

Secado de Bobinados de Transformador de Potencia Energizado con Sistema Automatizado de Tamiz Molecular Reciclable

(Power Transformer Winding Drying-out with Automated Recyclable Molecular Sieve System)

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Abstract — This paper presents a new drying-out system for the paper insulation of power transformers in service by using recyclable molecular sieve filters. The system has on-line sensors which monitor the water content of the inlet and outlet oils. This allows quantifying the amount of water extracted. Data presented in the paper show the positive results obtained by the application of the drying-out system on in-service transformers.

Index Terms— transformer – paper insulation – drying-out – on-line monitoring – molecular sieve – recycling

I. INTRODUCTION

THE paper insulation system of power transformers is dried out during factory manufacturing process down to a water content value as low as 0.3% typically. Ever since a transformer unit is placed in service, the water content of its paper increases on a continuous basis. There are two major causes which contribute to the increase of the water content of paper insulation:

- contamination with atmospheric moisture
- paper and oil degradation

The insulating oil is a means of moisture transfer within the transformer. Though moisture is usually in the dissolved form in the oil, it can also be adsorbed to solid particles such as cellulose fibers. The concentration of polar degradation by-products of the oil increases as it ages, and so does the solubility of water in the oil.

The thermodynamic equilibrium between the water adsorbed to cellulose particles and the water dissolved in the oil is favored if the oil temperature is kept high the longer the possible.

Small temperature increases or decreases can change the water content of the oil, but they have little effect on the water content of paper insulation where most part of the moisture is retained.

A very encompassing study on moisture within transformer insulation systems will be published shortly by CIGRE Working Group A2-30 [1].

II. MOISTURE ASSESSMENT

A. Solubility of Water in Mineral Oils

The solubility of water in mineral oils is dependent both on temperature and on the oil oxidation level. Table I presents test results obtained by three different laboratory studies [2-4] and IEC 60422 Mineral Insulating Oil in Electrical Equipment – Supervision and Maintenance Guidance [5], which compares solubility values obtained both from an unused oil with 0.03 mg KOH/g acid number and an oxidized oil with 0.30 mg KOH/g acid number.

TABLE I
WATER SOLUBILITY IN INSULATING OILS ACCORDING TO
DIFFERENT REFERENCES [2-5]

TEMP. (°C)	WATER CONTENT OF OIL (PPM)				
	Oommen [2]	Griffin [3]	Shell [4]	IEC 60422 [5]	
				Unused Oil	Oxidized Oil
20	53	56	55	55	70
30	82	83	84	82	118
40	122	122	124	120	200
50	179	174	180	172	-

B. Equilibrium Diagrams

Equilibrium diagrams correlating the water content of oil (ppm) with the water content of paper insulation (%) were proposed by different authors [2-3, 6]. Table II presents test results obtained by three different laboratory studies.

TABLE II
WATER CONTENT OF PAPER INSULATION ACCORDING TO

RVP-AI/2008 – TRO-02 PONENCIA RECOMENDADA
POR EL **COMITÉ DE TRANSFORMADORES**
DEL **CAPÍTULO DE POTENCIA DEL IEEE SECCIÓN MÉXICO** Y
PRESENTADA EN LA **REUNIÓN DE VERANO, RVP-AI'2008**,
ACAPULCO GRO., DEL 6 AL 12 DE JULIO DEL 2008.

EQUILIBRIUM DIAGRAMS FROM THREE REFERENCES [2-3, 6]

Water Content of Oil/ Temperature	WATER CONTENT OF PAPER INSULATION (%)		
	Oommen [2]	Griffin [3]	Fabre & Pichon [6]
10 ppm 30°C	3.1%	4.0%	3.4%
10 ppm 70°C	1.0%	1.0%	1.1%
60 ppm 60°C	2.9%	5.0%	4.5%
80 ppm 70°C	2.7%	3.8%	3.8%

C. Estimate of the Water Content of Paper Insulation

The water content of paper insulation can be estimated by using equilibrium diagrams. For example, a power transformer containing 10,000 liters of oil with a specific gravity at 20/4°C equal to 0.88 will have a corresponding mass of 8,800 kg of oil. A rough estimate of paper insulation mass corresponds to 10% of the oil mass, which is 880 kg of paper in this case. The average oil temperature can be obtained by summing up the top oil temperature and that of an oil sample collected from the transformer bottom oil-outlet valve, and dividing the resulting sum by two. If the average oil temperature is assumed to be 45°C and the water content of the oil is 40 ppm, the moisture content of the paper insulation is estimated to be 3.5% in accord with the equilibrium diagram published by Fabre and Pichon [6]. This means that the paper insulation of the example has approximately 30.8 liters of water. In order to reduce the moisture content of the paper insulation down to 2%, around 13.2 liters of water must be extracted. After finishing the drying-out process, the water content of the oil would have to be 18 ppm at 45°C reference temperature.

The use of equilibrium diagrams is valid only under equilibrium conditions. Depending on the temperature established, the equilibrium can be obtained after weeks or even months. As this is very difficult to obtain under field real conditions, we have developed our own method to calculate the moisture content of paper insulation by using the water content of the oil, the water relative saturation in the oil (%), and the oil temperature supplied by on-line data acquisition sensors [7].

III. ON-LINE PAPER INSULATION DRYING-OUT SYSTEM FOR POWER TRANSFORMERS

A. On-line Paper Insulation Drying-out Mechanism

The moisture removal from transformers is conducted by means of the insulating oil and the consequent migration of moisture from the paper insulation into the oil. This process is temperature dependent. Diffusion time depends on various factors such as oil type, paper insulation thickness, oil cooling system, oil oxidation level and temperature. There are several

paper insulation drying-out systems for field use. All of them employ the method of removing moisture from oil and its consequent redistribution in the paper insulation system.

B. Recyclable Molecular Sieve Drying-out System

The removal of moisture from insulating oil by using molecular sieve adsorbents is a very effective process. However, the adsorbent materials available in the Brazilian market are not recyclable. We have developed molecular sieve adsorbents produced from carbon and ceramic raw materials based on the literature [8]. Also a totally automated and unattended oil drying-out system was designed using the adsorbents developed.

The drying-out system (Figure 1) is connected to the transformer outlet valve at the bottom of the main tank, the oil is pumped through the system filters, and then back to the transformer into the outlet valve at the bottom of the oil expansion tank. The system valves are automatically controlled in order to avoid any oil leaks. Both inlet and outlet oil parameters such as temperature (°C), water content (ppm) and relative saturation (%) are monitored by the system. Figure 2 shows the control panel. Finally the data collected are remotely sent to the utility operations center. Such data can also be accessed remotely by a cell phone (Figure 3).



Fig. 1. Drying-out system installed on an in-service power transformer



Fig. 2. View of the drying-out system data-monitoring sensors and control panel



Fig. 3. Schematic diagram of the drying-out system data processing

C. Field Application Examples

On May 26, 2006 the system was installed in the field to dry the paper insulation of a free-breathing, 138/13.8 kV, 18.75 MVA power transformer, 18,700 liters of oil, manufactured in 1971. The drying-out process was concluded on September 9, 2006. The total amount of water extracted was 18.6 liters.

Table III shows the estimated water content of the paper insulation based on the calculation method developed by us [7].

TABLE III
ESTIMATED WATER CONTENT OF PAPER INSULATION

Date	Water content of oil (ppm)	Estimated water content of paper (%)
July 8, 2005	15	3.0
Sept.10, 2006	4	1.2
April 5, 2007	6	1.4

Table IV shows the amount of water extracted from 12 power transformers installed on the power system of Elektro, a power distribution utility whose service area is scattered through various counties in the State of Sao Paulo, Brazil. As can be seen in the table, the amount of water removed ranged from 9.14 up to 43.80 liters. The operation of the drying-out system is very simple since its filters can retain up to 25 liters of water without the need of replacement. Also, it is possible to assess filter performance by monitoring the water content of

both the inlet and the outlet oils. The transformers shown in Table IV were dried in 2006 and 2007, and the water content of their oil has been kept at approximately the same levels ever since. This confirms that their paper insulation was dried effectively.

TABLE IV
WATER VOLUME EXTRACTED FROM THE OIL OF 12 POWER TRANSFORMERS

SERIAL NO.	VOLTAGE RANGE (kV)	RATED CAPACITY (MVA)	OIL VOLUME (L)	WATER VOLUME EXTRACTED (L)
1845	69/13.8	12.5	6,100	27.41
30569	69/13.8	2	2,900	9.14
53093	69/13.8	2	3,874	9.32
7635	88/13.8	12.5	9,600	28.26
53374	138/13.8	12.5	16,300	30.60
8016	88/13.8	9	13,000	24.35
17483	138/13.8	18.75	18,700	21.78
500390	69/13.8	9	5,250	14.90
500138	138/13.8	12.5	11,800	20.78
33396	138/13.8	12.5	12,500	14.07
500372	138/13.8	30	12,950	43.8
55888	138/13.8	18.75	15,000	38.80

IV. CONCLUSIONS

An automated drying-out system for paper insulation using recyclable molecular sieve filters was developed to be employed in operational power transformers. The system is very effective in drying the paper insulation of wet transformers. The performance of the drying-out system can be monitored on-line and accessed remotely. The operation of the system is very simple since its filters can retain up to 25 liters of water without the need of replacement. Thirteen power transformers, rated 2-30 MVA, were dried in 2006-2007, and the amount of water extracted from each one of them ranged from 9.14 up to 43.80 liters. The water content of their oil has been kept at approximately the same levels ever since.

V. REFERENCES

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VI. BIOGRAPHIES

Aparecido dos Reis Coutinho (non-member) was born in Cabo Verde, Brazil, on November 11, 1956. He graduated from the University of Sao Paulo State (UNESP), Brazil, obtained his Ph.D. degree from the University of Campinas (UNICAMP), Brazil, and a post-doctorate degree from the Technological Institute of Aeronautics (ITA), Brazil.

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Dr. Coutinho received two honorary prizes: “I Premio Petrobras de Tecnologia” and “Bayer Young Environmental Envoy, organized by PNUMA-UNO” both in 2005. He was chair of the 1st Brazilian Carbon Congress (2002), and is a honorary member of the Brazilian Carbon Society.

Claudio Aparecido Galdeano (non-member) was born in Jundiá, Brazil, on August 3, 1955. He obtained his BS in Chemical Engineering from the Oswaldo Cruz College, Brazil.

Mr. Galdeano worked at the Quality Control Laboratory of TUSA Transformers in Brazil for 8 years. He also worked at Eletropaulo, a Brazilian power utility, for 20 years, as the Manager of the Insulating Oil Laboratory and the Oil Reclamation Plant. Since 2003 he has been the president of MGM Diagnosticos, Brazil.

Armando Bassetto F. (non-member) was born in Campinas, Brazil, on April 26, 1958. He obtained a BS in Civil Engineering from the Pontific Catholic University of Campinas (PUCAMP), Brazil, a BA in Chemistry from the Methodist University of Piracicaba (UNIMEP), Brazil, and a Ph.D. degree in Chemistry from the University of Sao Paulo (USP), Brazil.

Dr. Bassetto worked at CPFL, a Brazilian power utility, for 20 years, as an engineer responsible for developing new maintenance techniques of power transformers. In the last 10 years he has worked as consultant scientist responsible for developing several research and development projects for Brazilian power utilities.

Jose Henrique C. Hossri (non-member) was born in Pedreira, Brazil, on November 22, 1964. He obtained his BS in Chemistry from the Methodist University of Piracicaba (UNIMEP), Brazil.

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