A Diagnostic Method for the Service Span of Oil - Immersed Transformer with EXCEL Application Software

Ming-Jong Lin

Abstract— for the safety and reliability of operation in power systems, oil-immersed transformer's service span needs to detect strictly on a regular basis for the purpose of transformer safety diagnosis. On the review of the existing diagnostic approaches of oil-immersed transformer for aging or deterioration of insulation material, the gases of CO, CO_2, 2-Furaldehyde, 2-Furfuryl alcohol, 2-Acetyl Furan, 5-methyl-2-furaldehyde, and 5-Hydroxymethyl-2-Furaldehyde, are among the wildly used ones. The concentration of CO_2 and CO is been taken from the Dissolved Gas Analysis and the remaining gases taken from the IEC-1198 or ASTM D 5837. The concentration of those gases can inspect from a few of insulating oil out and know how long still leave of the service span of oil-immersed transformer is. The paper focuses on a diagnosis method for the service span of oil - immersed Transformer with EXCEL application software. Finding an accurate, effective and convenient method is motivating by how to improve diagnosis of transformer's service span. In some cases, the feasibility of the tool has undergone verification. The main advantage of the method is the effective diagnosis of transformer's service span by a form-reported computer program closely.

Index Terms— Oil - Immersed Transformer, Dissolved Gas Analysis (DGA), High-Performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC/MS), Furfural.

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1 INTRODUCTION

O NCE the transformer aging or deterioration is prone to failure, when the degradation or collapse point turn to find those gases of contents, its depends on the gas detection of annual oil and the detection data of 2-Furaldehyde every 2 or 3 years as the basis for diagnosis.

Currently, domestic and international reports show the service span of oil-immersed transformer with at least 35 to 40 years in normal operation. However, some large-scale transformers still operate normally for more than 63 years. Therefore, the service span of the transformer still depend on its internal insulation material including insulating paper deterioration as a diagnostic tool for determining the replacement of a new one. However, to achieve this goal, it is essential to follow the maintenance manual guide on a regular basis in order to take the insulating oil detected and to find the trend of change in gas content within the transformer, thereby to take an effective prevention as soon as possible.

2 BACKGROUND

Before 1993, the ratio of gas content of CO_2 to CO applied as the diagnosis of the pros and cons for insulating materials such as insulating paper in oil-immersed transformers. The transformer service span is analyzed accordingly.

The concentration of furfural is very low in new equipment

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or normal operation of oil-immersed transformer. The concentration of furfural is very low in new equipment or normal operation of oil - immersed transformer. The cracking or deterioration of the original cellulose of transformer insulation has transformed into a variety of furfural compounds, so that the concentration of furfural contained in the insulating oil becomes high, which means that the insulating material and the insulating paper are deteriorated. In this case, a new diagnostic method is developed as the method for analysis and detection of furfural in Insulating Oil is issued by IEC in 1993, known as the standard of IEC-1198.

Then, the United States also followed up with the announcement of the furfural diagnostic method (ASTM D-3612) in 1995, using the furfural concentration as an indicator of transformer aging or insulation deterioration. Those gases-the concentration of each gas of 2-Furaldehyde (2FAL), 2-Furfuryl alcohol (2FOL), 2-Acetyl Furan (5H2F), 5-Methyl-2-Furaldehyde (5M2F), and 5-Hydroxymethyl-2-Furaldehyde (2FAL) are dissolved from the transformer's insulating oil which only require the quantity of 10 c.c., taken from running transformer.

Then concentration of those gases is compared with previous data to diagnose the text which the as analysis is based on. The standard of IEC-1198 introduced a method for measuring, using high performance liquid chromatography as a paper-specific indicator of degradation from the concentration of furfural in transformer insulating oil. The paper of furfural is a special paper, which acts as an indicator to complement what is reduced from of Dissolved Gas Analysis.

These papers have been polished in conference or journal, which are discussed for the service span of oil - immersed transformer. The titles of papers include "Determination of Paper Degradation By-products by Direct Injection on an HPLC Column," "New Approach to Estimate Furan Contents in Transformer Oil Using Spectroscopic Analysis, "The experience of DP and Furan in Remnant Life Assessment of Power Transformer," and "Study on the Paper Ageing in Transformer Oil Using Furfural Concentration".

3 STANDARD DIAGNOSIS

3.1 STANDARD FOR TAIWAN POWER COMPANY

Before 1993, there was no standard method for the furfural of transformer's insulating, the diagnostic method only followed the maintenance manuals issued by Taiwan Power Company. If $CO_2 / CO \leqq 7$ ppm and $CO \geqq 350$ ppm or $CO_2 \geqq 10000$ ppm, it will start to draw attention. As for $CO_2 / CO \leqq 3$ ppm and $CO \geqq 500$ ppm or $CO_2 \geqq 10000$ ppm and $CO_2 \geqq 10000$ ppm, the raise rate for $CO_2 \geqq 1000$ ppm or $CO \geqq 570$ ppm per month will be determined as abnormal. For clearing purpose, those gases are shown in Table 1.

In brief, the ratio of CO_2 and CO is under 3 or over 10 suggest an abnormal condition of the transformer. [1], [2], [3]

TABLE 1

THE STANDARD OF DIAGNOSIS OF CO_2/CO UNIT: PPM

The standard of diagnosis of CO_2 and CO for Taiwan Power Company units: ppm				
Gas name	CO_2	CO	CO_2/CO	Condition
Quantity of gas	>=10000	/	/	attention
Quantity of gas	/	>=350	<=7	attention
Quantity of gas	/	>500	<=3	Abnormal
Quantity of gas	/	/	>10	Abnormal
Quantity of gas	>10000	>570	/	Abnormal

3.2 Standard for IEC 1198 and ASTM D5837

Those gases of 2-acetyl furan, 2-furfural, 5-methyl-2-furfural, 5-hydroxymethyl 2-furfural, and 2-furfurylalcohol are measured by High-Performance Liquid Chromatography (HPLC) or Gas Chromatography-Mass Spectrometry (GC/MS) based on the standard of ASTM D 5837.
The concentration of furfural of transformer's insulating oil is as a paper-specific indicator of degradation and a method for measurement using high performance liquid chromatography now are standardized (IEC 1198). [4]. [5]. In case any those gases experience a significant sudden increase in concentration, it is confirmed that a hot spot inside the transformer exists and it is necessary to open the cover of transformer for detailed inspection.

The degree of polymerization (DP) of paper insulation has

from 1000 to 1200 units of that belong to normal, once it drop up under 200 units belong to abnormal.

The same gas for any of five gases that compared with the last, if the value was over 350 ppm of that meant the transformer, which must be to shut down for maintenance. [6]

4 A DIAGNOSTIC FORM-REPORTED

For the purpose of reliability and quality of power supply, this paper proposes an effective technique for the estimation of the transformer's service span from insulating oil. A from - reported has been developed through the application software of EXCEL, which diagnoses the transformer's service span from the concentration of gases-CO_2, CO, 2-Furaldehyde, 2-Furfuryl alcohol, 2-Acetyl Furan, 5-Methyl-2-Furaldehyde, and 5-Hydroxymethyl-2-Furaldehyde.

4.1 FLOW CHART OF PROGRAM

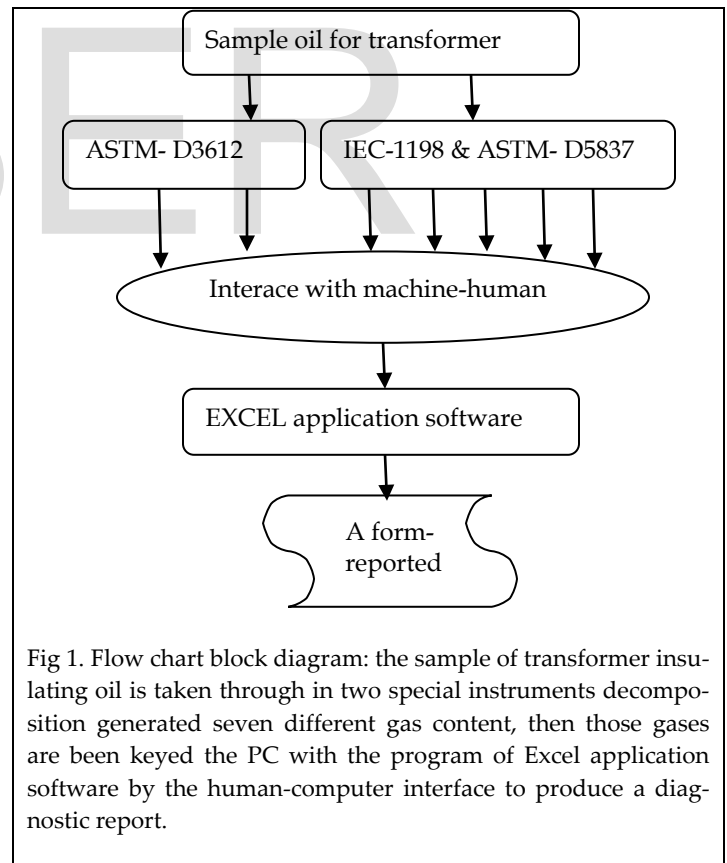The flow chart of the diagnostic method is been shown in Figure 1.

Fig 1. Flow chart block diagram: the sample of transformer insulating oil is taken through in two special instruments decomposition generated seven different gas content, then those gases are been keyed the PC with the program of Excel application software by the human-computer interface to produce a diagnostic report.

4.2 The Explain of Program

This diagnostic program of design meets the specification of IEC 1198, ASTM D5837, and Taiwan Power Company, when developed from the personal computer of this form-reported

sheet, as shown in Table 2 and 3. Of the content of columns are explained below. Several columns used for diagnosis and analysis are hidden in the program, which restricts the attitude of length.

TABLE 2
THE RESULT OF ANALYSIS FOR THE RATION OF CO_2/CO UNIT: PPM

The diagnostic method for service span of oil-immersed transformer units: ppm					
No	Date	CO_2	CO	CO_2/CO	Result
1	2	3	3	4	5
	2	3	3	4	5

TABLE 3
THE RESULT OF DIAGNOSIS FOR FURFURAL UNIT: DP(UG/L)

The diagnostic method for service life of oil-immersed transformer units: DP(ug/L)							
No	Date	A	B	C	D	E	Result
1	2	3	3	3	3	3	5
	2	3	3	3	3	3	

Symbol Description : A. 2FAL、 B. 2FOL、 C. 5H2F、 D. 2ACF、 E. 5M2F、 1.Equipment's name、 2.Detection's date、 3.The quantity of gas、 4.The ration of value、 5.The result of diagnosis

TABLE 4
THE RESULT OF ANALYSIS FOR THE RATION OF CO_2/CO UNIT: ppm

The diagnostic method for service life of oil-immersed transformer units: ppm										
No	Date	CO_2	CO	CO_2/CO						Result
# 1MTr	11/23,2016	35800	17	11.12	0	0	0	1	0	Well
	11/18,2017	2436	171	14.25	0	0	0	1	0	Well
# 2MTr	11/23,2016	4375	25	175.00	0	0	0	1	0	Well
	11/18,2017	4377	25	175.08	0	0	0	1	0	Well
# 3MTr	11/23,2016	1596	171	9.33	0	0	0	0	0	Well
	11/18,2017	1441	29	49.69	0	0	0	1	0	Well

The CO_2, and CO gases must pass the "Instructment of Decomposition Chromatography" and the remaining gases must pass the "Instructment of IEC 1198 or ASTM D5837" in order to separate from the sample insulating oil. The diagnostic result meets the conventional and IEC 1198 standards on one sheet; using the machine-human interface as input and text and graphics as output for diagnostic basis.

It shows of the result from Table 4, if it were shown (Degradation), which represents the transformer that needs to be shut down for maintenance, On the contrary is normal (Well). Table 5 shows that the concentrations of three different one as being used for analyzing the result of diagnosis by text. The form - reported sheet is shown in Table 3 (for CO2, CO) and Table 4 (for Furfural) . [7]

TABLE 5
THE RESULT OF DIAGNOSIS FOR THE FURFURAL   UNIT: DP (UG/L)

The result of diagnosis for Furfural unit: DP(ug/L)												
No	Date	A	A'-A	B	B'-B	C	C'-C	D	D'-D	E	E'-E	Result
# 1MTr	11/23,2016	25		0		0		0		0		
			0		0		0		0		0	Well
	11/18,2017	32		27		0		0		0		
# 2MTr	11/23,2016	0		9		0		0		0		
			0		0		0		0		0	Well
	11/18,2017	0		16		0		1		0		
# 3MTr	11/23,2016	3		9		0		0		0		
			0		0		0		0		0	Well
	11/18,2017	40		16		0		1		0		

Symbol Description : A. 2FAL、 B. 2FOL、 C. 5H2F、 D. 2ACF、 E. 5M2F、 A'-A(the value for preious -present)

5 VERIFY

The operation of these three oil-immersed transformers is currently normal in Tainan substation of Taiwan Power Company. To verify, the historic data of three sets of oil-immersed transformer were taken for comparison (detail data as shown in Table 4) while, the diagnostic results were all "Well" status.

There were two failures in oil-immersed transformer, where one accident failure of a shunt reactor of transformer had occurred in November 2012, and the other one had occurred in April 2016, after, each transformer's insulating oil was sampled for detection. The data of Case A were CO_2 (22983 ppm) and CO (925 ppm), and Case B were CO_2 (1530 ppm) and CO (542 ppm), where that the results for those gas of data passing through the program are shown in Table 6.

These were cases uncovered for inspection. Case A occurred on November 12, 2012, and Case B occurred on April 12, 2016, The result of Case A showed the deterioration of the insulation material, discovering arc – discharged by conductor-metaled bare, as shown as Fig 2. For Case B, short circuit of interlayer insulation for winding was found as a result of deterioration of the insulating paper, as shown as Fig 3. Since the service only operated for a period of ten years in power system, there was gas of data that could provide the analysis of the trend curve. Thus, this method was concluded as feasible for the diagnosis of the insulating oil in the estimation of transformer's service span.

Fig 2. A fault of Arc-discharged was yielded due to the insulation deteriorated.

Fig 3. The short circuit fault was copper wire-exposed yielded because the insulation paper deteriorated between winding the insulation layer.

TABLE 6
. THE RESULT OF ANALYSIS FOR TWO ABNORMAL A & B CASES   UNIT: PPM

The result of analysis for the ration of CO_2/CO unit: ppm										
No	Date	CO_2	CO	CO_2/CO						Result
A	10/11,2012	22983	925	24.85	1	1	0	1	1	Degradation
B	12/04,2016	1530	542	2.82	0	1	1	0	1	Degradation

6 CONCLUSION

This evaluation form is based on the change ratio of CO and CO_2 gas content in oil gas decomposition. The content of five - gas is been generated after decomposition from the Furfural what can provide detection and analyze the basis of the service span of the transformer. The accuracy of this diagnostic method was up 100% when been verified by 3 normal and 2 faulty of instances.

The characteristics are summarized as follows:

1. A diagnostic form is been generated from those gases of CO, CO_2, 2-Furaldehyde, 2-Furfuryl alcohol, 2-Acetyl Furan, 5-methyl-2-furaldehyde, and 5-Hydroxymethyl-2-Furaldehyde when performed using EXCEL application software.

2. The rate of changing value for CO and CO_2 can be detected from the analysis of transformer operative annually.

3. Those results of diagnosis are revealed from those gases – concentration of 2-Fur aldehyde, 2-Furfuryl alcohol, 2-Acetyl Furan, 5-methyl-2-furaldehyde, and 5-Hydroxymethyl-2-Furaldehyde are taken every 2 or 3 years.

4. The method is easy to operate and was verified through the performance of dual inspection and can increase the accuracy of detection. Consequently, it is feasible as a diagnostic tool for the service span of oil-immersed transformers.

5. Table 4 and Table 5 are shown on the same sheet for being easy analysis. This is shown as in Table 7.

6. The adoption of the specification of IEC-1198 or ASTM D 5837, only requires a few of quantity of insulating oil.

TABLE 7
THE DIAGNOSTIC METHOD FOR SERVICE SPAN OF OIL- IMMERSED TRANSFORMER

The diagnostic method for service span of oil- immersed transformer											
The result of analysis for the ration of CO_2/CO unit: ppm											
No	Date	CO_2	CO	CO_2/CO						Result	
# 1MTr	11/23,2016	2354	25	94.16	0	0	0	1	0	Well	
	11/18,2017	2436	171	14.25	0	0	0	1	0	Well	
# 2MTr	11/23,2016	4375	25	175.00	0	0	0	1	0	Well	
	11/18,2017	4377	25	175.08	0	0	0	1	0	Well	
# 3MTr	11/23,2016	1596	171	9.33	0	0	0	0	0	Well	
	11/18,2017	1441	29	49.69	0	0	0	1	0	Well	

The result of diagnosis for Furfural unit: DP(ug/L)											
No	Date	A	A'-A	B	B'-B	C	C'-C	D	D'-D	E	E'-E	Result
# 1MTr	11/23,2016	25	0	0	0	0	0	0	0	0	0	Well
	11/18,2017	32		27		0		0		0		
# 2MTr	11/23,2016	0	0	9	0	0	0	0	0	0	0	Well
	11/18,2017	0		16		0		1		0		
# 3MTr	11/23,2016	3	0	9	0	0	0	0	0	0	0	Well
	11/18,2017	40		16		0		1		0		

Symbol Description : A. 2FAL、 B. 2FOL、 C. 5H2F、 D. 2ACF、 E. 5M2F、 A'-A(the value for preious -present)

			Each Furfural gas changes curve units: DP(ug/L)					
			A	B	C	D	E	
	# 1MTr	Preious	25	0	0	0	0	
		Present	32	27	0	0	0	
			A	B	C	D	E	
	# 2MTr	Preious	0	9	0	0	0	
		Present	0	16	0	1	0	
			A	B	C	D	E	
	# 3MTr	Preious	3	9	0	0	0	
		Present	40	16	0	1	0	

ACKNOWLEDGMENT

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