation.

Measuring results are shown in tab. 2. In order to obtain reference values, DP was measured also for the new paper (new generation), which were used to patch, *i. e.* cover the spots wherefrom the probes had been taken.

This measurement could not be carried out directly, although the paper was without oil, because it was not possible to dissolve the new paper in the prepared solvent. It was possible to attain the complete dissolving only after the extraction by toluol and chloroform, washing with ethanol and drying. This certainly means that the new paper is very probably impregnated with a substance that is not soluble in CED, having the goal to make the ageing of paper under operating conditions slower. Therefore, it may be supposed that the paper, picked up as probes, had the polymerization index during the manufacturing of the transformer somewhat lower than the present paper of new generation. There are two reasons for this supposition: insulation properties of the new paper manufactured more than 30 years ago were worse than those of the modern paper, and the building-in process certainly involves some mechanical deformations [10].

It is therefore natural to suppose that the generator transformer had the approximately uniform DP value of the paper insulation about 1000-1100. Some probes taken from certain peripheral bus bars were found to have completely carbonized paper (DP = 124), where it is stated that the completely mechanically degraded paper, has the DP value 100-150. According to the data from some practical observation [4, 10] lower limit values are in the range 100 to 200; therefore, it may be assumed that the final operative value is 200, bearing in mind the degree of the transformer importance.

Figure 3 represents the procedure of determination the limit viscosity v by means of specific viscosity on the example of all 5 probe layers at the entrance to phase LV winding Y2 (OT2W). Values of the limit viscosity v of four insulation layers at the bus bar connection Y2 at the transformer top (OT2) are shown in fig. 4. For the purpose of comparing, the limit viscosity of the new modern paper is also given (NI).

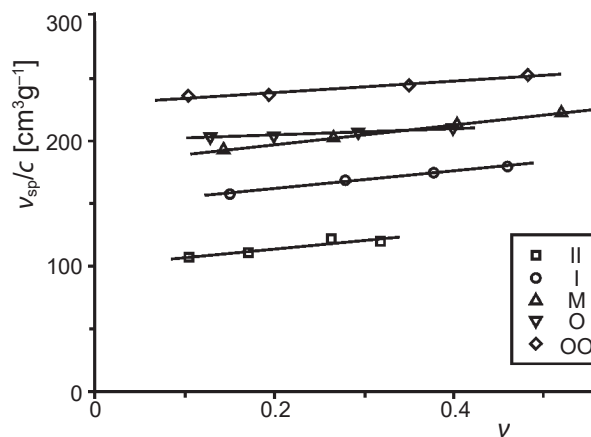


Figure 3. Limit viscosity v as the function of specific viscosity v_{sp} for 5 paper probes of the OT2W series

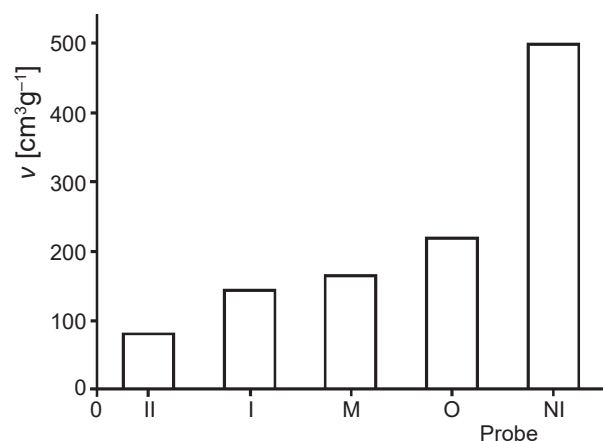


Figure 4. Comparison of limit viscosity v of all 4 probes of the series OT2 and the new insulation

An alysis of measured results

- (1) For the new paper, at the time when the transformer was manufactured and started with its operation, it may be supposed that (according to some measurement and to data from the literature), the viscosity index of polymerization had the value between $DP_0 = 1100$ to 1200, but – in accordance with the previous discussion – the value of 1100 will be taken. When the index reaches the values lower than 250, the mechanical degradation occurs; when paper is powdered, the index falls down to 150. Having in mind that the insulation properties are still present also when it is significantly mechanically degraded, it may be taken that the limit when both insulating and mechanical properties are lost – also in accordance with published literature – is at the value $DPI = 200$ or somewhat lower, but not less than 150.
- (2) LV bus bar connections, from primary bushings up to the entrance of winding themselves, have a rather low DP value, which means that the insulation is significantly degraded, especially paper layers near the copper. The main cause is the insulation age (more than 33 years of operation for GT), but other causes are also possible, especially for bus bar connections wherefrom probes were taken.
 - During probe taking, a number of loosened contacts at bus bar connections and bushings had been found as well as slightly burned insulation in their vicinity. This means that the cause of accelerated ageing at these locations is the excessive heating caused by loosened contacts.
 - Probes were taken at the upper bar connection (at the top of GT), where the oil is warmest and the oil circulation is also poor, and consequently the thermal ageing is in this part of space is accelerated.
 - Locations of probes were chosen at spots where the worst damage could be observed visually.
 - Presence of oxygen from the air (there is no membrane) caused the enormous appearance of ions between the copper and the inner layer of the paper, which resulted in acceleration of paper degradation process. It was confirmed by the fact that generally inner layers (close to the copper) are worse degraded than the outer ones (lower DP).

The influence of exposed individual reasons weakens when going down, *i. e.* towards the windings, so that it is logically to suppose that there the DP are at highest, *i. e.* the state of insulation is better. The state of paper insulation, which is similar to that on bus bar connection, may therefore be expected only at the winding hot spots.
- (3) It was noted in that, in several cases, the intermediate layers of insulating paper are in better condition than the outer and inner ones (for the transformer in question this holds for the insulation of bus bar contacts to bushings Y1, Z1, X2), which is the result of prevailing the mechanical and electrochemical stresses of the outer side of insulation in respect to thermal ones, transferred from the inner layers.
- (4) The insulation of bus bar connections increases their thickness, *i. e.* the number of paper layers grows when going to the winding beginning Y2, wherefrom the probes had been taken. It means that the first paper layer, closest to the copper, is in the worst position in respect to oil, and is therefore subjected to strong thermal stresses. This is why these layers are in completely degraded state (layers II with the $DP = 164$ and 206). But, owing to the fact that the number of paper layers at these locations is greater than 5, the loss of insulating properties of the first layer close to the copper, may be tolerated, especially when the next layers have a gradual and significant increase of the DP index. This is the case of the treated bus bar connection, but, due to the fact that this increase is not especially high (the last layer has

the DP = 519), it is advisable to verify the insulating property after a reasonable period of time, which understands a new probe taking and polymerization index measuring, in order to notice an accelerated increase of insulation degradation on time.

Life remainder estimation of the generator transformer based on its real condition

The next calculation will be carried out without two lowest DP index value from tab. 2, because the overheating is provoked by a big number of layers and weakened cooling. All other measured DP values fall in the range between 224 and 552. The dependence of life on temperature (*i. e.* load) has an exponential character [13]. For each temperature – or load – the DP index decreases with temperature approximately in the linear way, up to the value 200. Therefore it seems justified to suppose that the DP index decreases linearly during its operating life, so that the following relation may be introduced: the linear yearly degradation factor of insulation degradation YFD_x is:

$$YFD_x = \frac{DP_0 - DP_{av,x}}{Y}, \quad YFD_x \% = \frac{YFD_x \times 100}{DP_0} \tag{1}$$

where DP₀ is the depolymerization index of the paper at beginning of transformer operation, DP_{av,x} – the average value of measured DP of the paper layer marked with “x”, and Y – the number of years of transformer operation.

The estimated number of years of the remained life (L_{r,x}) at the location x is:

$$L_{r,x} = \frac{DP_{av,x} - DP_l}{YFD_x} \tag{2}$$

where DP_l is the depolymerization index of completely degraded paper.

Average DP values of individual paper layers at bus bar terminals of primary windings, as well as the estimated life remainder of individual layers and the entire insulation (as a full), are given in tab. 3. It may be noticed that the thermal effect is predominant for bus bar connections.

The insulation of turns in the upper layer of the second primary winding (X2, Y2, Z2), situated in the upper half of the transformer, is mostly exposed, because there the ambiance is at the highest temperature. It is real to suppose that the insulation of these turns, as well as the corresponding upper turns of the secondary, are in the quite similar state like the 3 last layers at the location of contact with entry bus bar connections (DP_{av} = 455). Taking these

Table 3. Average DP values and estimated life remainder of bus bar insulation

Location of probe taking-layers	Inner I	Middle M	Outer O
DP _{av}	276.6	409.9	425.3
Average yearly decrement YDF	25.7 (2.34%)	21.6 (1.96%)	21.1 (1.92%)
Life remainder	5 years	12 years	13 years
Average DP of the primary bus bar insulation		370	
Average yearly decrement YDF of the primary bus bar connections insulation		22.8 (2.1%)	
Estimated remain life of the insulation from average state of primary bus bar connections		11 years	

data as the basis, the life remainders may be estimated for turns situated directly in front of critical turns, and taking into account similar conditions and insulation type, the same may be done for upper layers of all transformer windings: The average yearly degradation factor

of transformer winding insulation YFD is 20.15 yearly, *i. e.* the yearly decrement of DP is 1.83%. The life remainder of winding insulation under test is consequently estimated to be approximately 13 years, which means that the transformer, provided that it is loaded in the same manner and scope as till now, will have the entire life of 45 years, which means that it “spent” 71% of its life up to now. However, it should be taken into account that this estimation cannot include dangerous local damaged spots, or irregular appearances, like long lasting overloads which may provoke a serious failure in transformer insulation with probable disconnections from the mains.

The contemporary access for ageing estimation based on IEC 60076-7 and CIGRE proposal uses the improved „Arrhenius model“ for paper degradation:

$$1/DP_l - 1/DP_{av,x} = kL = A e^{(-E_a/RT)} L \quad (3)$$

where E_a is the activation energy, A – the constant depending of operation conditions, presence of moisture and oxygen, *etc.*, R – the gas constant, 8.314 J/molK, and L – the remaining life. Hence:

$$L = \frac{1/DP_l - 1/DP_{av,x}}{k \cdot 24 \cdot 365} \text{ years} \quad (4)$$

For the generator transformer under consideration, with $DP_{av} = 455$, operation temperature of 80 °C (363 K) and 1-1.5% of moisture, constant $k = 2.45 \cdot 10^{-8}$ [14]. Hence remaining life is:

$$L = \frac{1/200 - 1/455}{2.45 \cdot 10^{-8} \cdot 24 \cdot 365} = 13 \text{ years} \quad (5)$$

This result corresponds with upper simplified calculation method based on linear yearly degradation factor YDFx.

Finally, formerly made calculations by authors of the life consumption based on the loading diagrams have shown that GT spent 19 relative years. An empiric formula for “spent life duration” ET of transformers based on the initial and measured values of the DP index in a certain instant is [4]:

$$ET = 20.5 \ln \frac{DP_0}{DP_{av}} = 20.5 \ln \frac{1100}{455} = 18.1 \text{ years} \quad (6)$$

which is good relationship based on the direct state computations by using DP index. It must be born in mind that the state of insulation in upper turns of the winding may be expected to be somewhat better than those at the entrance, close to the bus bar connections.

Determination of furan content and particles in oil of GT

The best method for the determination of the state and life remainder of the insulation is the measurement of the DP index. Unfortunately, this way is rather complicated and subject to many dangers, probe locations are frequently difficult to access, opening of the transformer is inevitable, which may result in contaminations, especially due to moisture penetration and to the fact that – because the method is invasive – putting new insulation patch may sometimes be very complex, almost always in very narrow space inside the transformer. Therefore, beside the DGA analysis, the method of liquid chromatography is most frequently used in the praxis

(HPLC – IEC 61198) which makes the determination of furan derivatives possible; it is well known that this product of paper degradation has a relation with the DP index. Recently, in our practice, numerous measurements of the number and dimensions of particles are also noted (ISO 4406 (1999)E, NAS 1638, SAE Codes) as well as other methods.

Furan derivatives in oil are the product of cellulose insulation degradation, so that their appearance is directly correlated to the degree of degradation, *i. e.* to the DP. There is generally a strong trend to establish a satisfactory relationship between the concentration of furan derivatives (most often 2-furfural or 2-FAL) and the DP, in order to create the condition to estimate the state and the life remainder of a transformer, based on the HPLC or other laboratory analysis of oil. This interdependence can be determined either by experimental curves for various paper types, or by a statistical arrangement of results, obtained on a large number of transformers, forming the basis for creating a series of interpolating formulas [4, 15-16], *etc.* There are some differences in expressing the concentration – either in mg/l or mg/kg. Although many empiric formulas are established, a solid relation does not exist up to now; therefore, there is no reliable estimation of the remaining life based on 2FAL concentration, but it is even quite sure that a significant concentration of furan derivatives means that the serious degradation of paper insulation had arisen. In tab. 4, measured values of 2FAL in the oil of GT are presented, and in tab. 5 the calculated values of DP indices by means of given relationship functions.

There are several reasons why it is impossible to establish a pretty valid (precise) relation for DP – 2FAL. This can be easily understood by looking the results from tab. 5. General factors are the following: type and design of the transformer,

paper-cellulose kind (origin) and the influence of the manufacturer, contact with the ambient atmosphere, oil state, operating conditions, elevated temperature that reduces its concentration, intervening onto the insulation system and general condition of forming 2FAL and its solubility. There are also particular reasons: uneven separation of 2FAL during normal ageing and abnormal (extraordinary) conditions, local failures, *etc.* It is therefore best to measure the DP indices but also to make other appropriate measurements.

Table 4. Measurement of 2-furfural contents in oils of GT

Measuring date	First	After 2 years	After 2.5 years
2-furfural concentration	0.57 mg/kg	0.40 mg/l	0.44 mg/l
Average values	0.505 mg/kg or 0.449 mg/l		

Table 5. Calculated DP by means of relationship functions with 2FAL

Chendong [16]	Saha [4]	De Pablo [2]	De Pablo [3]
$(1.51 - \ln 2FAL) / 0.0035 =$ = 530	$800 / (0.186 \cdot 2FAL + 1) =$ = 731	$1850 / (2FAL + 2.3) =$ = 659	$7100 / (8.88 + 2FAL) =$ = 756

Results of granulometric analyses of particles (x/100 ml) in the oil of GT of a sample measured are shown in tab. 6, together with results of testing new oil ready to be poured in.

Although the measured values satisfy the regulation demands, it is noticeable that significant quantities of particles exist even in the new prepared oil. According to the recommendation of well-known oil producers, the found number of particles exceeds the limit, so that filtering is recommended. Therefore, it may be concluded that the procedure used up to now for preparing the oil to pour in, is either not satisfactory, or there is a contamination in the vessel where the oil is kept. In each case, the complete procedure is to be revised, including the change of the method and/or taking new apparatuses.

Table 6. Results of granulometric analysis of particles in the oil of GT and in the new oil

Particle dimensions [μm]	BT	New oil ENOL-C
1-5	435897	1411765
5-10	35897	62562
10-20	5128	0
20-50	184	213
50-100	78	58
>100	20	21
Fibers	12	11
Class according to NAS 1638	8	8

Conclusions

The best estimation of the state and life remainder of a transformer in operation can be made by the application of measuring the DP index of winding insulation on specimens taken from various layers of upper parts of the windings, entrances to the windings and the bus bars, in other words from locations where strongest thermal, mechanical and chemical stresses may be expected. This procedure of measurement was applied to the 380 MVA generator transformer in the 400 kV power plant, which resulted in the following. The estimated life remainder was found to be 13 years. This

result represents an important factor when making the decision if it is justified to revitalize (redesign) and increase the rated power. The applied method is invasive, very complicated and involves many dangers; therefore, it should be carefully prepared and made: locations of probes are – as a rule – difficult to approach, opening of the transformer is unavoidable, which can provoke various contaminations, especially moisture penetration; due to rate of being invasive, it may sometimes be difficult to patch the insulation at the locations where the probes had been taken due to the fact that the space may very often be very limited and narrow, unsuitable to work. In order to take probes and afterwards to patch the insulation, it is necessary to pour out about 20% of oil content, in order to reach the LV winding. A warm day with low moisture content should be chosen.

The estimation of the insulation age and life remainder by means of furan derivative concentration is not reliable, since the satisfactory relationship DP-2FAL has not been found so far. On the other hand, measuring this concentration should be certainly included into regular program of oil testing (monitoring), together with gaseous chromatography method, because it has an important pre-emptive role – the increase of the concentration warns the staff to the insulation ageing, but its degree is to be determined by another method – direct DP index measurement.

It is strongly recommended to make repeated measurement of DP index, including bus bar connections of all spots in the direct neighborhood of winding entrances, including several layers every 2 or 3 years, in order to determine precisely the decrement (decrease) of insulating paper quality, as well as the life remainder, having in mind that old transformers grow older faster than new ones under the same condition. It is necessarily measurement of 2FAL every year for trend establishing.

During the regular yearly analysis of insulating oil, measurement of granulometric content in oil should be done. Having the life of the transformer in mind, as well as the wish to extend it as long as possible, and especially the trend to increase its rated power, it is highly desirable to make a treatment of the oil-paper system in order to eliminate the moisture content; although the values of this content may be within the prescribed limits, they are considerably higher than those of new high-quality oils. Other pollutants, as particles, should also be eliminated if their presence is higher than those prescribed in the literature; this has been noted in our case for the “new” oil prepared to be added in.

During the expected revitalization, it is absolutely necessary to build in the membrane, in order to minimize the negative effect of various pollutants, especially water and oxygen of the ambient air.

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