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Oil Chromatographic Analysis of First HVDC Converter Transformers Project in Pakistan – A real Project Case Study

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Abstract - This paper presents the concept of the creation of gasses inside the transformer oil and the fault produced inside the transformer is examined. Focusing on the issue of numerous trademark gases surpassing the norm in a 500 kV transformer oil, this paper dissects the issues keeping in view the trademark gas strategy and three-ratio technique and joined with prior tests, it was decided that the single-phase converter transformer Pole 1-YDA. The on-location review proves the rightness of the disappointment investigation results and the corresponding measures were taken on to dispense with the transformer flaws.

***Key Words*:** Converter Transformers, DGA, HVDC, Internal Faults.

1. INTRODUCTION

Transformer oil is the fundamental protection of a converter transformer. Notwithstanding its elements of protection and cooling, it likewise conveys the data regarding inside imperfections of the converter transformers. The idle shortcoming of the transformer can be found by chromatographic investigation of broken up gas in transformer oil [1]. Incomplete overheat and fractional release will cause the breakdown of transformer oil and strong protection, which will create gas inside the converter transformer. How much gas delivered increments with the expansion of the energy thickness at the shortcoming point. Essentially three gasses are noted by testing the oil of converter transformers "H2", "C2H2" and "TotHyd" [2]-[3].

During the work transformers are presented to electrical, warm and mechanical burdens, prompting debasement of the protection. The outcomes are quick to compound responses and corruption of materials (out of which many are framing gases in the oil or more), harm to the protection, decrease of functional wellbeing, and at last disappointment or breakdown. Reasons for framing gases can be characterized into three classes: crown or halfway release, pyrolysis (deterioration of substances affected by high temperatures), warm decay and starts.

The majority of the energy is delivered during sparkles, trailed by overheating, and ultimately because of the presence of the crown. Gases that show up during the issue are normal for corruption of the protection framework: hydrocarbons, carbon oxides and gases which don't come from disappointments [4]-[5].

Electrical or warm disappointment can cause a few C-H and C-C bonds in transformer oil to break, with the development of modest quantities of receptive hydrogen molecules and unsound hydrocarbon revolutionaries. Through complex substance responses, H2 and low sub-atomic hydrocarbon gases are framed. A limited quantity of CO and CO2 is delivered when the transformer oil is oxidized [6]-[7].

Transformer oil is broadly utilized in electric hardware like transformers, reactors and transformers. Transformer oil is the primary protection of oil-submerged transformers. Notwithstanding its elements of protection and cooling, it is additionally the transporter of data about interior imperfections of transformers [8]. The inert shortcoming of the transformer can be found by chromatographic investigation of disintegrated gas in transformer oil. Halfway overheating and fractional release will cause the breakdown of transformer oil and strong protection, which will create gas. Shortcomings in a transformer additionally in some cases lead to the debasement of protection materials and oil. How much gas created increments with the increment of the energy thickness at the issue point.

At the point when the substance of the trademark gas in the transformer oil surpasses the predetermined consideration esteem, a follow-up investigation ought to be performed. The person and sort of shortcoming not set in stone by the technique for trademark gas judgment. Guide for investigation and assurance of disintegrated gases in transformer oil. [9] When the grouping of some trademark part gases in the running transformer oil arrives at a specific worth, for instance, φ(C1+C2)>150μL/L or φ(C2 H2)>5μL/L or φ(H2)>150μL/L, consideration ought to be paid to the transformer. Yet, it doesn't actually intend that there should be a transformer issue as of now. We want to consolidate the recorded information to artificially pass judgment on the running condition of the transformer [10]-[11].

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Table 1 Gases produced by different fault types

Fault type	Main gas composition	Secondary Gas composition
oil superheat	CH_4, C_2H_4	H_2, C_2H_6
oil and paper superheat	CH_4, C_2H_4, CO, CO_2	H_2, C_2H_6
Oil and insulation paper partial discharge	H_2, CH_4, CO	C_2H_2, C_2H_6, CO_2
Spark discharge in oil	H_2, C_2H_2	
Arc in oil	H_2, C_2H_2	CH_4, C_2H_4, C_2H_6
Electric arc in oil and insulating paper	H_2, C_2H_2, CO, CO_2	CH_4, C_2H_4, C_2H_6

Electrical or warm disappointment can cause a few C-H and C-C bonds in transformer oil to break, with the development of modest quantities of receptive hydrogen iotas and temperamental hydrocarbon revolutionaries. Through complex compound responses, H2 and low sub-atomic hydrocarbon gases are shaped. A limited quantity of CO and CO2 is delivered when the transformer oil is oxidized [12]-[13].

The trademark gas parts of various transformer flaws are unique, and the fault type can be decided by table 1. Simultaneously, it should be noticed that dampness in the water or gas rises in the oil might build the hydrogen content [14]-[15].

Transformers and other oil-filled gear in ordinary working circumstances, the hotness created isn't to the point of breaking carbon bonds or dehydrogenating hydrocarbons. At the point when there are a few issues in the hardware, the energy created can break the obligations of hydrocarbon mixtures and produce low sub-atomic hydrocarbons or hydrogen [16]. The pyrolysis gas at low temperature is overwhelmed by immersed hydrocarbon, while the pyrolysis gas at high temperature is overwhelmed by alkenes.

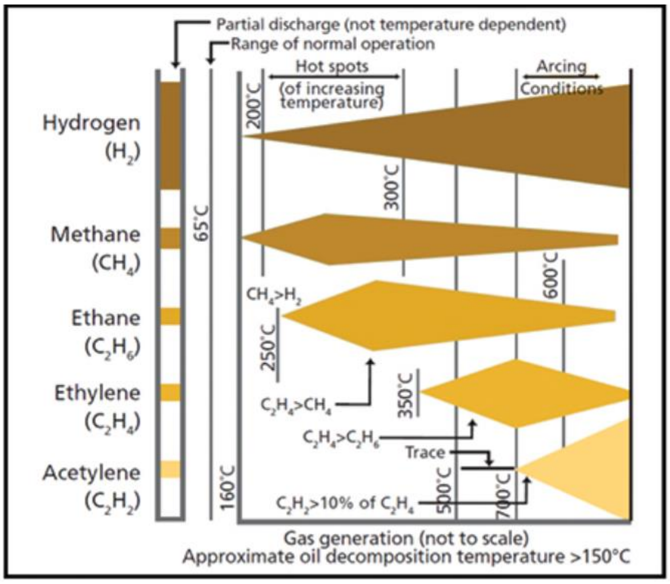

Fig. 1. The appearance of flammable gases at an average temperature of oil decomposition

The connection between the kind of gas delivered by the shortcoming and the fault temperature is displayed in Fig. 1. With the increment of issue energy, the arrangement of parts in pyrolysis gas is alkanes, alkenes and alkynes [17]-[19]. As per the various proportions of the volume parts of trademark gases, we can decide the transformer shortcoming type and general position. This technique is the most generally involved strategy for the shortcoming understanding. In this three-proportion strategy, the proportions of gas focuses are utilized for the translation reason [20]. The singular gases used to decide every proportion and its relegated limits are displayed in Table II. Codes are then dispensed by the worth acquired for every proportion and the comparing issue described.

Table II Three ratio method codes

Ranges of gas ratios	**Codes of different gas ratios**		
	R1	R2	R3
	C2H2/C2H4	CH4/H2	C2H4/C2H6
<0.1	0	1	0
0.1-1	1	0	0
1-3	1	2	1
>3	2	2	2

Oil chromatogram analysis investigation of converter transformer (Lahore converter station) was performed from 1/10/2021 to 15/12/2022 which shows the analysis of hydrogen, carbon monoxide, carbon dioxide, hydrocarbon gas, acetylene and was compared with traditional values of the gasses present inside the converter transformer as displayed in Table III. These kinds of faults that may be delivered inside transformer oil are fractional release, the release of low and high energy, the warm issue under 300 °C, beneath 300°C to 700°C and more prominent than 700°C.

The type of faults that may be introduced in the converter transformers are partial discharges of low energy density, partial discharges of high energy density, discharges of low energy density, discharges of high energy density, thermal fault of low temperature <150˚C, thermal fault of low temperature 150˚-300 ˚C, thermal fault of medium temperature 300 ˚-700˚C and thermal fault of high temperature >700 ˚C.

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Table III Three ratio method prior analysis

Fault type	C2H2/C2H4	CH4/H2	C2H4/C2H6
No fault	0	0	0
Partial discharges of low energy density	0	1	0
Partial discharges of high energy density	1	1	0
Discharges of low energy density	1 or 2	1 or 2	1 or 2
Discharges of high energy density	1	0	2
Thermal fault of low temperature <150˚C	0	0	1
Thermal fault of low temperature 150˚-300 ˚C	0	2	0
Thermal fault of medium temperature 300 ˚-700˚C	0	2	1
Thermal fault of high temperature >700 ˚C	0	2	2

2. SIMULATION ANALYSIS

On December 15, the Pak Matiari Lahore Transmission Company (PMLTC) organized a dissolved gas analysis (DGA) for the transformer, and the tester directed an analytic test on the transformer. Test things incorporate DC obstruction, bushing dielectric misfortune, winding dielectric misfortune, hamper and protection things. Among them, the information of transformer DC obstruction, bushing dielectric misfortune and protection opposition, winding ring misfortune and protection obstruction meet the prerequisites of the guidelines, and the information is typical. The caution and obstructed upsides of various gasses are displayed in Table IV.

Table IV Alarm and blocked parameters

Gasses	Alarm Value (ppm)	Blocked Value (ppm)
H2	120	150
C2H2	0.8	1.0
Tot Hyd	120	150
CH4	60	120
C2H4	25	50
C2H6	33	65

DGA is viewed as the best strategy for deciding a transformer's general condition and is presently a widespread practice. Benefits of DGA incorporate timely guidance of creating deficiencies, status minds new and fixed unit, advantageous planning of fixes, and checking of units under potential over-burden conditions. The utilization of proper DGA analytic techniques can offer better assistance dependability, aversion of transformer disappointment, and conceded capital consumptions for new transformer resources. To guarantee a positive outcome, we will examine the instruments accessible for DGA and how to appropriately decipher the outcomes [21]-[23].

The C2H2 gas found in the Pole 1-YDA converter transformer oil is shown in Fig. 2.

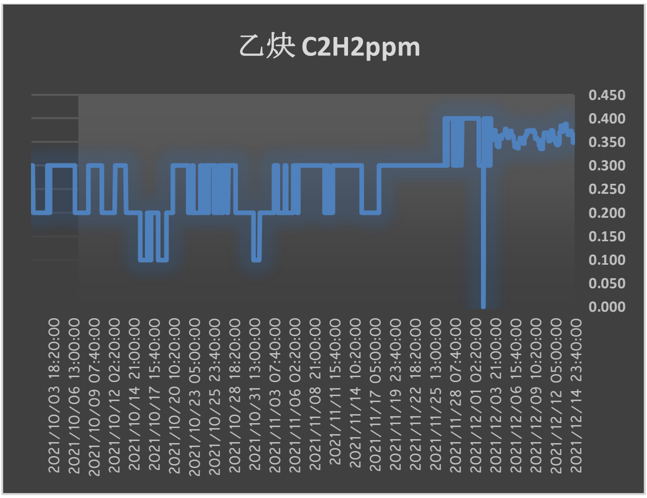

Fig. 2. C2H2 of Pole 1-YDA converter transformer

H2 gas found in the Pole 1-YDA converter transformer oil is shown in Fig. 3.

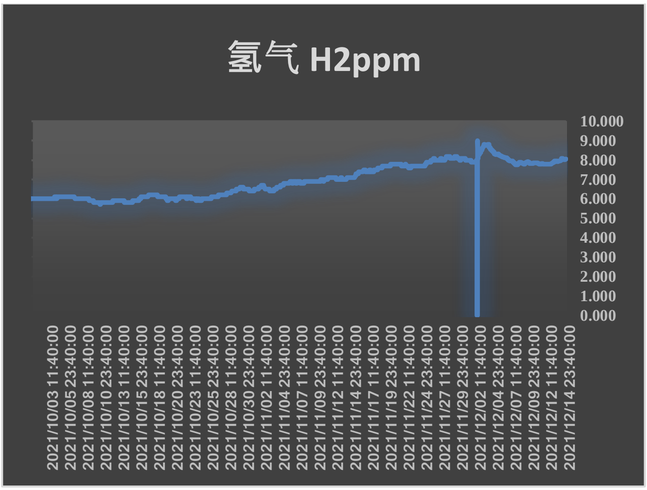

Fig. 3. H2 of Pole 1-YDA converter transformer

Total Hydrogen gas found in the Pole 1-YDA converter transformer oil is shown in the Fig. 4.

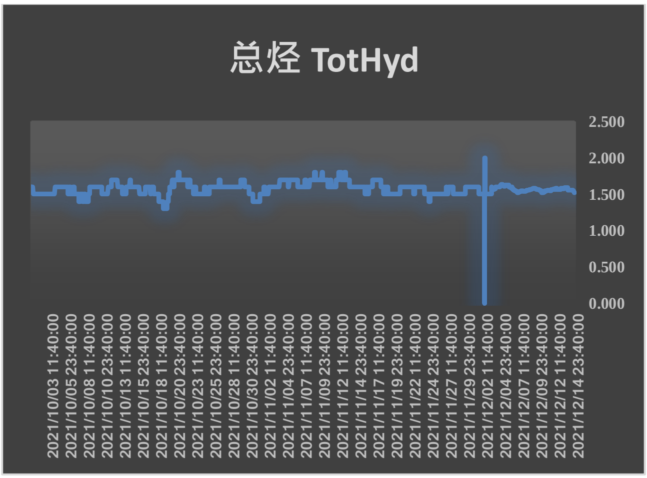

Fig. 4. Total Hydrogen of Pole 1-YDA converter transformer

CH4 gas found in the Pole 1-YDA converter transformer oil is shown in the Fig. 5.

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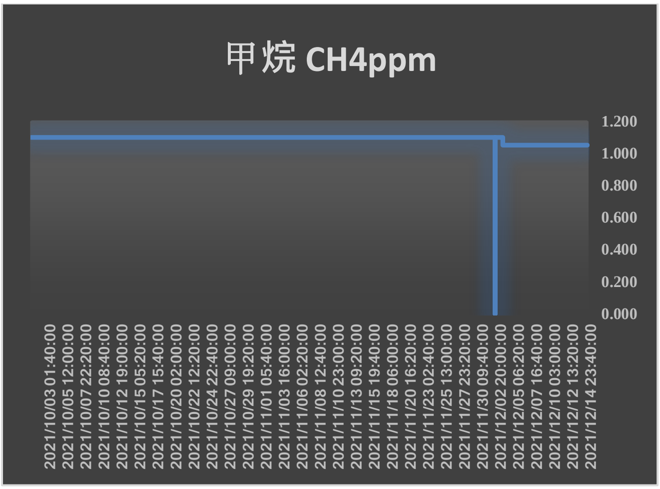

Fig. 5. CH4 of Pole 1-YDA converter transformer

C2H4 gas found in the Pole 1-YDA converter transformer oil is shown in Fig. 6.

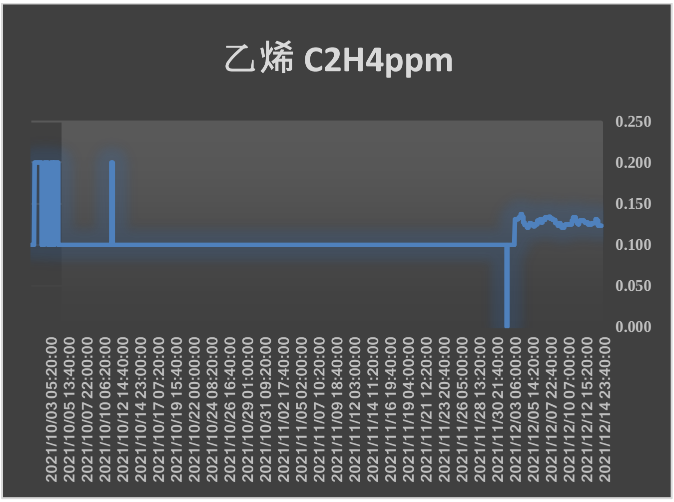

Fig. 6. C2H4 of Pole 1-YDA converter transformer

C2H6 gas found in the Pole 1-YDA converter transformer oil is shown in the Fig. 7.

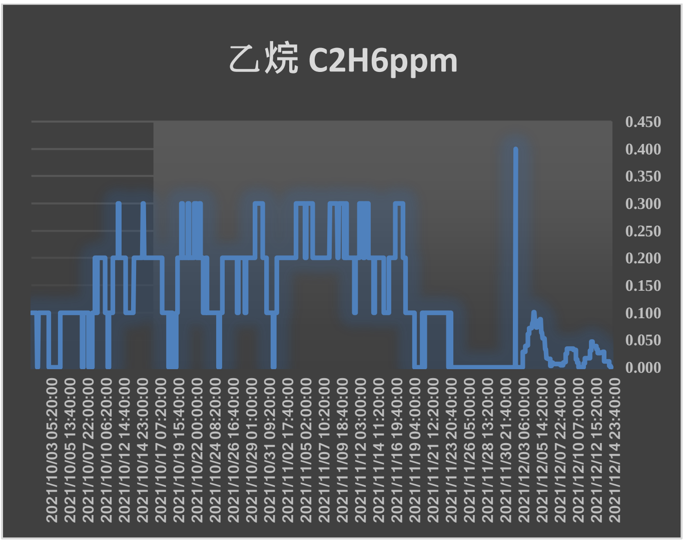

Fig. 7. C2H6 of Pole 1-YDA converter transformer

3. RESULTS

Table V shows the gasses values of the 15/12/2021 Pole 1 (YDA) converter transformer [24].

Table V Gasses achieved of Pole 1-YDA converter transformer

Sr.No	Gasses		Parameters
1.	H2		8.059
2.	C2H2		0.349
3.	Total Hydrogen		1.524
4.	CH4		1.05
5.	C2H4		0.123
6.	C2H6		0.1
7.	**R1**	C2H4/CH4	2.83
8.	**R2**	CH4/H2	0.13
9.	**R3**	C2H4/C2H6	1.23

In all graphs of the gasses achieved of the converter transformer Pole 1-YDA, it can be seen that C2H2 and H2 increase with the passage of time. This shows that there is a discharge of low energy density inside the converter transformer according to Table III, which is creating gasses inside the transformers due to minute sparking [25]-[27].

Exceptional consideration ought to be paid to the way that the investigation of transformer chromatographic experimental outcomes ought to be contrasted with recorded test information to judge whether there is a shortcoming. Simultaneously, it is important to make an exhaustive judgment in view of the test aftereffects of other electrical test things, in order to make the right judgment on the nature and area of the shortcoming. At the point when the outcomes were looked at, it was found that the gasses values are over the disturbing edge [28]. It was found that the converter transformer Pole 1-YDA has a discharge of low energy density fault which occurs in oil or paper, as indicated by large carbonized punctures in the paper (pinholes), carbonization of the paper surface (tracking), or carbon particles in oil [29].

Through the gas chromatography examination of transformer oil and the three-proportion technique, inner flaws of the transformer can be found really and early. Exceptional consideration ought to be paid to the way that the investigation of transformer chromatographic experimental outcomes ought to be contrasted with verifiable test information to judge whether there is a shortcoming [30]-[32].

Simultaneously, it is important to make a complete judgment in view of the test aftereffects of other electrical test things, in order to make the right judgment on the nature and area of the shortcoming. In the transformer issue investigation cases examined in this paper, we utilize the gas chromatography examination consequences of transformer oil and consolidate the test aftereffects of DC obstruction, bushing dielectric misfortune, winding dielectric misfortune, impede and protection things. We have precisely passed judgment on the interior issue of the transformer center multi-point establishing of the transformer. It checks the dependability of this transformer shortcoming finding technique [33].

4. CONCLUSION

It is vital to know the state of the transformer, during the tests and in the working mode. With the strategies for examination (chromatography) of gases from the transformer, it is feasible to get rapidly the effective key outcomes that will show the internal state of the transformer. Because of the addition of soil, dirt, extremely high failures, sparking and electrical burdens, it is important to orchestrate such tests and investigation of oil no less than one time per year. Conveniently identified deficiencies are helped simpler, quicker and are less expensive, on account of a lesser degree of the harm and the chance of fixing specific shortcomings on the spot, which disposes of the problems related to transportation of transformers (particularly enormous units) for repairing purposes. Moreover, the repairs can be arranged and lined up with the necessities of power systems and load centers.

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REFERENCES

1. Li Wenzhi. Analysis of Fault Causes of Excessive Characteristic Gas Content in Transformer Oil[J] Electrical & Electronics.2019. 10:39-41
2. Jin Daxin. Application examples of oil chromatographic characteristic gas analysis[J] Transformer, 2016, 53(6):71-72.
3. Liao Huaidong. Oil Chromatographic Analysis and Fault Diagnosis for Transformers[J] Hi gh Volt age Engineering 2006,32(1)112-113
4. International Electrotechnical Commission IEC60559: Interpretation of the Analysis of Gases in Transformers and Other Oil-Filled Electrical Equipment in Service, International, 1978.
5. M. J. Heathcote, The J&P Transformer Book, 12th edn., Newnes Imprint, UK: First Published by Johnson & Phillips Ltd, 1998.
6. R. Allan, Photoacoustic Spectroscopy, John Wiley & Sons, New York, 1980.
7. The Institute of Electrical and Electronics Engineers Transformers Committee of the IEEE Power Engineering Society, IEEE guide for the interpretation of gases generated in oil immersed transformers, IEEE Std. C57.104–1991. The Institute of Electrical and Electronics, 1994
8. CIGRE, Recent Developments in DGA Interpretation—CIGRE D1.01/A2.11 296, Tech. Rep., 2006.
9. R. R. Rogers, "Concepts used in the development of the IEEE and IEC codes for the interpretation of incipient faults in power transformers by dissolved gas in oil analysis," IEEE Transactions on Electrical Insulation, Technical Report, Central Electricity Generating Board, Transmission Development and Construction Division, Guilford, vol. EI-13, no. 5, pp. 349-354, 1978.
10. M. Duval, “The duval triangle for load tap changers, non-mineral oils and low temperature faults in transformers,” IEEE Electrical Insulation Magazine, vol. 24, no. 6, 2008.
11. H. Kan, “Automatic dissolved gas analysis for transformer monitoring,” Mitzubishi Electric Advance, June 1980
12. ZEC Publication 567, “Guide for the Sampling of Gases and of Oil from Oil-Filled Electrical Equipment and for the Analysis of Free and Dissolved Gases,” 1977.
13. ASTM Method D 3612, “Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography,” 1979.
14. J.E. Morgan, “Transformer Fault Detection,” “TransfoTester” available from Morgan SchafTer Corp., Montreal, Canada, US Patent 4,112,737, 1978
15. G. Belanger, M. Duval, “Monitor for Hydrogen Dissolved in Transformer Oil,” “Hydran” available from Syprotech Inc., Pointe-Claire, Canada. ZEEE Trans. Electr ZmuL, Vol. El-12, NO. 5, pp. 335-340, 1977. Vol. El-12, NO. 5, pp. 335-340, 1977.
16. H. Tsukioka, IC Sugawara, E. Mori, S. Hukumori, S. Sakai, “New Apparatus for Detecting H,, CO and CH, Dissolved in Transformer Oil,” ZEEE Trans. Electr Znsul.,
17. E. Juelke, “Method and Device for Continuous Determination of Acetylene Produced by Glow Discharge,” Swiss Patent CH 677740 A5, 1988.
18. R.R. Roger, “IEEE and IEC Codes to Interpret Incipient Faults in Transformers, Using Gas-In-Oil Analysis,” ZEEE Tram. Elect. Znsul., Vol. EI-13, No. 5, pp. 348-354, 1978.
19. M. Duval, “Fault Gases Formed in Oil-Filled Breathing EHV Power Transformers. The Interpretation of Gas Analysis Data,” ZEEE-PES Con$ Paper C 74-476-8, 1974.
20. J.O. Church et al. “Analyze Incipient Faults with Dissolved-Gas Nomograph,” Electrical World pp. 40-44, Oct. 1987.
21. E. Dornenburg, W. Strittmatter, “Monitoring Oil-Cooled Transformers by Gas Analysis,” Brown Bourn‘ Review, Vol. 61, No. 5, 1970, p. 238.
22. R. Wilputte, M. Random, “Enseignements des Contrdles Programmes des Huiles Isolantes des Transformateurs de Puissance du Reseau Belge,” CZGRE Paper 12-07, 1986.
23. T. Kawamura et al, “Dissolved Gas Analysis. Its Use for the Maintenance of Transformers”, CZGRE Paper 12-05, 1986.
24. ANSI-IEEE C 57, 104, “American National Standard Guide for the Detection and Determination of Generated Gases in Oil-Immersed Transformers and Their Relation to the Serviceability of the Equipment,” 1978.
25. M. Duval, F. Langdeau, P. Gervais, G. Belanger, “Interpretation of Dissolved Gas-in-Oil Levels in Power Transformers,” Minutes of the 55th Annual International Conference of Doble Clients, Sec. 10-7.1110-7.10, 1988.
26. M. Duval, F. Langdeau, P. Gervais, G. Belanger, “Acceptable Dissolved Gas-in-oil Concentration Levels Versus Age in Power and Instrument Transformers,” Minutes of the 56th Annual International Conference of Doble Clients, Sec. 10-3.1110-3.9, 1989.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 03 | March - 2022 ISSN: 2582-3930

27. M. Duval, F. Langdeau, P. Gervais, G. Belanger, ‘‘Muence of Paper Insulation on Acceptable Gas-in-Oil Levels in Transformers,” Annual Report of the CELDe 1989.

28. M. Duval, J:P. Crine, “Dielectric Behavior and Stabilization of Insulating Oils in EHV Current Transformers,” IEEE Tram Elect. InsuL, Vol. EI-20, No. 2, pp. 437441, 1985.

29. C.E. Riese, J.D. Stuart, “TOGA-An Expert System for Transformer Fault Diagnosis,” Artificial Intelligence Applications in Chemistry, American Chemical Society Ed., pp 25-30, 1986

30. N. Recrosio, Y. Jegou, M. Carballeira, “Dyonysos: Aide au Diagnostic de Defauts Dans les Transformateurs,” SEE Club 1 l4tudes Gh&rales--Diagnostic et Maintenance Par Systdme Expert Paris, Oct. 8, 1987

31. M.A. Marin, J.L. Jasmin, “Cooperating Expert Systems for Diagnoses of Electrical Apparatus,” Con$ on Expert Systems Applications for the Electric Power Industry, EPRI, Orlando, Florida, June 5-8, 1989.

32. M, Duval, Y. Giguere, “Preparation of Standard Samples of Dissolved Gases in Insulating Oils,” Minutes of the 51st Annual International Conference of Doble Clients, Sec. lOC-Ol/lOC-O7, 1984.

33. IEC Publication 599, “Interpretation of the Analysis of the Gases in Transformers and Other Oil-Filled Electical Equipment in Service,” 1978.

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