Gaussian distribution Diagnoses in Transformer's Insulating Oil

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Abstract. With the purpose of applying a Gaussian distribution as a diagnostic tool for detecting incipient faults in power transformers, we investigated the fundamental characteristics of Gaussian distribution than theorem of the form – the mean and variance of the uniform distribution to take the parameters of Gaussian distribution that are μ and σ^2 (Equation 1). From Gaussian distribution establishes a reference value for comparison. The result of detecting is shown by probability that it is classified - 1 (Flaw)、0 (No flaw)、Nu (Probability). The innovative tool not only provided the probability of accuracy and effectiveness, but also showed the result of diagnosis in text and graphs.

Introduction

Transformer plays important equipment in power system. So that maintenance of transformer and insulating oil of detection were cautioned carefully. If the result of diagnosis was unapt this will lead a tremendous maintenance costs to waste. The insulating oil gas analysis is a good way to diagnose with transformer of incipient fault all over world widely. Some methods were used such as - the Key Gas method, Dornenburg and Roger method , The Duval Triangle method, and Linear SVM diagnosis method and so on [1-2]. For the sake of the correct judgment, we developed an iconic reference graph to compare with each detective gas by the Gaussian distribution [3]. This method takes advantage of the ANSI / IEEE C57.104 specification from the start value of abnormal to the start value of dangerous range which regarded as a Gaussian distribution area. To view the measured value of transformer insulating oil that one was been shown by graphs and texts where on Gaussian distribution area as well as diagnostic probability.

Gaussian distribution Formula

A Gaussian distribution, often simply referred to as some Equations (1) and (2) [3]:

$$u = \frac{A + B}{2} \text{ and } \sigma^2 = \frac{(B - A)^2}{12} \quad \text{……………………………….….…………(1)}$$

$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-u}{\sigma}\right)^2} \quad \text{……………… ………………...……..………(2)}$$

Normalized Gaussian curves with expected value μ and variance σ^2. The corresponding parameters are a = $1/\sigma\sqrt{2\pi}$, b = μ, c = σ, and d = 0 Gaussian distribution is analytic, and their limit as $x\rightarrow\infty$ is 0. The graph of a Gaussian is a characteristic symmetric "bell curve" shape. The parameter's "a" is the height of the curve's peak, "b" is the position of the center of the peak and "c" (the standard deviation, sometimes called the Gaussian rms width) controls the width of the "bell" which is shown Figure 1. Gaussian distribution is widely used in statistics where they describe the normal distributions. We think they can define gas content of insulating oil as well as used to compare diagnosis form curves of Gaussian distribution.

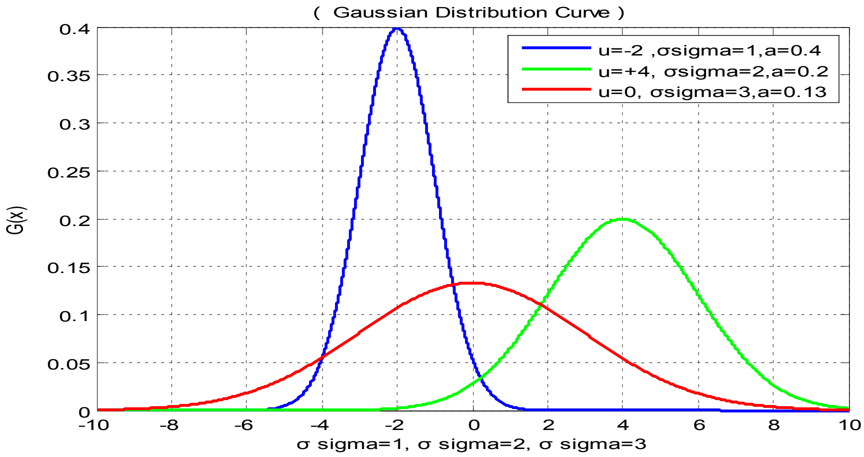


Figure 1. The curve of Gaussian distribution [3]

To take the mean (μ) and variance (σ) of the uniform distribution Form the book [2]. The μ and σ^2 were calculated from Equation 1, then Equation (1) A and B will be replaced from the start value abnormal (A) and dangerous (B) of the ANSI/IEEE C57.104 specification. In this way, those parameters were as an iconic diagnostic value. The date was shown in Table 1.

Table 1. The parameters from the ANSI/IEEE C57.104 Specification unit: ppm

Position	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
Danger(B)	1801	1001	151	201	35	1400
Abnormal(A)	701	401	101	101	10	571
μ	1251	701	126	151	22.5	985
σ	317	173	14.4	28.8	7.2	239
a	0.125	0.002	0.030	0.014	0.055	0.002

Notice: σ (Sample Standard Deviation) μ (Sample Mean) a (The height of the curve's peak)

The ANSI / IEEE C57.104 Specification

The ANSI/IEEE C57.104 specification is widely conformed as the criterion of diagnosis of transformer's insulating oil [4]. As shown in Table 2.

Table 2. Gas in Oil Diagnostic for the ANSI / IEEE C57.104 Specification unit: ppm

Name	Content value	Property	Name	Content value	Property
H_2	> 1801	Danger	CH_4	> 1001	Danger
	> 701	Abnormal		> 401	Abnormal
	> 101	Attention		> 121	Attention
	< 100	Normal		< 120	Normal
C_2H_6	> 151	Danger	C_2H_4	> 201	Danger
	> 101	Abnormal		> 101	Abnormal
	> 66	Attention		> 51	Attention
	< 65	Normal		< 50	Normal
C_2H_2	> 35	Danger	CO	> 1400	Danger
	> 10	Abnormal		> 571	Abnormal
	> 2	Attention		> 351	Attention
	< 1	Normal		< 350	Normal

The diagnosis of Gaussian distribution

The diagnosis of Gaussian distribution consist of six gases, the parameters is been calculated out “μ”, “σ”, and “a” [4]. The relative data are shown in Table 3 as the reference curve of comparison. Then the each graph which is drawn via program. As shown in Figure 2.

Table 3. Gaussian Diagnosis Standard Reference unit: ppm

	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
μ	1251	701	126	151	22.5	985
σ	317	173	14.4	28.8	7.2	239
a	0.125	0.002	0.030	0.014	0.055	0.002

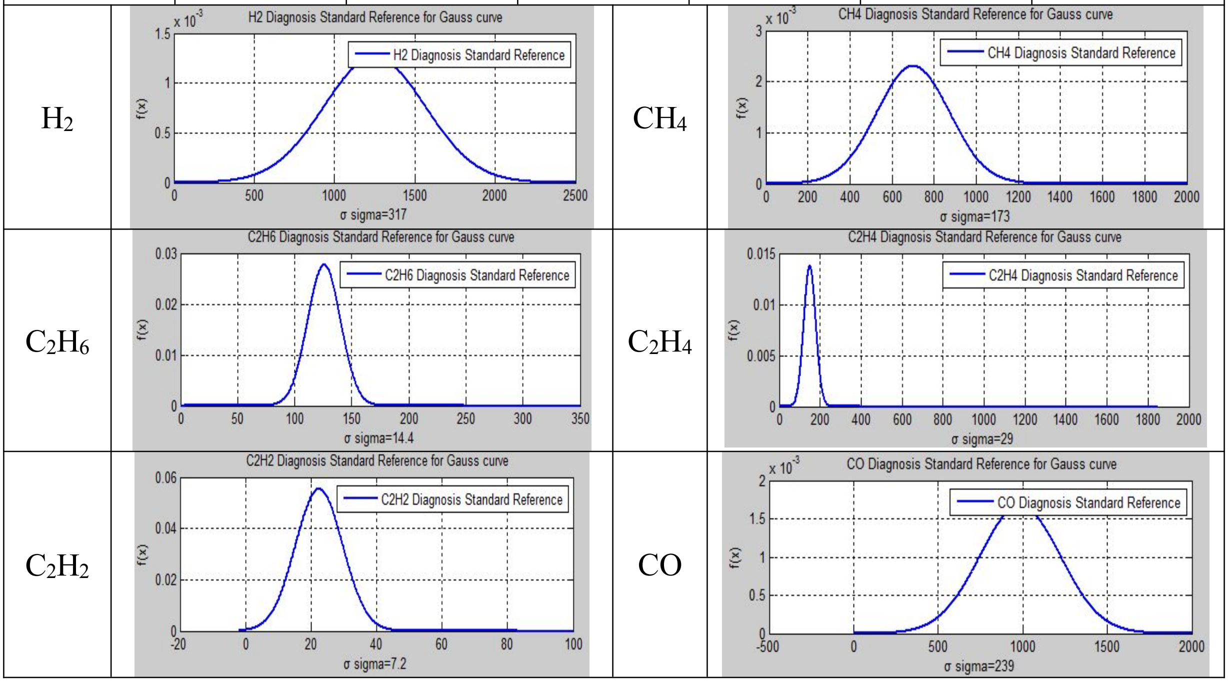


Figure 2. The figure of standard reference of diagnosis

The flow chart of program

The flow chart of the program is made up of the data of reference for the mean and variances of the uniform distribution are shown (Figure 3) the probability by text and graphs.

Probability = $(u_t - u_b) / \sigma$……………………………………………………………(3)

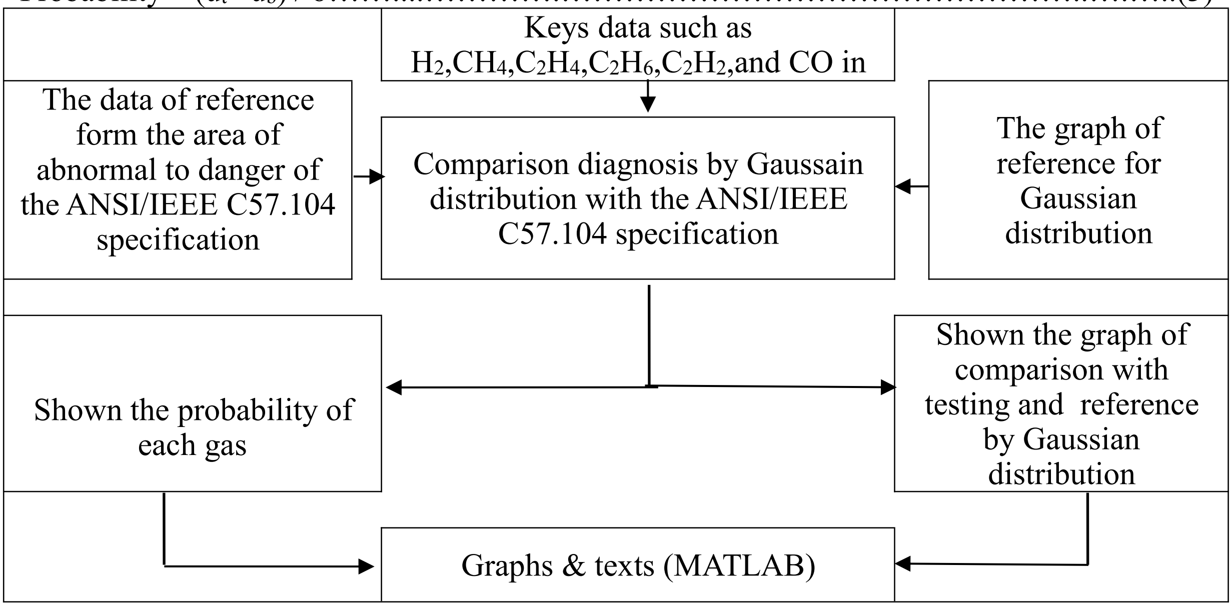


Figure 3. The flow chart of the program

u_t = (Testing Mean) , u_b = (Base Mean) , σ = (Base Standard Deviation) Notice: Each gas differs with u_b and σ_b . The probability was been transformed with reference value (in Equation 3).

Diagnostic Practices and Verification

Diagnostic Practice case 1 & case 2

Case 1, Taiwan Power Company E D/S # 2DTr's insulating oil, inspected these gas component content Hydrogen, Methane, Ethane, Ethylene, and Acetylene data are described (in Table 4), the quantity of the C_2H_2 is over the level of the attention but else behind danger level, for safety operation, authority decided the #2DTr must been stopped to check up [5]. After repair, We were used the diagnosis of Gaussian distribution to test, the result (No flaw) of the judgment, the picture (in Figure 4) proved what it was a suspect flaw in exactly. Case 2, Siemens Company's Report by Ivanka Atanasova-Hohiein [6], these gases data are described (in Table 5), used the diagnosis of Gaussian distribution, shown in Figure 5, where the result (carbon deposits on PLTC contracts) of the judgment by text and graphs. The picture proved it exactly.

Table 4. Case 1: E D/S #2DTr gas data   unit: ppm

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
2014.11	11	6	6	7	7.1	48

Each gas's probability with Reference Quantity	Overhauled Picture(Nothing)
H_2 =The probability for (0) CH_4 = The probability for (0) C_2H_6 = The probability for (0) C_2H_4 = The probability for (0) C_2H_2 =0.0139 CO = The probability for (0)	

Graphs of Gaussian distribution for comparison reference with testing

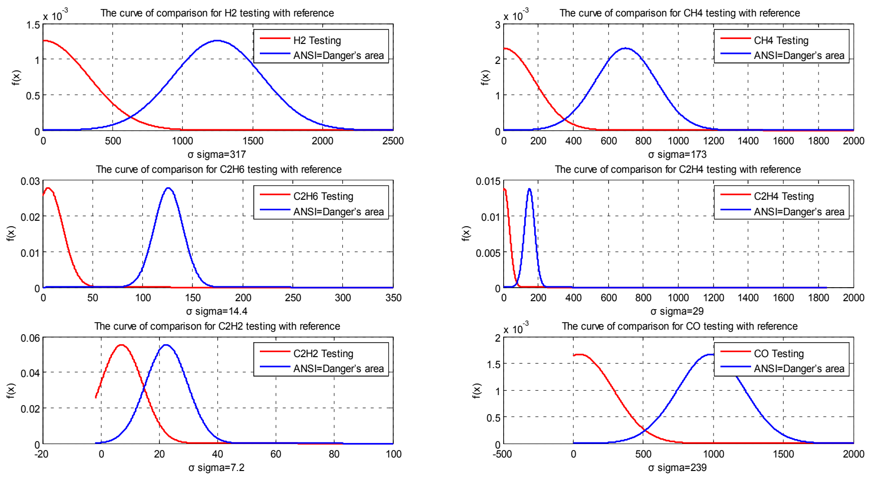


Figure 4. Case 1: Each gas's probability with Overhauled Picture and compared graphs

Table 5. Case 2; Ivanka Atanasova-Hohiein's report gas data unit: ppm[6]

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
2012.05	537	1041	295	1726	25	1047

Each gas's probability with Reference Quantity	Overhauled Picture
H_2 == 0.0107 CH_4 == 0.9713 C_2H_6 == The probability over (1) C_2H_4 == The probability over (1) C_2H_2 == 0.6179 CO == 0.5793	

Graphs of Gaussian distribution for comparison reference with testing

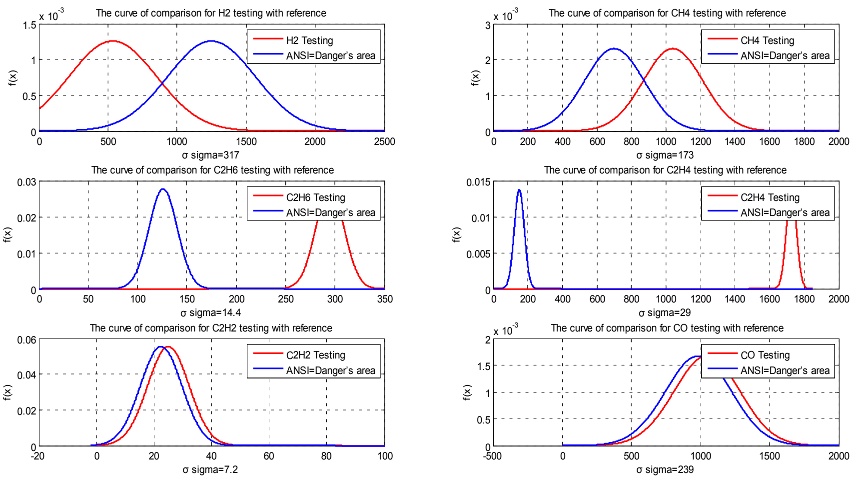


Figure 5. Case 2: Each gas's probability with Overhauled Picture and compared graphs [6]

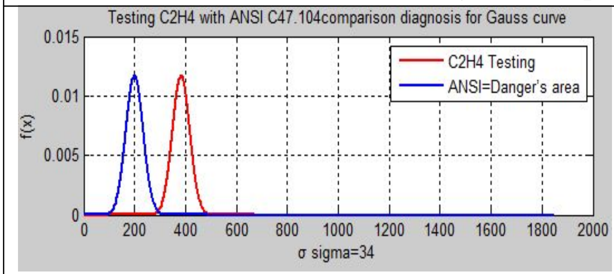
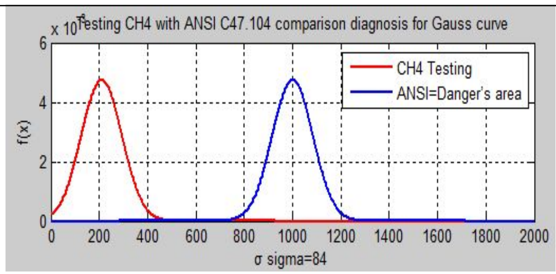
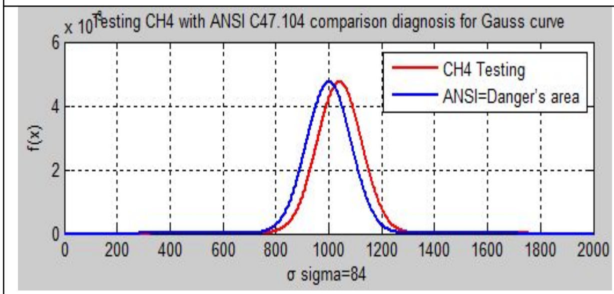
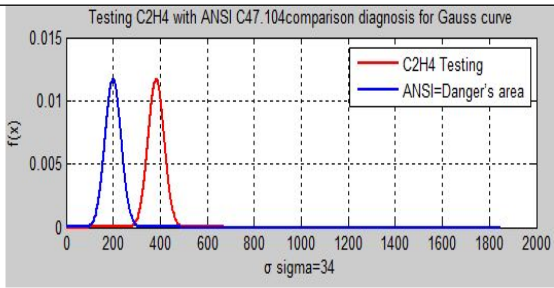
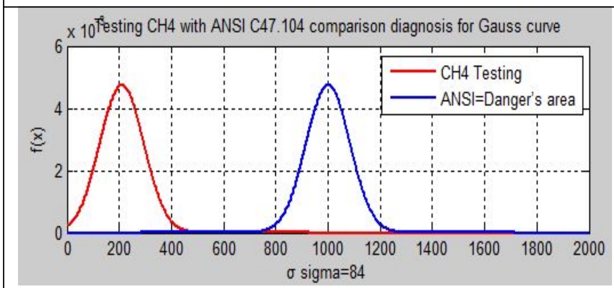
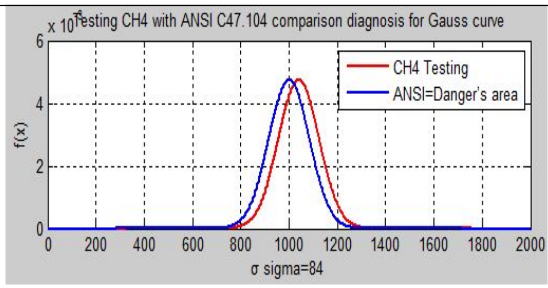
Verification

For the sake of verification, we took some cases (in Table 6) from Taiwan Power Company that those cases were overhauled, one case did not find out any flaw , others cases was found out a flaw point from in the internal of transformer either Arc or Partial Discharge [7]. So those data were taken to compare with the Gaussian distribution diagnosis to verify the practicality of the program.

	Name	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	Diagnosis of result	*Repair of state*
Case1 (2007.05.10)	Quantity	44	41	88	7	10.1	57	0	N
	Probability	0+0	0+0	Nu	0+0	0+0	0+0		
	Graph	0-	0-	Cr	0-	0-	0-		
Case2 (2010.09.05)	Quantity	140	54	79	21	53.8	35	1	Ac
	Probability	0+0	0+0	0+0	0+0	1+1	0+0		
	Graph	0-	0-	Cr	0-	1+	0-		
Case3 (2011.12.26)	Quantity	935	271	116	330	420	128	1	Pd
	Probability	0+0	0+0	Nu	1+1	1+1	0+0		
	Graph	0-	0-	Cr	1+	1+	0-		

Case4 (2012.05.10)	Quantity	239	346	78	787	24	312	1	Ac
	Probability	0+0	0+0	0+0	1+1	0+0	0+0		
	Graph	0-	0-	Cr	1+	0-	0-		
Case5 (2012.07.08)	Quantity	48	694	356	1077	0.4	36	1	Pd
	Probability	0+0	0+0	1+1	1+1	0+0	0+0		
	Graph	0-	Cr	1+	1+	0-	0-		
Case6 (2013.09.23)	Quantity	133	211	66	384	1.9	411	1	Pd
	Probability	0+0	0+0	0+0	1+1	0+0	0+0		
	Graph	0-	0-	Cr	1+	0-	0-		

Symbols: N (Normal)、Ac (Arc)、Pd (Partial Discharge)、1 (Flaw)、0 (No flaw)、1+(Graph over the reference)、0-(Graph under the reference)、Cr(two Graph curves cross)、1+1(The probability for (1))、0+0(The probability for (0))、Nu(The probability for (number)). This is evident in Figure 6.

Symbol Explanation Graph	
	
1+, over the reference	0-, under the reference
	
Cr, two curves cross	1+1, The probability for (1)
	
0+0, The probability for (0)	Nu, The (number) probability

Conclusions

This paper combines the Gaussian distribution and the ANSI/IEEE C57.104 specification to develop an innovative diagnosis tool in transformer's insulating oil. The parameters of the Gaussian distribution were calculated from the mean and variance of the uniform distribution. Transformer insulating oil is so complicated that it's difficult to diagnose because up to nine parameters in. How to use an accurate and simple diagnosis method it is must. From on

November, 2014 E D/S # 2DTr case and on May, 2012 Siemens Report of transformer‘s data. The Gaussian distribution tool was not only validated so easy to use at any analysis of transformer insulating oil, but also improved the accuracy of diagnosis.

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