TECHNIQUES FOR INCIPIENT FAULT DIAGNOSIS

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Abstract - The paper is structured in four parts. The first part includes the importance of the power transformers' in the power system. The second part presents the techniques for incipient fault diagnosis. In the third part it is introduced a diagnosis program which identifies different types of faults using the techniques presented and artificial intelligence, being given the result obtained with the program.

Keywords: diagnosis, dissolved gas analysis, fault, transformer

1. INTRODUCTION

Power transformers are major power system equipment. The faults which can appear in power transformers can interrupt the distribution of electricity leading to important losses. The lifetime of the power transformers is influenced mainly by the lifetime of the weakest subsystem. The insulation is considered to be the weakest part from material point of view, this being thermally, electric and mechanically stressed during the operation of the power transformers.

Each thermal, electric or combined fault is accompanied by a significant generation of different gases. So, the dissolved gases in oil are keys identifiers of incipient faults and can be generated in certain models and quantities depending on the fault characteristics. The qualitative and quantitative determination of the dissolved gases in oil can have a great importance for the evaluation of the fault and further the reliable operation of the transformers.

The selection of a monitoring and diagnosis system is determined mainly by two purposes, and namely, the failures must be promptly recognized, in order to avoid critical states, and on the other way, the maintenance works to be planned only if the state of the equipment needs it.

2. TECHNIQUES FOR INCIPIENT FAULT DIAGNOSIS

The dissolved gas analysis is the most efficient instrument for recognising and classification of thermal and electrical faults.

The evaluation of the measurements can be made according to the following:

- IEEE C57.104-2008
- IEC 60599

Different diagnosis schemes were developed for DGA interpretation. [1]

These methods try to present the relationships between gases and fault conditions. These criteria include the key gas method and the gas ratio method based on the variations with temperatures at which the materials are exposed to.

The proportion of each gas concentration depends on the type and severity of the fault. Partial discharges (low energy), thermal faults and arcing (high energy discharges) are the main faults which can be identified by the DGA techniques. [2]

The most used DGA techniques are Rogers, IEC 60599, Doernenburg and Duval. Each technique uses some of the ratios of gases for the faults diagnosis, and other techniques compare the gas concentrations with the levels specified for the transformer state evaluation. [3-8].

The gases inside the transformer start to form at specific temperatures. Hydrogen and methane start to form in small quantities around 150°C, while ethane starts to be produced at about 250°C and ethylene is produced at 350°C. Acetylene starts to be produced between 500 and 700°C. [3]

Between 200 and 300°C the ethane quantity overcomes the hydrogen quantity. Starting with 275°C the ethane quantity overcomes the methane quantity. Around 450°C, the hydrogen production overcomes all the others until close to 750-800°C, and then is produced more acetylene. Small hydrogen quantities, methane and carbon dioxide are produced by the normal aging.

2.1. Key Gas Technique

The first step is represented by the establishment if there is or isn't a fault by using the IEEE method. Only when these levels overcome a certain threshold is suspected a fault. The second step is represented by the determination of the fault type.

The diagnosis with the help of key gases method is based on the predominance of a certain gas in relation with Total Combustible Gas (TCG) from the insulating oil. TCG is calculated by adding the hydrogen, methane, ethane ethylene acetylene and carbon dioxide concentrations which can be found dissolved in oil. [5].

Table 1. Dissolved key gas concentration limits in ppm [6]

State	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2	TCG
Cond.1	100	120	35	50	65	350	2500	720
Cond.2	101-700	121-400	36-50	51-100	66-100	351-570	2500-4000	721-1920
Cond.3	701-1800	401-1000	51-80	101-200	101-150	571-1400	4001-10000	1921-4630
Cond.4	>1800	>1000	>80	>200	>150	>1400	>10000	>4630

Condition 1: The total combustible gas under this level indicates that the transformer operates normally.

Condition 2: The total combustible gas from this class indicates a higher level of combustible gas than the normal one. A fault can be present.

Condition 3: The total combustible gas from this class indicates a high level of decomposition of the cellulose and/or oil insulation.

Condition 4: The total combustible gas from this class indicates the excessive decomposition of the cellulose and/or oil insulation. Continuing operating could result in a failure of the transformer.

2.2. Duval Triangle Technique

This method uses only three hydrocarbons: methane, ethylene and acetylene. These three gases correspond to the increased levels of energy necessary to generate gases in the operating transformers. Acetylene and ethylene are used in all the interpretation methods as representing high energy faults and high temperature faults.

Firstly, it is determined if there is a problem using IEEE method. At least one of the hydrocarbons or the hydrogen must be in the condition 3 and raises from a generating rate from the table below before a problem to be confirmed. In order to use the table without the IEEE method, at least one of the individual gases must be at level L1 or over and the generation rate at least G2. Limits L1 and generation rates of the gases are more reliable than the IEEE method. There must be used both methods to confirm that the problem exists.

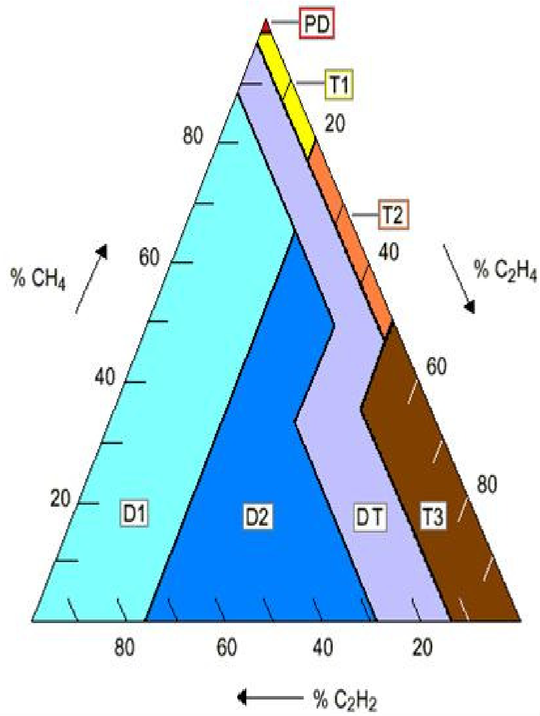

Fig.1. Duval Triangle

with: PD – partial discharges

T1 – thermal fault, <300°C

T2 – thermal fault, 300÷700°C

T3 – thermal fault, >700°C

D1 – low energy discharges

D2 – high energy discharges

DT – combination between thermal and electrical faults

Table 2. Limits and generation rates limits per month in ppm

Gas	Limits L1	Limits G1	Limits G2
H_2	100	10	50
CH_4	75	8	38
C_2H_2	35	3	3
C_2H_4	75	8	38
C_2H_6	75	8	38
CO	700	70	350
CO_2	7000	700	3500

It is calculated the quantity of the three gases used in the triangle generated since it began the sudden increase in the gas. The extraction of the gas quantity priority generated at the sudden increase will give the gas quantity generated since the fault has begun.

There are calculated the three numbers (differences) obtained from the step before. This gives a 100% percentage of the three key gases generated since the fault appeared.

Each difference of individual gases is divided with the total difference of the gases obtained before, resulting the percentage of increase of each gas from the total increase.

It is noted the percentage of each gas on the Duval triangle, starting with indicated part for the particular gas.

2.3. Doernenburg ratio method

This method made the difference between thermal and electrical faults using four ratios and six gases. In the table below are presented the gases and the ratios used.

Table 3. Definition of the ration from ratios methods

Ratio	CH_4/H_2	C_2H_2/C_2H_4	C_2H_2/CH_4	C_2H_6/C_2H_2	C_2H_4/C_2H_6
Abrev.	R1	R2	R3	R4	R5

The method has more validation tests before taken the final decision and usually fails. The most important validation test is L1 – standard test, which establishes a critical level for each gas. In order to apply this method, at least one gas from each ratio must overcome the standard corresponding to L1. The limits are given in the following table.

Table 4. Limit L1 Doernenburg

Gas	H_2	CH_4	CO	C_2H_2	C_2H_4	C_2H_6
Limit	100	120	350	35	50	65

Table 5. Doernenburg ration method

Fault	R1	R2	R3	R4
Thermal decomposition	>1.0	<0.75	<0.3	>0.4
Corona	<0.1	insignificant	<0.3	>0.4
Arcing	>0.1and <1.0	>0.75	>0.3	<0.4

2.4. Rogers ratios method

The original method uses the table below for diagnosis where 1 indicates that the actual value is 1 and 0 indicates that the actual value is less than 1.

Table 6. Original Rogers method diagnosis

CH_4/ H_2	C_2H_6/ CH_4	C_2H_4/ C_2H_6	C_2H_2/ C_2H_4	Diagnosis
0	0	0	0	If CH_4/H_2 is 0.1or more →partial discharges, otherwise normal deterioration
1	0	0	0	Insignificant overheating – under 150ºC
1	1	0	0	Insignificant overheating – 150-200ºC
0	1	0	0	Insignificant overheating – 200-300ºC
0	0	1	0	Overheating of the main conductor
1	0	1	0	Circulating currents

The improved Rogers method uses two tables: one defining the code and the other defining the diagnosis rules. These preliminary methods use four ratios. The ratio C_2H_6/CH_4 indicates a limited class of decomposition temperature, but it doesn't help at the fault identification.

Table 7. Defining the code for improved Rogers method

Ratio	Class	Code
CH_4/H_2 (R1)	<0.1	5
	0.1<R1<1	0
	1<R1<3	1
	>3	2
C_2H_6/CH_4 (R4)	<1	0
	>1	1
C_2H_4/C_2H_6 (R5)	<1	0
	1<R5<3	1
	>3	2
C_2H_2/C_2H_4 (R2)	<0.5	0
	0.5<R2<3	1
	>3	2

Table 8. Diagnosis of improved Rogers method

R1	R4	R5	R2	Diagnosis
0	0	0	0	Normal deterioration
5	0	0	0	Partial discharges
1 or 2	0	0	0	Insignificant overheating – under 150ºC
1 or 2	1	0	0	Insignificant overheating – 150-200ºC
0	1	0	0	Insignificant overheating – 200-300ºC

Formation of CO_2 and CO from the degradation of paper impregnated with oil rises rapidly with the temperature. The ratios CO_2/CO smaller than 3 are considered an indication of possible involvement of paper in an electrical fault, together with a paper carbonization.

The normal Ratios for CO_2/CO are around 7. Ratios over 10 indicate a thermal fault with the involvement of cellulose. The ratio CO/CO_2 is used as main factor at the diagnosis of the cellulose degradation.

In the following table are presented the advantages and disadvantages of the main methods used in the dissolved gas analysis.

Rogers ratios method	
Advantages	Disadvantages
Has the ability to ignore small errors	It's not capable to use multiple faults
Uses three or four ratios	Hard to calculate. The reports can generate codes which don't have comments
Understandable comments	Are necessary enough gases
IEC 60599	
Advantages	Disadvantages
Has the ability to ignore small errors	It's not capable to use multiple faults
Uses three ratios	Hard to calculate
Easy to understand comments	Are necessary enough gases (the gases must overcome the minimum level)
Internationally recognized	The reports can generate codes which don't have comments
Continuous update by IEC	
Doernenburg ratios	
Advantages	Disadvantages
Has the ability to ignore small errors	Has only three levels of diagnosis, being very limited
Uses four ratios	Hard to calculate
	Are necessary enough gases (the gases must overcome the minimum level)
	The reports can generate codes which don't have comments
Duval triangle	
Advantages	Disadvantages
Graphic interpretation	Hard to build
Easy establishment of the problem	Time consuming
	Wrong interpretation at very small gas concentrations

Table 9. Advantages and disadvantages

3. DIAGNOSIS PROGRAM

For a diagnosis system of transformers, it is needed to obtain some rules. For guidance there can be use IEC or IEEE. These are revised from time to time and need a correct interpretation of the rules.

Figure below represents a part of a power transformer diagnosis engine using the IEEE conditions and ratio method. The rules are represented in IF-THEN structure.

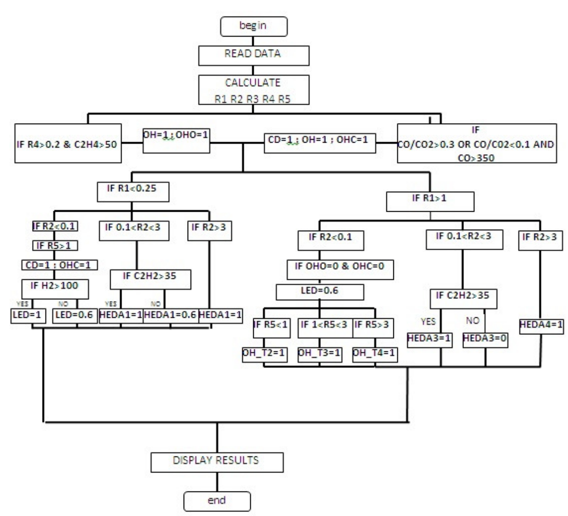

Fig. 2. Power transformer fault diagnosis engine

The input data considered for the drafted program are the gas concentrations given in ppm, and namely:

- Hydrogen
- Methane
- Ethane
- Ethylene
- Acetylene
- Carbon monoxide
- Carbon dioxide

R1, R2, R3, R4, R5 represent ratios between gas concentrations and namely:

R1=CH4/H2;
R2=C2H2/C2H4;
R3=C2H2/CH4
R4=C2H6/C2H2;
R5=C2H4/C2H6.

Verification of the program functionality was made with the following input data:

Table 10. Verification case

Normal operating case	**Faults operating case**
H2=120 CH4=100 CO=350 C2H2=5 C2H4=50 C2H6=65 C02=2500 R1=0.833333 R2=0.1 R3=0.05 R4=13 R5=0.769231	C:\PROGRA~2>program H2=120 CH4=100 CO=360 C2H2=5 C2H4=50 C2H6=65 C02=4000 After execution of the program the following information is obtained: R1=0.833333 R2=0.1 R3=0.05 R4=13 R5=0.769231 Cellulose degradation Overheating of cellulose

5. CONCLUSION

To manage the life of transformers, to reduce failures and to extend the life of the transformer, some tests must be taken. The tests are carried out to prove that the transformers are ready to operate or to find the faults.

Equipment failures do occur even with the best equipment designs available and using the best utility practices. In order to operate a power system reliably, transformer failures must be anticipated.

Dissolved gas analysis is very important to determine the condition of a transformer, it can identify a problem such as: deteriorating insulation oil, overheating, partial discharge and arcing.

The transformers have different gassing characteristics because of their size, structure, manufacture, loading and maintenance history.

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