by Y. Ohki

Development of "Top-Runner" Distribution Transformers Using Palm Fatty Acid Ester Insulating Oil

The government of Japan inaugurated in 1998 a unique program called "the Top Runner Approach" for improving the energy efficiency of end-use products and for developing the most energy-efficient products in the world [1]. At the start of this program in April 1999, nine products including passenger automobiles and air conditioners were chosen as targets. In December 2002 power transformers were added as targets, and six other products such as automated vending machines and gas cooking ranges.

Fuji Electric, Tokyo, has for many years been making and selling top-runner transformers with various output capacities. The company has been using both mineral oil and palm fatty acid ester (PFAE) oil for electrical insulation in these transformers. Until recently PFAE oil was used mainly in medium or large capacity transformers, and mineral oil was used mainly in small capacity transformers. PFAE oil is more environmentally friendly than mineral oil, i.e., PFAE oil is bio-decomposable and therefore is less hazardous to the environment in the event of oil leakage. Accordingly, Fuji Electric decided to extend the use of PFAE oil to air-seal type transformers of small capacity, since their production is very large compared to that of large capacity transformers. Figure 1 shows a typical Top-Runner distribution transformer.

Figure 1. A Top-Runner distribution transformer.

Degradation of the insulating oil in a power transformer must be prevented. For this purpose a diaphragm-seal type conservator using thin rubber is incorporated in large capacity transformers, while a diaphragm seal type conservator and the nitrogen seal method are used in medium capacity transformers. The air seal method, which is widely used in distribution transformers, does not need auxiliary equipment, so that transformers using this method are strongly competitive in price.

Hokuriku Electric Company Ltd., Toyama, Japan, and Fuji Electric together manufacture the new distribution transformer. Fuji Electric is an investor in Hokuriku Electric Company. The two companies carried out much research and conducted many tests while developing the new transformer. They compared various properties such as oxidation stability, kinetic viscosity, thermal stability, partial discharge inception voltage, relative

Table 1. Specifications of the four tested transformers

Single phase, 100 kVA, 60 Hz		
Voltage (primary/secondary): 6,600 V/210–105 V		
Transformer	**Oil**	**Sealing**
A	PFAE[1]	N_2
B	PFAE	Air
C	Mineral	N_2
C	Mineral	Air

[1]PFAE = palm fatty acid ester.

Table 2. Concentrations of dissolved gases in oil (ppm) after the loading test					
Load factor	Dissolved gas[1]	Transformer			
		A	B	C	D
40%	O_2	1,790	19,629	3,262	16,892
	CO_2	285	569	422	759
	CO	23	85	46	101
	$H_2 + C_n$	4	5	5	7
	$CO + CO_2$	308	654	468	860
70%	O_2	1,554	12,158	1,860	14,775
	CO_2	717	1,533	1,186	2,008
	CO	41	215	85	164
	$H_2 + C_n$	4	9	7	12
	$CO + CO_2$	758	1,748	1,271	2,172
100%	O_2	1,253	1,787	1,531	1,613
	CO_2	5,178	9,797	7,243	11,869
	CO	81	678	104	447
	$H_2 + C_n$	9	23	27	68
	$CO + CO_2$	5,259	10,475	7,347	12,316
[1]C_n is the sum of the concentrations of CH_4, C_2H_6, C_2H_4, and C_2H_2.					

permittivity, volume resistance, and breakdown voltage across a wide range of vegetable oils, and decided to use PFAE oil for insulation [2].

The lifetime of a transformer is mainly governed by the tensile or elongation strength of the insulating paper wrapped around the coil wires. The degree of polymerization (DP) of the insulating paper is known to correlate well with its tensile strength. Therefore, DP is a mandatory test item. Another important item for power transformers is the volume of various gases dissolved in the oil. When insulating oil or insulating paper or both are degraded, various gases such as CO_2, O_2, CO, H_2, and hydrocarbon gases accumulate in the oil. Measurement of the volumes of these gases is therefore important.

Fuji Electric and Hokuriku Electric made four model transformers and conducted experiments to check their long-term reliability, focusing on DP and gas analysis. Table 1 shows the specifications of the four transformers. Transformers A and B used PFAE oil for insulation, while transformers C and D used conventional mineral oil. The transformers were tested using the "loading-back method," which is often used when at least two identical transformers are to be tested simultaneously. The magnetizing voltage was set at the normal operating voltage. The load factor was 40% for the first 120 days, 70% for the following 120 days, and 100% for the last 169 days.

Table 2 shows the gas analysis results. C_n is the sum of the concentrations of CH_4, C_2H_6, C_2H_4, and C_2H_2 [3]. It is reasonable that the volume of dissolved gases of O_2, CO_2, and CO are bigger

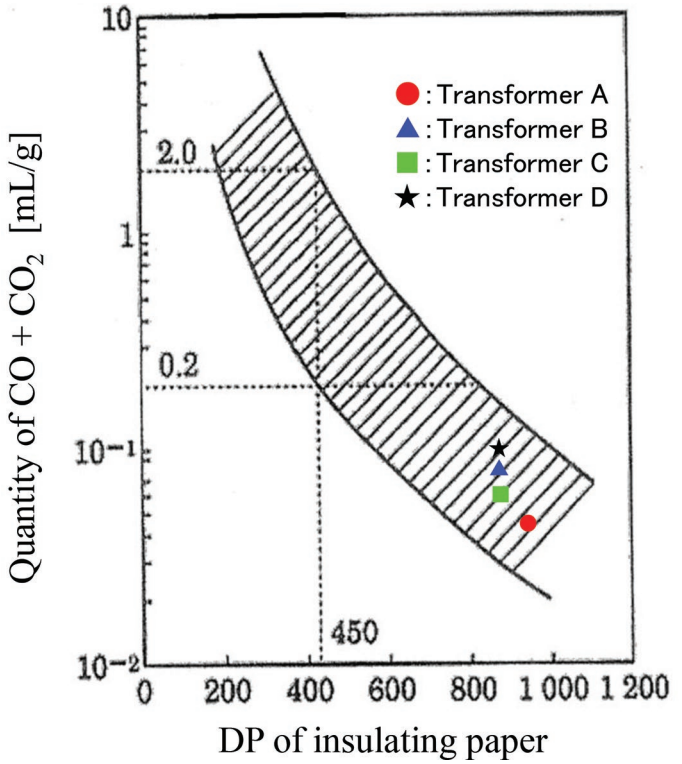

Figure 2. Relationship between the degree of polymerization (DP) of the insulating paper in the upper part of the windings and the total concentration of dissolved CO + CO_2.

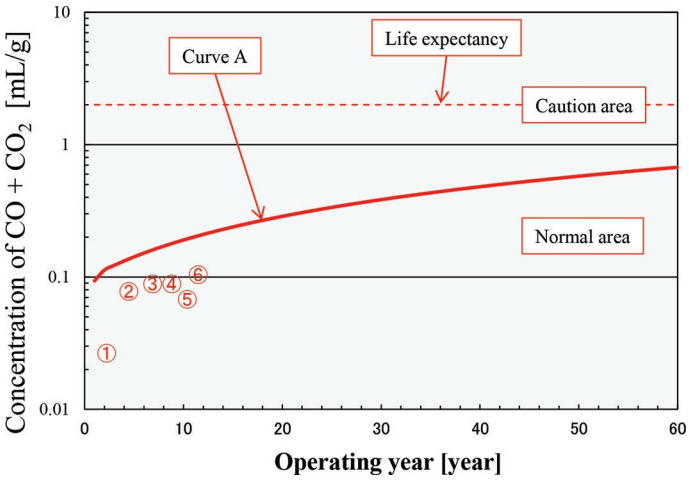

Figure 3. CO + CO_2 concentrations in six operating Top-Runner air-sealed type transformers as a function of time in service (years), shown as circled numbers 1 to 6. Curve A is a maintenance guideline.

in transformers B and D than in A and C, since B and D were sealed with air and A and C were nitrogen sealed. The sum of the concentrations of CO and CO_2 is lower in A than in C, and lower in B than in D.

Figure 2 shows the relationship between the DP and the sum of the concentrations of CO and CO_2 per unit mass (= 1.0 g) of the insulating paper. Note that this relationship is considered normal if each pair of points lies within the shaded area. PFAE was used in the nitrogen-sealed transformer A, and its DP value was higher than that of transformer C, which used a mineral oil.

Figure 3 shows the sum of the concentrations of CO and CO_2 measured in operating air-sealed Top-Runner transformers. The mass ratio of oil to cellulose is low in Top-Runner transformers compared to the same ratio in power transformers. The concentrations of the dissolved gases CO and CO_2 are therefore generally higher than those in other medium and large power transformers. Top-Runner transformers operating in the absence of faults might therefore be wrongly considered as faulty. Curve A in Figure 3 is a maintenance guideline for Top-Runner transformers. Each of the six transformers shows CO + CO_2 concentrations well below curve A, suggesting lengthy life expectancy.

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