Original Research Article

The Method of the Probability Analysis of Area with Dissolved gases in Power Transformer Insulating Oil

ABSTRACT

Transformer insulating oil plays an extremely important role in power transformers and is used for insulation, arc suppression, cooling and other purposes. However, its other focus is on dissolved gases analysis in the oil to monitor internal operating conditions, which is the responsibility of preventive maintenance. This paper uses the normal distribution theory and the American National Standard Specification (hereinafter referred to as ANSI/IEEE C57.104) to reorganize as a diagnostic tool. The range of each gas from three stages of the specification - normal, caution, and abnormal are incorporated to a stage of abnormal, which is divided intoequal different values of 1000 as the maternal body of a qualitative normal distribution. Then the benchmark is been calculated from those parameters of a qualitative normal distribution.The data of detectionhas to pass through "Gas chromatography" to generate dissolved gases. At last, the benchmark value compares with dissolved gases to find the abnormal probability valueas a diagnostic tool inmaintenance evaluationof equipment. This method was developed using EXCEL application software, and repeatedly tested and verified with examples to confirm its feasibility and high accuracy. Therefore, this diagnostic method can replace the traditional multi-stage judgment and be represented by a single probability value to show. Based on technology sharing, the development process is specially written into a technical article as referenced by scholars and electrical maintenance personnel in the field of power engineering.

Keywords:Insulating Oil, Dissolved gases Analysis, ANSI/IEEE C57.104, Normal Distribution.

1. INTRODUCTION

The internal insulating oil of transformer plays an important role in the operation of power transformers. It is related to the quality of power and the safety of power system supply. So that, we are very cautious in monitoring and control, especially internal testing. When it comes to internal testing, it falls on dissolved gases analysis from the insulating oil.The dissolved gases analysis (DGA) is a crucial method for identifying incipient faults in power transformers.it is been dissolved from the insulating oil of transformer which is running condition. Whenthe data of detectionof insulating oil must pass through"Gas chromatography" to obtain various dissolved gases of the flammability properties such as - hydrogen (H_2), methane (CH_4), ethane (C_2H_2), ethylene (C_2H_4), acetylene (C_2H_6) and carbon monoxide (CO). However, how tointerpret~~interpretation those~~the analysis number of ones in insulating oil are based on the ANSI/IEEE C57.104 [1,2]. When it comes to ANSI/IEEE C57.104 - the specification covers a wide range of areas: 1) The relationship between the insulating oil in the transformer; 2) Purpose and application; 3) Quality verification and limitations; 4) Interpretation and specifications; 5) Failure type definition and identification; 6) Case studies and explanation examples. Its purpose is to provide operators or maintenance personnel with maintenance information and introduce various diagnostic techniques, such as Key gases, Rogers ratio, Duval triangle method and other methods. This paper only proposes improvements from the fault definition and identification of the fifth paragraph. It uses all the characteristics of the "Normal Distribution" theory and applies the number covering each gas from normal to abnormal in the ANSI/IEEEC57.104 as the maternal body to make a qualitative normal distribution. The method is been used with the dataof detection compared with as diagnosis, so that it is called the probabilistic method. In addition to this paragraph, there are also paragraphs such as literature review, research steps, program testing, case verification, discussion, conclusion and references.

2. LITERATURE REVIEW

Before discussing the analysis of various gases in oil, we need to introduce the " Gas chromatography."This instrument can be traced back to the work of Russian scientist Mikhail SemenovichTswett in 1903 and German graduate student Fritz Prior invented gas-solid layer analysis in 1947. In 1950, gas-liquid layer analysis was invented. Until Archer John Porter Martin laid the foundation for the development of gas chromatography and won the Nobel Prize for his contribution because the development of liquid-liquid chromatography in 1941 and paper-published in 1944. Then named after "Gas chromatography", it is a chromatography technology that separates and analyzes flammable organic chemical mixtures that are not easily decomposed. It must be separated by an inert gas (such as helium) or a less reactive gas (such as nitrogen), with a thin layer of liquid or polymer attached to the surface of an inert solid carrier. Those different gas substances are eluted at different times and temperatures. The "Normal Distribution" was used by the great mathematician Gauss in 1794 to describe the small error in repeated measurements of the same variable. However, the curve of the error resembles a bell and is called the bell curve. It was not until 1872 that the American logician Peirce discovered that it is a continuous probability distribution. The curve drawn by its density function is also called the normal curve and has been verified. Its function is shown in Formula 1 as follows.

$$\boldsymbol{f(x) = (1/\sigma\sqrt{2\pi})e}^{-(x-\mu)^2/2\sigma^2} \qquad (1)$$

Then, those related articles were selected from numerous literatures, and each characteristic is summarized as follows: [3] Apply a lot of historic number to construct a new qualitative normal distribution and then convert it into a probability value as a tool of judgement according to its characteristics to judge whether the opening and closing stroke time of the power circuit breaker is normal or not. Toutilize the relationship between the mean, variation, standard deviation and its height in the generalized normal distribution parameters, and proposes evaluation and real number sets for analysis and explanation. [4] The new deviation from normal distribution parameters is not mainly three but one that can be used in life and industry. Increase the flexibility of its use by adding random variables. As for [5 - 12], those literatures describe the normal distribution, compilation instructions, bell curve drawing and other related rules. Based on the above reference number and by standardizing the gas ranges of ANSI/IEEE C57.104, a novel detection method - " A New Method for Identification within Dissolved gases - Probability Method " was developed.

3. RESEARCHMETHODS

Taking "Normal Distribution Theory" and "ANSI/IEEE C57.104" as the main axis, taking the number range of all stages as the maternal body of normal distribution to construct a qualitative normal distribution. Those parameters are calculated by EXCEL application software, and then draw the bell-shaped curve area according to the characteristics of normal distribution, and converting it into a probability value inpercentageas a diagnostic benchmark to compare with the detection data. After the above evolution and attributes are described:

3.1 NORMAL DISTRIBUTION

The normal distribution is used to describe the small error in repeated measurements of the same variable. However, its shape curve of errors value to make a bell-shaped, so that is called a "bell curve." It is a continuous probability distribution and the density function has been verified and it is been drawn bell curve and also called the normal curve. The curve area is calculated based on the maternal body of aqualitative~~qualitive~~ normal distribution from those parameters - mean, variation, standard deviation, and is then converted into standard scores and probability values through the EXCEL application software, as shown in Fig.1. As for, how to convert and calculate from those formulas ~~each other~~, such as formulas 2, 3, 4, 5, 6 and the symbols are explained as follows:

$$\boldsymbol{X} \sim \boldsymbol{N}(\boldsymbol{\mu}, \boldsymbol{\sigma}^2) \quad (2)$$

$$\boldsymbol{\mu} = \sum_{i=1}^{n} (\boldsymbol{x}_i)/\boldsymbol{n} \quad (3)$$

$$\boldsymbol{\sigma}^2 = \sum_{i=1}^{n} (\boldsymbol{x}_i - \boldsymbol{\mu})^2/\boldsymbol{n} \quad (4)$$

$$\boldsymbol{\sigma} = \sqrt{\sum_{i=1}^{n} (\boldsymbol{x}_i - \boldsymbol{\mu})^2/\boldsymbol{n}} \quad (5)$$

$$Z = (X - \boldsymbol{\mu})/\boldsymbol{\sigma} \quad (6)$$

where $\sigma \neq 0$.

X is a random variable of normal distribution.

μ is the mean value of the sample group.

$\sigma^2$is the ~~variation~~(variance)of the sample group.

σ is the standard deviation of sample group.

Z is the standard score.

P is the probability of the area of the bell shape.

If σ=1, the Z value is approximately from – 3 to + 3. The area of the bell shape is 1 of the total value of the probability, as shown in the Fig. 1below.

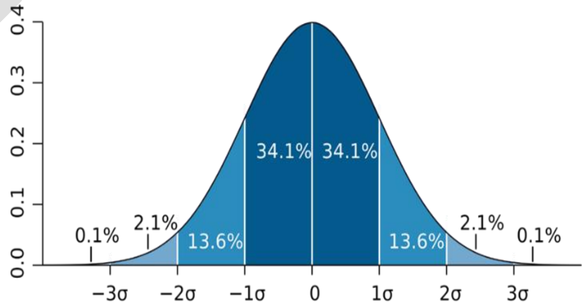

Fig 1. Bell-shaped curve [12]

Because the probability value can be converted to the standard score or the curve area ~~any,~~ using Formula 6 and Formula 7, the probability conversion value can be calculated because, Z ~ N (0,1).

$$P(a \leq \boldsymbol{X} \leq \boldsymbol{b}) = \boldsymbol{P}((\boldsymbol{a}-\boldsymbol{\mu})/\boldsymbol{\sigma} \leq (\boldsymbol{X}-\boldsymbol{\mu})/\boldsymbol{\sigma} \leq (\boldsymbol{b}-\boldsymbol{\mu})/\boldsymbol{\sigma}) \; \boldsymbol{P}((\boldsymbol{a}-\boldsymbol{\mu})/\boldsymbol{\sigma} \leq \boldsymbol{Z} \leq (\boldsymbol{b}-\boldsymbol{\mu})/\boldsymbol{\sigma}) \quad (7)$$

3.2 ANSI/IEEE C57.104 STANDARD

The American National Standards Institute (ANSI) describes detailed procedures for interpreting the results of dissolved gases analysis of insulating oils. This paragraph only discusses the definition of fault stages and the content of each gas (ppm) in the identification, divided into four stages - normal, caution, abnormal and dangerous, the number ranges of each stage according to the specification to provide a basis for judgment on equipment maintenance, and it is an important element that is been discussed in this paper.

3.3 BLOCK FLOW CHART

There are three blocks of schematic chart to show what it is been developed, procedure in this section, as shown in Fig.2. the detailis as describedin~~ behind.~~

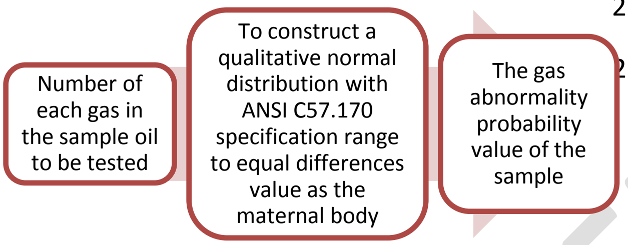

Fig 2.Block flow chart

3.4A QUALITATIVE NORMAL DISTRIBUTION

This section includes: 1) Each gas range and column location are been set, 2) Each gas related parameter is been calculated by formula anddescribed~~descripted~~ the result value ~~in,~~3) Bell curve area is been drawnwith command description, 4) How to convert between standard score and probability through formula command, and result value explain,5) the result value of the detection data is explained.

3.4.1 The amount is sum from the range of the normal, caution and abnormal, taking it from the range of each gas in the ANSI/IEEE C57.104. Then divided it into 1000 equal differences value, as the maternal body of a qualitative normal distribution. As for formulas of the column location explain, such as H_2 (from normal stage 0 to abnormal stage maximum value 1800) and the command of EXCEL application software is shown in Table 1, such as H_2 (A5:A1005).

Table 1. Each gas range and column location

Gas	Range(ppm)	Column location
H_2	0 ~ 1800	A5:A1005
CH_4	0 ~ 1000	B5:B1005
C_2H_2	0 ~ 35	C5:C1005
C_2H_4	0 ~ 200	D5:D1005
C_2H_6	0 ~ 150	E5:E1005
CO	0 ~ 1400	F5:F1005

3.4.2 TakingH_2 gas column location for an example, calculate the qualitative normal distribution of each gas parameter - mean, variation, standard deviation and other calculation formula symbol description column location from A5 to A1005, those formulas been shown =AVERAGE (A5:A1005) is 900, =VARPA (A5:A1005) is 270540, and =STDEV (A5:A1005) is 520, as shown in Table 2 below.

Table 2. Results of various parameters of H_2 gas

Parameters	Formula (EXCEL)	Result
Mean	=Avera(A5:A1005)	900
Variation	=Varpa(A5:A1005)	270540
Standard deviation	=Stdev(A5:A1005)	520

3.4.3 To draw a "bell curve area" after constructing the qualitative normal distribution, taking H_2 gas for example. First,using relevant parameters to calculate the results of group boundaries and frequency according to those parameters formulas in Table 3, that is, use the mean ($I$5) and standard deviation ($I$9) to plot a symmetrical bell shape, as shown in Fig.3.

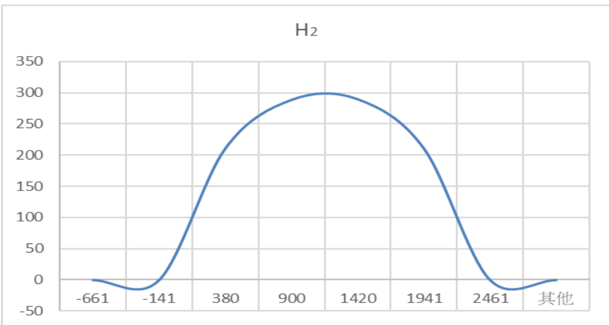

Fig 3. Bell curve area of H_2 gas a qualitative normal distribution

3.4.4 The bell curve area, the standard score and the probability value of the relationship between is obtained from the calculation formula in Table 4. The standard score is calculated from column location (A5) subtracting the mean of the gas ($I$5) and then dividing the standard deviation ($I$9) of the gas. The formula is=(A5-$I$5)/($I$9). Taking H_2 for an example, column location (A5) is 0, the calculation result is -1.729(Z), as for the formula is been shown =Norm.Dist(A5,900,520,true) and the probability value is 0.04(P). The rest can be deduced by analogy. If the column location (A1005) of the H_2 is 1800, its value is 1.729 (Z), and the probability value becomes 0.96 (P). Another description of the formula symbols: $I$5 is the 5 rows of I column, which is 900, which is the mean of H_2 gas; $I$9 is the 9 rows of I column, which is 520, which is the standard deviation of the H_2 gas.

Table 3. Bell curve area drawing and formula instructions

Formulas	Result	boundaries	frequency
=$I$5-3*$I$9	-661	-661	0
=G17+$I$9	-141	-141	0
=G18+$I$9	380	380	211
=G19+$I$9	900	900	289
=G20+$I$9	1420	1420	290
=G21+$I$9	1941	1941	211
=G22+$I$9			0

Table 4. Standard score and probability value conversion of H_2

Name	Formula	Result
Z	=(A5-$I$5)/$I$9	-1.729
	=(A1005-$I$5)/$I$9	1.729
P	=Norm.Dist(A5,900,520,true)	0.04
	=Norm.Dist(A1005,900,520,true)	0.96

3.4.5 When the diagnostic comparison is between the detected data and the benchmark of a qualitative normal distribution. Taking H_2 for an example, if the gas number is 600ppm, the result of the related parameters is as shown in Table 5. Its standard score is -0.57 and the probability value is 0.28, that is, the abnormality degree of H_2 gas is 0.28 in the detection equipment.

Table 5. Detection number of H_2& diagnosis results

Number	Name	Formula	Result
600	Z	=Norm.Dist(600,900,520,true)	-0.57
	P	= (600-900)/520	0.28

The above description uses EXCEL application software to divide the range values of each gas in the normal, caution and abnormal stages of the ANSI/IEEE C57.104 into 1000 parts in an arithmetic series, as the maternal body of the qualitative normal distribution, and taking the range of H_2 gas stage as an example - normal (0 to 100), attention (101 to 700), abnormal (701 to 1800) stages to sum one stage abnormal (0 to 1800), then find those parameters of H_2 gas - mean, variation, standard deviation, and then convert it into standard scores and probability values serve as diagnostic benchmarks.

4. VERIFICATION

This paragraph respectively describes – First, how to take those gases from the device. Secondly, how to construct a qualitative distribution to compare with the gases of the detection, and the diagnostic result is verified from this method of a qualitative normal distribution benchmark and the repair status of record from maintenance department. Finally, the pros and consare tocompare between the ANSI/IEEE C57.104 and this method.

4.1 The oil quality detected of #4 autotransformer for Taiwan Electric Power Company's Nanke Extra High Voltage Substation was regularly tested on October 9, 2012, and the data of detection was taken and passed through the "Gas chromatography," so that can obtaindissolved gases. those steps are must with the operating standard procedures.The number of detection gases are as follows: H_2 (194), CH_4 (602), C_2H_2 (1.8), C_2H_4 (579), C_2H_6 (204) and CO (75) unit (ppm), the results of this method to calculate with those parameters of a qualitative normal distribution are shown in Table 6. Green fonts are detecteddata, Red fonts are the probability values of each gas, and Black fonts are the relevant parameter values of each gas in the qualitative normal distribution. Such as the abnormal probability of CH_4 gas has reached 0.64, and the probabilities of

C2H4 and C2H6 have reached 1 (in dangerous stage). The verification results of this case are consistent with the repair status of the maintenance department at that time (A screw inside the transformer is severely corroded).

4.2 To compare ~~with~~ between this probability method and the ANSC/IEEE C57.104, as shown in Table 7, the later presents the abnormality degree of each gas in percentage, while the former indicates which range in, such as normal, attention or abnormal or even dangerous stage appears. This probability method is distinguished by the percentage value within a single abnormal stage. Taking H2 gas number as an example, the probability value 0.04 corresponding to gas number 0 ppm,while the probability value 0.96 corresponding to gas number 1800 ppm, that is the range of the probability from 0.04 to 0.96. If the probability value is greater than 0.96, it means the gas number is in a dangerous stage.

Table 6. Test results report

H2 u	CH4 u	C2H2 u	C2H4 u	C2H6 u	CO u
900	500	17.50	100	75	700
H2 σ^2	**CH4 σ^2**	**C2H2 σ^2**	**C2H4 σ^2**	**C2H6 σ^2**	**CO σ^2**
270540	83500	102.288	3340	1879	163660
H2 σ	**CH4 σ**	**C2H2 σ**	**C2H4 σ**	**C2H6 σ**	**CO σ**
520	289	10.12	58	43	405
H2	**CH4**	**C2H2**	**C2H4**	**C2H6**	**CO**
0.09	0.64	0.06	1.00	1.00	0.06
Gases data of the detection (ppm)					
H2	**CH4**	**C2H2**	**C2H4**	**C2H6**	**CO**
194	602	1.8	579	204	75

Table 7. Comparison between probabilistic method and ANSI/IEEE C57.104

Gas name	H2	CH4	C2H2	C2H4	C2H6	CO
ANSIC57.104	A	AB	N	D	D	N
P(%)	9	64	6	100	100	6

A : attention、AB: abnormal、D: danger、N: normal。

4.3 The single abnormal probability method adapts percentage compare with the stage range of the ANSI/IEEE C57.104. The former can clearly distinguish the severity of the abnormality based on the percentage, while the latter only knows which stage area it falls in, which is vaguer. So, the former is better than the latter.

5. DISCUSSION

During the development and testing period, those results were discovered what the probability method value of a qualitative normal distribution resembled the result of arithmetic method, itis very similar by being compare the results. Taking the actual gases dataas an example, the number of each gas is respectivelyCH4 602 ppm, C2H4 579 ppm, and C2H6204 ppm, the result of the arithmetic method is 0.60, 2.89 and 1.36, and the probability method is 0.64, 1 and 1. This is sufficient reason to prove that it isfeasible~~feasibility~~ andaccurate~~accuracy~~in this probability method. In addition, the range of the maternal body of each gas is not ~~be~~the same range (for an example, each range of gas takes from ANSI/IEEE C57.104, H2 is from 0 to 1800, CH4 is from 0 to 1000), but the standard score and probability valve are consistent according to rule of the area of the bell curve to convert. ~~and~~ the number of the group of maternal body (n) mustbe1000 with equal difference value and not equal value of ~~any~~one random.

6. CONCLUSION

Based on the above theory, use EXCEL application software to compile available detection tools. First, taking those number of all from the three stages of normal, caution and abnormal in the ANSI/IEEEC57.104 to covert a stage of attention which is been divided into 1000 by equal difference level as the maternal body of a qualitative normal distribution. Those related parameters of a qualitative normal distribution converted into standard scores and probability values as the diagnostic benchmark, and then combined with case gases to verify its feasibility and accuracy. The comparison results prove that this method is superior to the traditional judgment method.This method is carefully developed under tried and tested ~~a~~ novel probability value diagnosis method. It has been verified and is worthy of being introduced to colleagues in the field of power engineering as reference, also hopes that advanced professionals and scholars will not hesitate to criticize and give advice.

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