FAULT INTERPRETATION OF POWER APPARATUS USING HEXAGON BASED DISSOLVED GAS ANALYSIS

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Abstract

In protecting a Power Apparatus (PA), the limiting of damage becomes a by product of the protection system function. To interpret the type of fault by analysing the dissolved gases, a simple algorithm incorporating all the different zone areas for fault interpretation is developed and implemented in this paper. To interpret the faults occurring in power apparatus like Power Transformers (PT), Load Tap Changers (LTC) and Bushings from the Dissolved Gas Analysis (DGA) data, the Hexagon algorithm is developed that interprets the faults when the DGA data is imported. DGA data samples collected from various substations are used to test this algorithm for fault interpretation. In this Hexagon algorithm the data of fault gases from various Power Apparatus evolved from mineral as well as non mineral, cooling and insulating media is given as input and the type of fault interpreted by the algorithm is obtained as output. All the cases of equipments and insulating media can be tested using this Hexagon algorithm. This window based Hexagon results are useful for control and protection of electricity in transmission and distribution side.

Keywords

Dissolved Gas Analysis (DGA), Power Apparatus, Power Transformers (PT), Hexagon, Fault Interpretation.

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1. Introduction

Power apparatus Power Transformers (PT), Load Tap Changers (LTC) are key elements in a power system. Failure of any one may cause long interruptions of the power supply. It is therefore highly desirable to detect incipient failure as early as possible. A wide variety of electrical and mechanical approaches can be applied to early detection of faults. For the interpretation of the type of fault a simple algorithm is developed by analysing the dissolved gases.

The window based Hexagon is useful for data sets pertaining to DGA of mineral or non mineral oil in PT, LTC or Bushings. Gas chromatography help the electrical power engineer to device techniques for the identification of fault gases dissolved in transformer insulating oil from the early nineteen sixties [1]. An IEEE standard (C57.104-1991) [2] introduced the DGA as one of the most accepted methods for detecting incipient fault conditions in PTs. The correlation between the DGA and the corresponding fault conditions in the transformers has been well established and formulated and for the routine monitoring of in-service transformers it is used over the past five decades [3]. IEC Standard 60599 and

IEEE Standard C 57 provide guidance for the interpretation of DGA results in service [4].

In addition to mineral oil non mineral oils like Midel, Silicone, FR3, and Biotemp are increasingly used as insulating liquids in electrical equipments because they are less flammable and more environmentally friendly. The non mineral oils have high percentage of biodegradability and are more hygroscopic in nature. Due to their high percentage of biogradability and more hygroscopic than mineral oils non mineral oils are slowly introduced into applications like PA insulation and cooling purposes in order to replace the mineral oils as the non mineral oil also has the same DGA fingerprints as mineral oil [5].

Due to its speciality of arc quenching ability, non mineral liquids evolve gas only by one fourth of the gas that would have been produced by the regular transformer oil [6], [7]. In this work a simple algorithm is developed in Java platform to interpret faults

- in equipments like LTC filled with mineral oil and non mineral oils
- in equipments for low temperature faults where stray gassing of oils may interfere with diagnostics and
- in Power Transformer (PT) immersed in mineral oil

The number of characteristic faults due to thermal stress and electrical stress are classified as seven by Duval by using the relative percentages of three gases namely Methane (CH_4), Ethylene (C_2H_6) and Acetylene (C_2H_2). These three gases correspond to the increasing levels of energy necessary to generate gases in transformers in service [8].The gas ratios as well as the relative proportions of gases and the rules from case studies are used for fault diagnosis from DGA data of mineral oil [9]. A combination of neural network and fuzzy system for enhancing the performance of the diagnostic system has been presented to identify only five types of faults [10].

Faults have been analysed and compared with the conventional methods but none of the non mineral liquids have been considered [11]. Wavelet network methodology was proposed to monitor the condition of PT immersed in mineral oil [12]-[14]. Visually presented information can be accessed by human perception in a most natural way. Complex structures and relation can be perceived in less time in greater number and with fewer errors than in any other way. Models of the real world or Models of abstract concepts are hardly dealt with by humans without taking resort to visual representations. This is the reason why the prediction of faults by visual presentation has been proposed. In this paper DGA data samples collected from various substations are used fault interpretation.

2. Interpretation of Fault Gases

In the DGA method oil samples are taken from the transformer at various locations. Then, chromatographic analysis will be carried out on the oil sample to measure the concentration of the dissolved gases. The extracted gases are then separated, identified and quantitatively determined such that the DGA method can then be applied to obtain reliable diagnosis. The extracted gases meant for analysis purpose are Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen (N_2) and Oxygen (O_2). C_2H_2 and C_2H_4 are used in all interpretation methods to represent high energy faults such as arcing and high temperature faults.

H_2 is preferred in several of these methods to represent very low energy faults such as PDs, where it is produced in large quantities. CH_4, however, is also representative of such faults and always formed in addition to H_2 in these faults. CH_4 has been chosen rather than H_2 because it not only allows identifying these faults, but provides better overall diagnosis results for all the other types of faults than when using H_2. For the interpretation of faults The Duval Triangle was developed by Michel Duval in 1974 using three of these hydro carbon gases in relative proportions of percentage. Michel Duval proposed regions to represent seven types of faults. The fault zone boundaries proposed by Michel Duval slightly differ when the insulation media differs with different sets of fault gases. The electronic version of the Duval Triangle has to be changed every time when the type of Power Apparatus or the type of insulation media changes.

To save time and memory a single algorithm is implemented in this paper incorporating all the different zone areas for fault interpretation regardless of whether it is a mineral oil or nonmineral oil. The Interpretation of Faults in the proposed Algorithm Hexagon is listed in Table-1. If the data pertains to P3, the algorithm checks for four cases of non mineral liquids, via, Silicone, FR3, Biotemp and Midel. These polygons uses the same types of fault gases but their zone boundaries are slightly differ. So they are designated as P3S, P3F, P3B and P3M representing Polygon3 for Silicone, Polygon 3 for FR3, Polygon 3 for Biotemp and Polygon 3 for Midel respectively. For interpretation of faults in both mineral oil and FR3 (Non mineral oil P6) at low temperatures (P4),the fault gases of importance are H_2, CH_4 and C_2H_6. As the Polygon 4 and Polygon 6 differ in their inner zone boundaries alone, they are represented by the same polygon with difference in zone boundaries.

Location of Point inside the Polygon (Gas Type)/Zone		**Interpretation of Type of Fault**
Polygon	**Zone**	
P1	PD	Partial Discharge
(CH_4,C_2H_4,C_2H_2)	D1	Discharges of low energy
	D2	Discharges of high energy
	T1	Thermal faults of temperature < 300^0C
	T2	Thermal faults of temperature 300^0C< T < 700^0C
	T3	Thermal faults of temperature >700^0C.
	DT	Combination of Thermal and Electrical Fault.
P2	N	Normal
(CH_4,C_2H_4,C_2H_2)	T3	Thermal faults of temperature >700^0C.
	X3	Fault T3 or T2 in progress, or severe arcing D2
	T2	Thermal faults of temperature 300^0C< T < 700^0C
	D1	Abnormal Arcing D1
	X1	Thermal fault in progress
P3	PD	Partial Discharge
P3S	D1	Discharges of low energy
(CH_4,C_2H_4,C_2H_2)	D2	Discharges of high energy
P3F	T1	Thermal faults of
(CH_4,C_2H_4,C_2H_2)		temperature < 300^0C
P3B	T2	Thermal faults of
(CH_4,C_2H_4,C_2H_2)		temperature
P3M	T3	300^0C< T < 700^0C
(CH_4,C_2H_4,C_2H_2)	DT	Thermal faults of

		temperature > 700^{0}C. Combination of Thermal and Electrical Fault.
P4 (H_2,CH_4,C_2H_6)	PD S C O	Corona Partial Discharges Stray Gassing of Mineral Oil Hotspots T > 300^{0}C Overheating T < 250^{0}C
P5 (CH_4,C_2H_4,C_2H_6)	PD S C O T3	Corona Partial Discharges Stray Gassing of Mineral Oil Hotspots T > 300^{0}C Overheating T < 250^{0}C Thermal faults of very high temperature >700^{0}C.
P6 (H_2,CH_4,C_2H_6)	PD S C O	Corona Partial Discharges Stray Gassing Hotspots T > 300^{0}C Overheating T < 250^{0}C
P7 (CH_4,C_2H_4,C_2H_6)	PD S C O	Corona Partial Discharges Stray Gassing Hotspots T > 300^{0}C Overheating T < 250^{0}C

Table -1: Interpretation of faults in the proposed Hexagon

3. Proposed Hexagon in Java Platform

For speedy and easy interpretation of faults in any type of power apparatus, a window based Hexagon is developed to determine visually whether a fault evolves from a relatively harmless thermal fault into a potentially more severe electrical one or not. The Hexagon consists of number of polygons as shown in figure 1 with respect to that listed in Table 1. The result of implementation of generating the electronic form of hexagon with the fault coordinates M, N, H, I, J, K obtained inside the different fault zones on implementation of the algorithm is presented in figure 2. The user friendly phase to import DGA data in is presented in figure 3; the user can select the option of his choice by clicking the buttons.

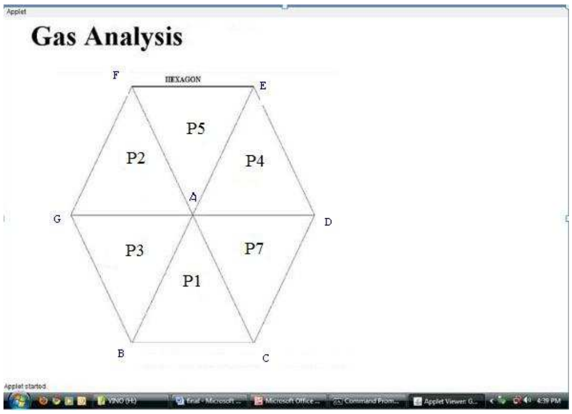

Figure 1: hexagon divided into six polygons P1, P2, P3, P4, P5, and P7 with each side of each polygon representing a gas value in % (P6 is same as P4)

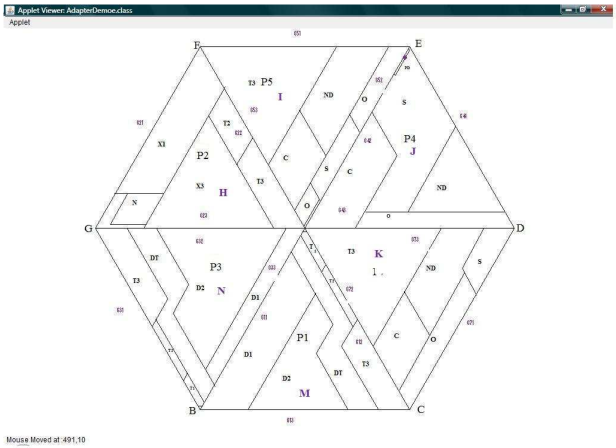

Figure 2: Fault Co-ordinates M, N, H, I, J, K

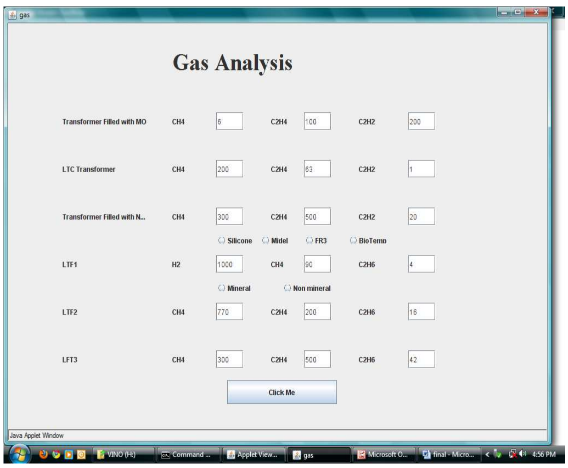

Figure 3: Sample window of Phase II function

The algorithm is implemented using the Cartesian Co-ordinate system. The abscissa values of rectangular co-ordinate systems remains the same for the Processor Co-ordinate System, but the ordinate values are changed by subtracting from the maximum value of the screen resolution. The algorithm developed in this work adopts modular fashion minimizing the number of "go to" statements.

Hexagon algorithm when implemented in window based Java, first draws the Hexagon with polygons and inside zones and then checks the presence of O_2 and N_2 from the "n" number of DGA data imported to it. If $O_2 / N_2 < 0.3$, then the algorithm tests the Total Combustible Gases (TCG) value and proceeds for further calculation of co-ordinate values corresponding to gas values in percentages of parts per million (ppm) and interpretation of fault. The DGA data imported are integer values and the relative proportions of the gas values are real values.

With respect to coordinates of B (BX and BY), all the coordinates are computed by letting the length of each side of the Hexagon as L. The fault coordinates are calculated taking relative proportions of gas values G11, G12 etc in percentage. For the points that lie on the boundary lines, the probability of the type of fault is predicted by computing a small circular area around that point and evaluating the maximum number of predicted types inside the circle. The fault on the boundary then will be included to the type of fault which resulted as maximum cases of prediction. For example in Polygon 5 in figure1 (b), if the point lies on the zone boundary between C [Hot spot with carbonization of paper ($T>300^0C$)] and T3 [Thermal faults of very high temperatures ($T > 700^0C$)], the maximum number of predicted fault around that point if computed belong to T3, then the fault point under prediction is included into the maximum predicted case of fault i.e. T3.

4. Experimental Results

Java provides facilities to the programmer to define a set of objects and a set of operations (methods) to operate on that objects. All types of data are declared as per standard syntax of java. On compilation of the Algorithm Hexagon shown in Section 3, the results are visually presented.

The software for interpreting the faults in transformers is designed in java platform by developing a Hexagon where all the faults are interpreted. This algorithm provides more flexibility in diagnosing the faults occurring in PT, LTC and PA immersed in mineral and non mineral liquids. This software is designed in such a way that data obtained from DGA for various PA which differ in insulation media employed in them can be used for importing input at an instant of time. The results obtained for few sets of data samples listed in Table 2 are presented in Figure 4.The dots display the interpretation of the faults inside the respective zones.

Samples	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO_2
I	46	168	37	286	2	840
II	64	224	49	376	2	1164
III	38	219	52	377	1	1340
IV	29	189	75	353	2	1454
V	14	67	42	111	0	1223
VI	22	94	43	138	3	1823
VII	25	96	50	158	6	1964

Table-2: Data Samples from Power Transformer 16 MVA, 110/11kV

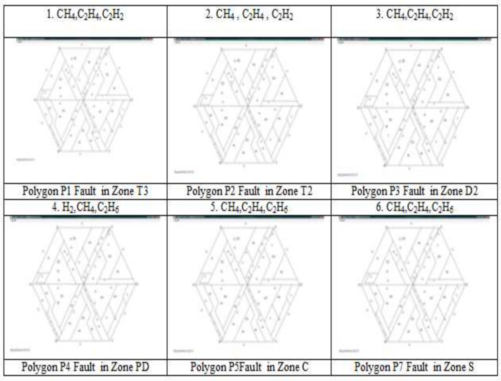

Figure 4: Visual Presentation of the results for sample datasets

5. Conclusion

In this paper, a simple algorithm incorporating all the different zone areas for fault interpretation is developed and implemented. The proposed system gives the indication of fault type and helps the control engineer to be caucious to protect the power apparatus before failure takes place by analyzing the severety of the fault. Experimental result verifies the effectiveness of the Hexagon algorithm, so it is useful for control and protection of electricity to increase the reliability of power system.

References

[1] Michel Duval IREQ Canada, "A Review of faults detectable by Gas in Oil Analysis in Transformers," *IEEE EI Magazine* vol.18, no.3, pp. 8-17, June 2002.

[2] Mohammad Golkhah,Sahar Saffar Shamshirgar and Mohammad Ali Vahidi, "Artificial Neural Networks applied to DGA for fault diagnosis in oil-filled power transformers," *JEEER* ,vol.3(1),pp.1-10, January 2011.

[3] M.Dural,Hydro-Quebec, "Dissolved Gas Analysis: It Can Save Your Transformer," *IEEE EI, Magazine,* vol-5, no.6, pp. 22-27, 1989.

[4] Jyotishman Pathak,Yong Jiang,Vasant Honavar,James McCally, "Condition Data Aggregation with Application to Failure Rate Calculation of Power Transformers," in *Proc. System Science Conf. Hawaii*, pp. 1- 10, 2006.

[5] Imad –U-Khan,Zhongdong Wang and Ian Cotton,&Susan NorthCote , "Dissolved gas Analysis of Alternative fluids for Power Transformers," *IEEE EI Magazine* , vol.23, no.5, pp. 5-14, 2007.

[6] T.V.Oommen, "Vegetable oils for Liquid-filled Transformers," *IEEE EI., Magazine*, vol. 18.no.1 pp. 6-11, 2002.

[7] I.Hohlein, "Unusual Cases of Gassing in Transformers in service," *IEEE EI Magazine*, pp.24-27, 2006.

[8] Michel Duval(IREQ), "The Duval Triangle for Load Tap Changers, Non mineral oils and low temperature faults in transformers," *IEEE EI* Magazine vol.24, no.6,pp 22-29, Dec 2008.

[9] Xiaohui Li,Huaren Wu and Danning Wu, "DGA Interpretation Scheme Derived From Case Study," *IEEE Trans. Power Del.*, vol.26, no.2, pp. 1292 – 1293, April 2011.

[10] R.Naresh,Veena Sharma and Manisha Vashisth, " An Integrated Neural Fuzzy Approach for Fault Diagnosis of Transformers, " *IEEE Trans.Power Del.*, vol.23, no.4, pp 2017-2024, Oct.2008.

[11] N.A.Muhamad,B.T.Phung ,T.R.Blackburn and K.X.Lai, "Comparative study and Analysis of DGA methods for Transformer Mineral Oil," in *Proc.Power Tech. Conf.*, pp.45-50, 2007.

[12] Yann.Chang Huang and Chao.Ming Huang, "Evolving wavelet networks for Power Transformer Condition Monitoring," *IEEE Trans. Power Del.*,vol.17,no 2, pp. 412-416, April 2002.

[13] M.Duval and A.dePablo, "Interpretation of Gas-in-Oil Analyses Using New IEC

Publication 60599 and IEC TC10 Databases," *IEEE EI Magazine*, vol.17, no.2, p.31, 2001.
[14] C.E.Lin,J.M.Ling,C.L.Huang, "An Expert System for Transformer Fault Diagnosis Using Dissolved Gas Analysis," *IEEE Trans. Power Del.,* vol 8,no.1, pp. 231-238, January 1993.