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Combines the method of Duval Triangle 2 and theory of Correlation Coefficient to Diagnose the Operation Status in On–Load Tap Changers' Equipment with Dissolved Gases Analysis

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Abstract—**this paper takes advantage of the characteristics theory of the correlation coefficient to develop a practical approach of diagnosis On–Load Tap Changers' Operation Status in oil-immersed transformer. In this paper, three references data were taken as the random variables of correlation coefficient from the literature of the ANSI/IEEE C57.139 specification, namely – the danger level of it's for the threshold dataset, coking and arcing of failure datasets. Those references performed correlation coefficient with the sample oil data in a program individually. This approach was been verified from the databases of IEC TC 10 database and Taiwan Power Company, which has the accurate degree better than tradition approaches. The advantage of this approach is not only shows each gas concentration of the sample data and the reference data, but also the diagnostic text on report. The accurate degree is confirmed up 96.1% from IEC TC 10 database and Taiwan Power Company data. Thus it illustrates that it can an alternative tool for On–Load Tap Changers' Operation Status diagnosis.**

Index Terms—Oil - Immersed Transformer, Dissolved Gas Analysis (DGA), On–Load Tap Changers' (OLTC), Correlation Coefficient , IEC TC 10 database , ANSI/IEEE C57.139 Specification.

1 INTRODUCTION

OIL-immersed transformer, one of the most important equipment in a power system, according to th specification ANCE/IEEE C57.104, it must be monitored and diagnosed as a regular basic to assure its reliable operation. Then the on – load tap changers' is its subsidiary equipment, its purpose is responsible for voltage regulation. It is the only movable part of a transformer because the switching of load current from one tap position to other tap can result in heating and arcing. Therefore, it suffers from various ageing mechanisms. The insulating oil inside the tap changer compartment becomes dirty due to switching arcs, which leads to weakened insulation properties. The increased contact resistance due to the oil film layer can cause coking (creation of hard and porous carbon material) at places where the load current flows [1].

In order to effectively implement preventive maintenance, regularly detect the on–load tap changers' insulation oil of transformer to understand the status of equipment, the hiding weakness can be found which main goal for this paper is. For this purpose, a large amount of data should be collected to establish background information which can provide discussible and analytic data in future. This background information was been diagnosed with the ANSI/IEEE C57.139 specification, and Duval triangle 2 was to analyze on the OLTC's insulating oil. Those methods have been used along the years in electrical utilities around the world but there have still some lacks in.

A new approach has been proposed to overcome the limitations posed by Duval triangle 2. Insulating oil of the body and on-load tap changers of diagnosis approach in transformer is very different. For study, lots of OLTC maintenance instructions that were investigated from manufacturers and literature [2]-[3].

A lot of diagnostic approaches were collected from researching about the diagnostic approach of OLTC's insulating oil. A practical approach with the characteristics of the correlation coefficient was come up to diagnose. This diagnostic approach requires the same parameters of three sets to take advantage of the principle of the correlation coefficient for comparison.

Among the parameters of two reference sets were extracted from the literature of ANSI/IEEE C57.139 specification that were data of actual fault in the past. So that this approach can be applied to diagnose the status of OLTC operation by insulating oil.

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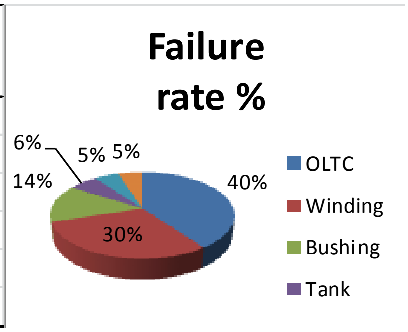
2 Transformer Insulation Oil Detection Background

We learned from the database of literature, which detective components of oil-immersed transformers according to a CIGRE international survey, the failure statistics was shown in Table 1. Lots of methods have been proposed for diagnosis in oil-immersed transformer with dissolved gas analysis of insulating oil.

Table 1

The ration of fault of oil-immersed transformer

Failure Condition	Failure rate %
OLTC	40
Winding	30
Bushing	14
Tank	6
Core	5
Auxiliary	5



The Duval triangle 2 is only a method for being insulating oil of OLTC equipment; it is been described in the ANSI/IEEE C57.139 specification. It can assist the technician in charge of the OLTC's equipment and maintenance decisions by being evaluate the condition of OLTC without de energize. The accuracy and the analysis of diagnosis and timely repairs of OLTC can avoid a huge disaster of transformer.

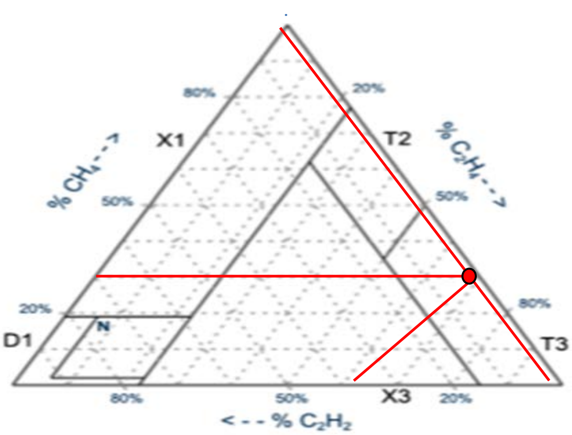


Fig 1 A diagnostic point on the Duval triangle 2,which is shown how to calculate the condition of diagnostic point from Duval trangle 2 method.

In terms of The Duval Triangle 2, what a diagnostic approach is widely used in insulating oil of OLTC equipment. It is dividend sex regions to show what fault typical, which is shown in Table 2. Being calculation is shown in Table 3. In order to verify the diagnostic mode, a failure case was taken from the specification of ANSI/IEEE C57. 139, the data is shown in Table 4, according to the steps of Duval triangle 2 calculated the cross point which was plotted at T3, as shown in Figure 1 ; then paper approach diagnosed what the set data has condition abnormal in too.

Table 2

The regions of Duval Triangle 2

Diagnostic zone	Diagnostic result	Recommended action
N	Normal	/
T3	Severe thermal fault T3 (T > 300℃), heavy coking.	Change the oil an inspect the LTC for coking of contracts
T2	Severe thermal fault T2 (300 < T < 700℃), coking.	
X3	Fault T3 or T2 in progress (mostly) with light coking or increased resistance of contacts or severe arcing D2	Test or inspect the LTC signs of light coking or resistance of contracts, or severe arcing
D1	Abnormal arcing D1 (outside of zone N)	Inspect the LTC for small signs of arcing
X1	Abnormal arcing D1 or thermal fault in progress	Are still under investigation

Note: to distinguish D2 from T3, rinse and change the oil. Run a few LTC operations (~100) then a DGA. If the DGA point remains at the same place as before changing oil, this may indicate a fault D2. If the DGA point has moved the left, a fault T3 is most likely.

Table 3

Method calculation for Duval triangle 2 (unit: ppm)

Gas concentration (%) for (X+Y+Z)	Method calculation for Duval triangle 2
CH_4	Y * 100 / (X + Y + Z)
C_2H_4	Z * 100 / (X + Y + Z)
C_2H_2	X * 100 / (X + Y + Z)

Abbreviation: X = C_2H_2 ; Y = CH_4 ; Z = C_2H_4

Table 4

The data and diagnostic result for Duval triangle 2 (unit: ppm)

H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
7425	52779	76848	122821	990	38
CH_4 (%) = 30		C_2H_4 (%) = 69		C_2H_2 (%) = 1	
Diagnostic zone		T3		Severe thermal fault T3 (T > 300℃), heavy coking.	
paper approach			Abnormal		

After studied, this paper took three sets data – one set data for the danger level of ANSI/IEEE C57.139 specification, other two kinds of fault status – coking and arcing of data form ANSI/IEEE C57.139 specification. The data of danger level regarded as "D/I", the data coking regarded as "A reference" (A/I), and the data of arcing regarded as "B reference" (B/I), any set data of those are

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taken in the program of the correlation coefficient as random variables.

3 Diagnosis Method

Because the OLTC operation must cut off the load current, the traditional diagnostic approach for the OLTC of transformer insulating oil, it only takes the ANSI/IEEE C57.139 standard and Duval triangle 2. After collecting relative literature for the diagnostic insulating oil, a novel diagnostic approach for the OLTC insulating oil was developed named correlation coefficient diagnostics method. In this paper, the variable value of the correlation coefficient formula was taken from each set's gas component such as H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, and CO.

3.1 Diagnosis approach chart flow

For the sake of brevity, the chart flow will be described with 13 boxes. As shown in Figure 2. Those symobles of abbrevation is interpretation in Table 5.

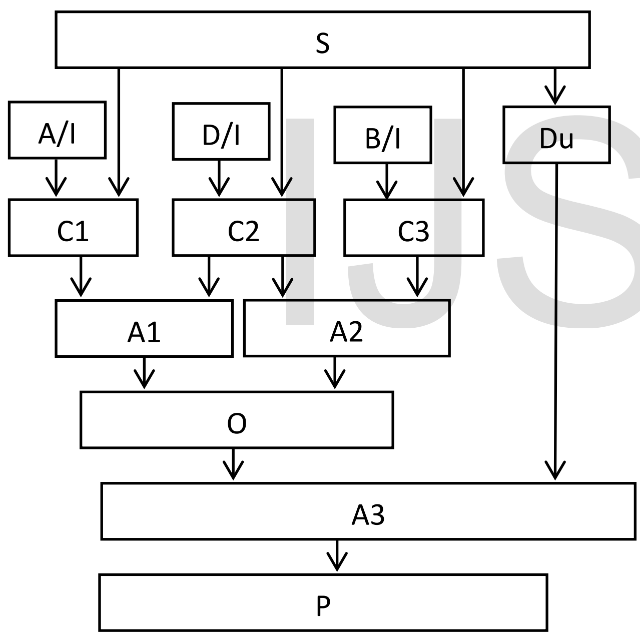


Fig 2 shows what each department 's function are relative with one another,that is the Diagnosis approach chart flow.

TABLE 5
THE INTERPRETATION FOR ABBREVIATION IN FIG 2

Abbr	Interpretation	Function
S	Sample oil data	Input
A/I	The fault case of B reference data in ANSI/IEEE C57.139 Sepecification	Reference criteria
B/I	The fault case of B reference data in ANSI/IEEE C57.139 Sepecification	Reference criteria
D/I	The danger level (ANSI/IEEE C57.139 Sepecification)	Criteria
Du	Duval triangle 2 diagnostic method	Criteria
C1	The out for S and A/I (correlation coefficient)	Judgement
C2	The out for S and D/I (correlation coefficient)	Judgement
C3	The out for S and B/I (correlation coefficient)	Judgement
A1	The out for C1 and C2	Judgement
A2	The out for C2 and C3	Judgement
O	The out for A1 or A2	Judgement
A3	The out for Du and O	Judgement
P	The out for text and figure	Output

3.2 Correlation coefficient

According to the Spearman correlation coefficient [4], the correlation between two statistical variables is evaluated by using to compare with two sets of data.

The correlation coefficient is a measure of the relationship between the two groups of pairs of bivariate random variables. Usually they are used to measure two random variables X and Y of the relevant measure (measure of correlation) and its value should be between -1 and + 1, the higher positive value represents, the more irrelevant. When discussing the correlation coefficients, we must discuss the covariance between two random variables.

Such as the Pearson correlation coefficient r_{xy} are the two random variables X and Y, as shown in Equation (1).

$$\gamma_{xy} = \frac{\sum x_i y_i - (\sum x_i y_i)/n}{\sqrt{\sum x_i^2 - (\sum x_i)^2/n}\sqrt{\sum y_i^2 - (\sum y_i)^2/n}} \quad (1)$$

Because the connection between variables is insignificant, and the computational process is simplified by observing the rank difference between two variables, expressed as in Equation (2). Here, n represents the number of data (in this paper n =6), and di represents the rank difference between two variables. Those parameters and result are shown in Table 6, xi, yi ; (i=1, 2, 3, 4, 5, 6); n is the number of gases in each group.

$$\gamma_{xy} = 1 - \frac{6 \times \sum d_i^2}{n(n^2 - 1)} \quad (2)$$

TABLE 6
CORRELATION VALUES FOR X AND Y SETS (UNIT: PPM)

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	Coe
x	27072	4161	551	7041	33887	632	0.87
y	17995	5083	12584	22547	9735	24	

3.3 Correlation coefficient set

In the program, there are two kinds references - arcing and coking of data, each data of gases was made up of H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, and CO. Those were taken from the fault case of insulating oil of faulty OLTC, as for the danger level, the arcing and coking reference data of ANSI/IEEE C57 139 specification were shown in Table 7, in Table 8, and in Table 9 [5]-[6]. Any one of those data is regards as the X set variable and the sample data is regards as Y set variable within the Equation (1) of correlation coefficient (r_{xy}). Then the two kinds of fault reference data were verified to meet the rule of The Duval Triangle 2 in the fault area strong arcing (D1) and sever coking (T3).

TABLE 7

A SET OF DATA FOR DANGER LEVEL OF ANSI/IEEE C57.139 SPECIFICATION (UNIT: PPM)

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
Content	/	4423	/	7617	31410	/

TABLE 8

A SET OF DATA FOR ARCING FAULT (UNIT: PPM)

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
Content	24075	4181	3373	10395	28755	283

TABLE 9

A SET OF DATA FOR COKING FAULT (UNIT: PPM)

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
Content	7731	53263	70456	115154	979	36

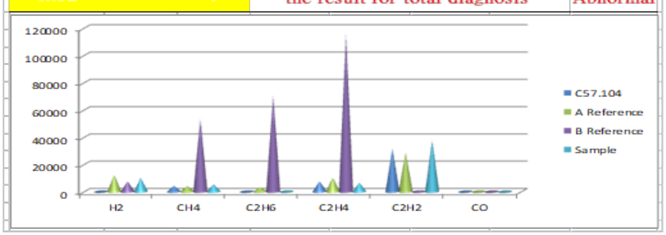
4 THE DIAGNOSTIC PROGRAM

The diagnostic program provides a novel approach to diagnosis of OLTC insulating oil for understanding the status of operation; it was been so easy designed operation by machine-human interface.

TABLE 10

THE RESULT OF PAPER DIAGNOSIS REPORT (UNIT: PPM)

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	Correl
C57.104	0	4423	0	7617	31410	0	0.95
A Reference	12345	4181	3373	10395	28755	283	0.97
B Reference	7731	53263	70456	115154	979	36	-0.40
Sample	10092	5399	530	6500	37565	42	
1	0	1	The result of diagnosis for correlation				Abnormal
49464	0.11 0.13	1 1	0 0	1 1	Diagnosis for Duvel		Abnormal
TRUE		1	the result for total diagnosis				Abnormal



The 0.85 of the correlation coefficient was set as the fault threshold value of diagnosis point in the program, and less than 0.85 was considered "normal" status whereas "abnormal". The diagnostic report was shown in Table 10. It is noticed, that is the sample oil must be passed the "Decomposition Chromatography". Diagnosis performed using the Duval triangle 2 method.

5 VERIFYING

In order to verify this program, this approach has conducting an experiment on transformers of 14 sets from Taiwan Power Company and IEC TC 10 databases (12 sets), the result were shown in Table 11.

TABLE 11

THE ACCURACY DEGREE FOR IEC TC 10 WITH T.P.C DATA

IEC TC 10 databases		Taiwan Power Company data	
Miss	Right	Miss	Right
1	11	0	14
12 (including 3 fault)		14 (normal condition)	
Accuracy degree		96.1%	

6 CONCLUSION

For the sake of stable and reliable power system, the policy of reducing improper maintenance cost must be performed throughly. The paper approach was developed from the method of the Duval triangle 2 and correlation coefficient, which is more accurate than previously mentioned methods. This approach provides operation simple and interface machine – human to diagnose analysis. That is the accurate degree confirmed up to 96.1% from the IEC TC 10 databases (12 transformers including 3 fault condition) [7] and Taiwan Power Company's data (14 transformers normal condition). This approach was not only verified feasible to diagnose the insulating oil of OLTC and to understand the status of internal operation in practical, but also can be applied to other devices diagnostics if the program parameters are replaced.

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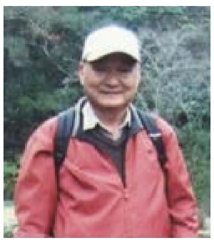

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