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IN-SERVICE ASSESSMENT OF WATER CONTENT IN POWER TRANSFORMERS

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INTRODUCTION

The dielectric strength of transformer insulation is determined to a significant degree by the dielectric strength of its liquid component - oil[1]. The dangerous effects of water are - reduced dielectric strength of oil due to an increase in percent saturation at lower temperatures[2,3] and formation of water vapor bubbles at elevated temperatures[4]. The purpose of water monitoring is to detect elevated water content and prevent hazardous conditions caused by a serious reduction of the oil's dielectric strength.
Two options are available to assess the water content on-line:

- determining the water content or percent saturation of oil and determining the dielectric strength of the oil.
- estimating the water content in the solid insulation modeling the essential features of the insulation structure.

The criteria for an in-service assessment should correlate with the transformer's serviceability and should be defined on the basis of service experience.
ZTZ-Service's water estimation methods typically consist of:

- on-line assessment of moisture in transformer by means of a "water heat-run test"
- off-line inferring of average water content in insulating barriers using insulation resistance and dissipation factor measurements
- direct measurement of water in samples of solid insulation

This paper will describe ZTZ-Service's experience with in-service assessment of the insulation condition using the water heat run test.

MAIN SOURCES OF WATER CONTAMINATION

The origins of water contamination can be divided into two groups; in-service and during repair. Our experience[5] shows that the main in-service contamination sources are:

- moisture ingress through breathing system
- moisture ingress through through poor gaskets
- moisture ingress from water cooling system
- result of aging

The main sources of contamination during repair are:

- moisture adsorption when tank is open
- moisture condensation on the tank during improper drying
- use of inadequately dried materials
- ingress of residual moisture from oil-filling equipment

WATER DISTRIBUTION IN POWER TRANSFORMERS

Cellulose insulation is both an accumulator of water and a main source of oil moistening. Cellulose insulation can be divided into two groups:

- A "thin" insulation such as conductor-paper insulation, barrier pressboard insulation, etc.. This insulation is distinguished by a rather large surface that can absorb water and a relatively small total mass.
- A "thick" insulation such as supporting components. This insulation is distinguished by a relatively small absorbing surface and a large total mass.

Of equal importance are the differences in temperature. The solid insulation closest to the conductor can run approximately 20 to 30°C hotter than the bulk oil and the components exposed to average oil temperatures. There is also an axial temperature gradient.

Both the thickness of the insulation and the temperature to which the insulation is exposed are important factors as they affect the water distribution in the transformer.

The water content of the oil influences the dielectric strength of the oil-barrier insulation. This influence is dependent on the condition of the water; bound, dissolved, emulsified (held in suspension), and condensed (free water). The situation becomes more dangerous toward the end of this sequence. Oil is also a water transferring medium.

Based on our experience, most of the water is concentrated in approximately 30% of the cellulosic insulation ("thin" insulation). About 10-15% of the mass contains the areas of the elevated water content. The elevated water content is 1-2% above average.

Transformers often contain free water at the bottom of the tank or in the coolers; however, this situation will not always result in elevated water content in the solid insulation.

The characteristics of water distribution (determined by evaluating the transformer insulation condition) do not compare with traditional models based on the equilibrium between the oil and the cellulose material.

WATER HEAT RUN TEST

Traditionally, transformer water assessment consisted of periodic measurements of water concentration in oil[6]. Reference 6 also recommends the estimation of the moisture content of the cellulose insulation from a dissolved-moisture-in-oil measurement, presuming that an equilibrium condition exists. The actual distribution of water in a transformer challenges the reliability of such an approach.

Our approach consists of assessing the increase of water content in oil after heating a loaded transformer (by reducing the cooling) up to the maximum working temperature and maintaining this temperature long enough to allow a significant quantity of water to migrate into the oil. This procedure accelerates the water diffusion within the cellulose, increases the solubility of the water in oil, and brings the condition closer to equilibrium. The temperature range (60-70°C) and the duration of test (3 days, see Figure 1) were selected on the basis of the theoretical analysis. The ratings correspond to the following water concentrations: GOOD ≤15 ppm (wt/wt); FAIR >15, ≤20 ppm; PROBABLY WET >20, ≤30 ppm; and WET >30 ppm.

(Estimated increase of water content in oil due to desorption out of the solid insulation at 70°C, and where in the initial state 30% of the pressboard had water content of 2% by dry weight)

Classes of Water Contamination
FIGURE 1

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Class I corresponds to the condition of a new transformer or a service-aged transformer after drying. Class II corresponds to the condition of a transformer in service, which maintains a relatively low percent saturation of water in oil (<50%) within the range of service temperatures (from 0 up to 70°C). Class III corresponds to the condition of a transformer which may result in an increase of the percent saturation of water in oil to the region of 50-100% in the range of service temperatures. Class IV corresponds to the condition which may result in an increase of the percent saturation of water in oil over 100% in the range of service temperatures.

EXPERIENCE WITH WATER HEAT RUN TEST

More than 70 large power transformers have been tested for water content in this program to date. The tests performed were a part of a refurbishment process[7] that included drying of the insulation. Typical results are shown in Table I. The water estimation results in the cellulosic insulation, through electrical and water measurements in cellulosic insulation samples, and results of water extraction during the dry-out are also included.

The results showed the following:

- There is a good correlation between the water content in oil and in the solid insulation in transformers under test.
- The correlation between the water content in oil and the condition assigned in Figure 1 is not attainable for temperatures lower than 60-70°C.

CONCLUSIONS

1. A reliable correlation between the water content in oil and the solid insulation in real power transformers can rarely be expected when the traditional approach is applied.
2. A reliable correlation between the water content in oil and the classes of water contamination has been obtained as a result of the water heat run test.
3. The water heat run test may be used as an on-line monitoring technique when sampling is conducted manually as well as with on-line moisture sensors.

REFERENCES

1. Beletsky, Z., et al., "Short-Term Dielectric Strength of High-Voltage Power Transformer Insulation", Electrichestvo, 1978, N9.
2. Griffin, P. J. "Testing of Electrical Insulation Oil (A Review of Practices)", *Minutes of the Fifty-Eighth Annual International Conference of Doble Clients*, 1991, Sec. 10-3.1.

3. Ryzhenko, V. and Sokolov, V. "Effect of Moisture on the Dielectric Strength of Winding Insulation in Power Transformers", Electricheskie Stantzii, 1981, N9.
4. McNutt, W. J. et al., "Short-Time Failure Mode Considerations Associated with Power Transformer Overloading", IEEE Transaction on Power Apparatus and Systems, Vol. Pas-99, No. 3, May/June, 1980, pp. 1186 - 1197.
5. Sokolov, V. "On-Line Evaluation of Moisture in Transformer Insulation", ZTZ-Service - Doble Symposium on "Diagnostic and Maintenance of Power Transformers After a Long-Time Service", May, 1994.
6. IEC - 422 "Maintenance and Supervision Guide for Insulating Oils in Service", Bureau Central de la Commission Electrotechnique Internationale, 1973.
7. Sokolov, V. "Experience with the Refurbishment and Life Extension of Large Power Transformers", *Minutes of the Sixty-First Annual International Conference of Doble Clients*, 1994, Sec. 6-4.1.
8. Oommen, T. V. "Moisture Equilibrium in Paper-Oil Insulation Systems"; Electrical Electronics Insulation Conference, Chicago, October, 1983.

TABLE I
WATER ASSESSMENT IN LARGE POWER TRANSFORMERS

								Water Inference Through Electrical Characteristics, %	**Water Content in Insulation Samples, %**	**Extracted Water, Liters**
			0	**1**	**2**	**3**	**Class**			
1	**S/N 114065**									
	250MVA 400/110 kV M*, 12 years in operation	t,°C	40	70	70	70	I	<10	0.85	5.0
		W,								
		ppm	6.6	9.9	11.5	9.8				
2	**S/N 107383**									
	200MVA 330/110 kV M, 15 years in operation	t,°C	56	65	66	67	I	<10	0.9	9.8
		W,								
		ppm	11.4	12.1	13.4	14.3				
3	**S/N 111439**									
	133MVA 400/231/34kV AB*, 13 years in operation	t,°C	35	60	60	60	I-II	1.5	0.5 mm - 2.0	8.0
		W,								
		ppm	10	13.6	16.3	--				
4	**S/N 95385**									
	150MVA 400/15.75 kV	t,°C	40	60	60	60	II	1.5	3.0 mm - 1.5	8.8
		W,								

	AB, 18 years in operation	ppm	10	16.5	19	18				
5	**S/N 84158**									
	125MVA 400/13.8 AB, 22 years in operation	t,°C	35	65	60	60	II	1.9	3.0 mm - 0.62 0.5 mm - 1.9	8.9
		W,								
		ppm	15	21.6	19.3	17.7				
6	**S/N 85132**									
	125MVA 400/13.8 kV AB, 22 years in operation	t,°C	35	55	60	62	II-III	1.9	3.0 mm - 1.4 0.5 mm - 3.1	7.5
		W,								
		ppm	10.1	16.9	15.5	20.9				
7	**S/N 85179**									
	125MVA 400/13.8 kV AB, 22 years in operation	t,°C	40	65	65	65	III	1.9	3.0 mm - 1.9 0.5 mm - 2.7	12
		W,								
		ppm	10	22	16	24				
8	**S/N 110023**									
	125MVA 330/110/10 kV AB*, 14 years in operation	t,°C	29	64	65	66	III	2.6	3 mm - 2.5	27.7 ----***
		W,								
		ppm	17.9	20.7	27.1	29				
9	**S/N 57523**									
	200MVA 330/110/35 AB, 26 years in operation	t,°C	36	67	63	61	III	2.5	3 mm - 2.5	23.5
		W,								
		ppm	15.8	27.6	29.8	25.4				
10	**S/N 57116**									
	200MVA 330/15.75 AB, 28 years in operation	t,°C	60	70	70	70	IV	2.4	3 mm - 2.3	----***
		W,								
		ppm	70	77.8	58.5	68.8				
11	**S/N 60855**									
	200 MVA 330/15.75 AB, 27 years in operation	t,°C	40	70	70	70	IV	2.8	3 mm - 2.8	36
		W,								
		ppm	24	44.2	47.2	49.0				
12	**S/N 8498**									
	250MVA 220/15.71 AB, 12 years	t,°C	25	65	65	65	IV	2.3	2 mm - 2.5	
		W,								
		ppm	18	42	44	48				23

	in operation									
13	**S/N 106246**									
	250MVA 400/15.75 M, 14 years in operation	t,°C	40	65	65	65	IV	<1.0	3 mm outer barrier 4.75	27.7
		W,								
		ppm	15	32	35	35				
14	**S/N 401430**									
	26MVA 150/13 AB, 46 years in operation	t,°C	0	65	65	65	IV	~4	----***	----***
		W,								
		ppm	30.2	61	61	57				

Preservation:
* - M (Membrane sealed);
* - AB (Air breather).
** - samples of pressboard of different thickness.
*** - no data.