

# Analysis of Dissolved Gas in transformer oil by conventional Techniques and Artificial Intelligence approach-A Review.

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**Abstract**— The Dissolved Gas Analysis has been widely used by utilities throughout the world as the primarily diagnostic tool for transformer maintenance. The gas generated in mineral oil of power transformer can be monitored by all conventional methods, online DGA system and by application of various Artificial Intelligence practices. This sequential hybrid system ANN and FIS can be a good solution for reliable results for predicting faults because one should not depend on a single technology when dealing with real-life applications. This paper compares the conventional system of DGA and various analysis techniques by application of Artificial Intelligence.

**Keywords:** Transformer Oil, Dissolved Gas Analysis (DGA), Artificial Intelligence, Hybrid Systems.

## I. INTRODUCTION

Dissolved gas analysis (DGA) of transformer oil is one of the most effective power transformer condition monitoring tools which can be facilitated to determine transformer criticality ranking. Insulating materials within transformers and related equipment break down to release gases within the unit. The distribution of these gases can be related to the type of electrical fault and the rate of gas generation can indicate the severity of the fault. The identity of the gases being generated by a particular unit can be very useful information in any preventative maintenance program. This technique is being used relatively successful throughout the world. Apparent advantages of fault gas can provide a) Advance warning of developing faults b) Determining the improper use of units c) condition checks on new and repaired units d) Convenient scheduling of repairs. The methods used for the evaluating the ageing process and the deteriorating cellulose material are Dissolved Gas Analysis (DGA) of the transformer oil, the degree of polymerization measurements, Furan Analysis of the paper.

The degree of polymerization assesses the aging of insulating paper from service-aged power transformers and voltage regulators. It is an invasive test which requires a sample of the paper which may present some difficulties such as taking the unit out of service. Each cellulose fiber of paper is composed by a bundle of cellulose molecules of different lengths, lying side by side. These molecules are held together due to hydrogen bonds between the hydroxyl groups (-OH) existing in their structure. The cellulose molecule is a linear polymer formed by a chain of glucose rings linked by glycosidic bonds. The glycoside bonds break and the molecule are shortened as the paper ages, thus causing the paper to lose its mechanical strength, and the useful life of the transformer is also reduced.

Furan Test is carried out to determine whether the paper in a given transformer has been or is being damaged

by heat. Furans are produced from temperature buildups. These are generated either by a localized area of high heat and paper damage or by the general overall heating of the entire insulation system. As for now there are no limit values or normal values for these compounds. Hydrolytic, thermal, oxidative breakdown of paper insulation can be detected through furan analysis. Among the existing methods of identifying the incipient faults, DGA is a method widely applied by utilities and researchers for fault diagnosis. By sampling and examining the insulating oil of transformers, ratios of specific gas concentrations, their generation rates, the total combustible.

gases are often used as the attributes of classification by diverse DGA approaches. Temperature measurements have been made for some time and can even be incorporated into certain key gases. The DGA has been widely used as a diagnostic tool for transformer maintenance.

## II. SYNOPSIS OF CURRENT DGA INVESTIGATION METHODS IN PRACTICE:

Through application of DGA technique, fault gases dissolved in oil can be determined and interpreted. State of the art online monitoring systems by DGA have become highly advantageous and suitable to detect any abnormal increase of gas concentrations due to any incipient or potential fault developing in a power transformer. In some cases, DGA interpretation schemes may differ with respect to type and amount of identified faults. That fact is for sure in conflict towards a reliable fault diagnostics. Most of the interpretation schemes are generally based on defined principles such as, gas concentrations, key gases, key gas ratios, and graphical representations. Some of the more applied interpretation schemes are IEC 60599, Key Gas Analysis, Roger and Doernenberg Ratio Methods, Duval Method and Gas Nomograph Method. They are included into the IEEE Standard C57.104-1991.

### A. Key Gas Method

The presence of the fault gases depends on the temperature or energy that disrupts the chemical structure of the insulating oil. This method detects faults by measuring individual gases rather than by calculating gas ratios. The significant and proportion of the gases are called “key gases”. The tables 1 and 2 describes the type of faults depending upon the various gas compositions.

KEY GAS	NATURE OF FAULT
Acetylene, C <sub>2</sub> H <sub>2</sub>	Electrical arc in oil
Hydrogen H <sub>2</sub>	Corona , partial discharge

Ethylene C <sub>2</sub> H <sub>4</sub>	Thermal degradation of oil
Carbon Monoxide	Thermal ageing of oil

Table:1 Various Types of Faults Depending on the Gas Composition

Gas Content		Nature of Fault
Major	Minor	
Ethylene	Ethane	Thermal Decomposition
Methane	Hydrogen	(Hot Spots)
Hydrogen Methane	Acetylene Ethylene Ethane	Electrical Discharge (Except Corona)
Hydrogen	Methane Ethane	Internal Corona
Carbon Monoxide	---	Cellulosic insulation decomposition
Carbon Dioxide		

Table:2 Various Types of Faults Depending on the Mixed Gas Composition

#### B. Dorrnenburg Ratio Method

For convenient fault diagnosis, gas ratio methods use coding schemes that assign certain combinations of codes to specific fault types. The codes are generated by calculating ratios of gas concentrations and comparing the ratios with predefined values derived by experience and continually modified. A fault condition is detected when a gas combination fits the code for a particular fault. The Dorrnenburg Ratio method identifies faults by analyzing gas concentration ratios such as CH<sub>4</sub>/H<sub>2</sub>, C<sub>2</sub>H<sub>2</sub>/CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>6</sub> and C<sub>2</sub>H<sub>2</sub>/C<sub>2</sub>H<sub>4</sub>, which can be used to identify thermal faults, corona discharge and arcing. This method, which is specified in IEEE Standard C57.104-2008, characterizes dissolved gases of transformer oil. However, the method may obtain numerous “no interpretation,” results due to incomplete ratio ranges.

#### C. Roger's Ratio Method

The most common gas ratio method is the Rogers ratio method, which distinguishes more thermal fault types compared to the Dorrnenburg ratio method. The Rogers method analyzes four gas ratios: CH<sub>4</sub>/H<sub>2</sub>, C<sub>2</sub>H<sub>6</sub>/CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>6</sub> and C<sub>2</sub>H<sub>2</sub>/C<sub>2</sub>H<sub>4</sub>. Faults are diagnosed via a simple coding scheme based on ranges of the ratios. This method is effective because it correlates the results of numerous failure investigations with the gas analysis of each case. However, some ratio values are inconsistent with the diagnostic codes assigned to various faults in this method. Also, since the method does not consider dissolved gases below normal concentration values, a precise implementation of the method may still misinterpret data.

#### D. Nomograph Method

This improves the accuracy of fault diagnosis by combining fault gas ratios and the concept of Key Gas threshold. By

graphically presenting fault gas data, it simplifies interpretation of fault gas data. A nomograph is a series of vertical logarithmic scales for representing the concentration of individual gases as straight lines drawn between adjacent scales. The lines connect points representing the values of individual gas concentrations. Straight lines are diagnostic criteria for determining fault type. Fault types are identified by visually comparing the slopes of line segments with the keys at the bottom of the nomograph. Fault severity is indicated by the position of lines related to the concentration scales. The threshold value of each vertical scale is indicated by an arrow. For the slope of a line to be considered significant, at least one of the two tie points should exceed the threshold value. The fault is not considered significant if the tie point lies above a threshold value.

#### E. IEC Ratio Method

The IEC Ratio Method excludes the C<sub>2</sub>H<sub>6</sub>/CH<sub>4</sub> ratio, which only indicates a limited temperature range of decomposition. Here, the remaining three gas ratios have different ranges of code in comparison with the Rogers ratio method. The four detected conditions are normal ageing, partial discharge of low and high energy density, thermal faults and electrical faults of varying severity.

However, it does not classify thermal and electrical faults into precise subtypes. Dissolved gases must be assessed for ‘normality’ limits before interpretation by ratios. Another improvement in the second version of IEC method is the 3D graphical representation of ratio ranges. Faults that cannot be diagnosed are plotted onto the graph so that its nearest distance to a certain fault region can then be observed. Power transformer faults are typically classified as partial discharges, discharges of low and high energy, and thermal faults in which severity depends on fault temperature.

#### F. Duval Triangle Method

The Duval Triangle Method uses values of only three gases Methane CH<sub>4</sub>, Ethene C<sub>2</sub>H<sub>4</sub> and Ethyne C<sub>2</sub>H<sub>2</sub> and their location in a triangular map. The three detectable faults are partial discharges, electrical faults (high and low energy arcing), and thermal faults (hot spots of various temperature ranges). Although this method is easily performed, careless implementation can obtain false diagnoses since no region of the triangle is designated as an example of normal ageing. Hence, before using this method to analyze transformers that have been in service for the many years, the permissible amount of dissolved gases should be determined. An identified problem is diagnosed by calculating the total quantities of the three Duval Triangle gases (CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub> and C<sub>2</sub>H<sub>2</sub>) and dividing the quantity of each gas by the total to find the percentage of each gas of the total. The percentages of the total are then plotted on the triangle to obtain the diagnosis.

#### G. CIGRE Method:

CIGRE proposed a DGA interpretation method that has attempted to improve previous interpretation schemes with the purpose to contribute to more reliable fault diagnostics. The CIGRE Interpretation (CI) scheme consists of a two-step evaluation based on key ratios of gas concentrations

and key gas concentrations, both of them compared to thresholds. FIS (Fuzzy Interface System) adopted here to improve the CIGRE interpretation (CI). The use of a FIS as a tool could already eliminate some deficiencies of CI on the basis of the following statements. CI describes two methods that use two key criteria for fault detection. The new approach uses two key criteria as well, but they have been well integrated into one single method. CI uses thresholds to decide whether a transformer is faulty or not. That can lead to wrong interpretation, especially in case of values close to the thresholds. This new approach eliminates thresholds and uses steady membership functions instead. CI attempt to define the type of fault that might be taking place. The new approach estimates the likelihood of fault occurrence for each possible fault types. However, DGA may not reliably predict rapidly occurring instantaneous faults. Instantaneous failures that cannot be prevented by DGA are: (1) flashover with power follow-through, and (2) serious failures that develop too rapidly for detection by DGA.

The major (minor) fault gases can be categorized as follows by the type of material (Table-3) that is involved and the type of fault present. Mineral oil insulating fluids are composed essentially of saturated hydrocarbons called paraffins, whose general molecular formula is  $C_nH_{2n+2}$  with  $n$  in the range of 20 to 40. The cellulosic insulation material is a polymeric substance whose general molecular formula is  $[C_{12}H_{14}O_4(OH)_6]_n$  with  $n$  in the range of 300 to 750.

	A	B
1	1. Corona	
2	a. Oil	H <sub>2</sub>
3	b. Cellulose	H <sub>2</sub> , CO, CO <sub>2</sub>
4	2. Pyrolysis	
5	a. Oil	
6	Low temperature	CH <sub>4</sub> , C <sub>2</sub> H <sub>6</sub>
7	High temperature	C <sub>2</sub> H <sub>4</sub> , H <sub>2</sub> (CH <sub>4</sub> , C <sub>2</sub> H <sub>6</sub> )
8	b. Cellulose	
9	Low temperature	CO <sub>2</sub> (CO)
0	High temperature	CO (CO <sub>2</sub> )
1	3. Arcing	H <sub>2</sub> , C <sub>2</sub> H <sub>2</sub> (CH <sub>4</sub> , C <sub>2</sub> H <sub>6</sub> , C <sub>2</sub> H <sub>4</sub> )

Table-3 The major (minor) fault gases and type of fault

### III. ARTIFICIAL INTELLIGENCE TECHNIQUES APPLIED TO DGA

Data of the dissolved gas in oil can be incorporated into expert systems to facilitate decision making. There also exists certain amount of uncertainty in the data concerning dissolved gas analysis due to generation, sampling, and chromatography analysis. There is thus variation in interpreting the variation of the gases by the utilities. Due to the diverse gas content of the insulating oil of transformers many AI techniques have been presented. The AI techniques studied and used by the researches for application to DGA are Expert Systems, Fuzzy Inference Systems (FIS) and various type of Artificial Neural Networks (ANN), Genetic Algorithm (GA) and even Novel Cerebellar Model Articulation Controller based method for off line and on line monitoring and Discrete Wavelet Transforms for on line monitoring.

#### A. Expert Systems

The expert system is decision support systems that have been applied for fault diagnosis and maintenance to advance the DGA information and incorporate it to build diagnostic rules. The effectiveness of the knowledge expert systems depends on the precision and knowledge base, which is usually very complicated and must be constricted carefully. Such an expert system can neither acquire knowledge from new data samples through self-learning process and nor can it adjust its diagnostic rules automatically. C. F. Lin et al. Developed an expert system to diagnose transformer faults using DGA and also suggested proper maintenance. Data of 251 samples from transformers of Taiwan Power Company were used; three cases are discussed in details for the last five to six tests carried out. For the first two samples the diagnostic results agreed with the actual fault type causes and appropriate maintenance was suggested. For the third case the transformer unit after more than seventeen years of operation suffered an arc tracing fault. After repairing and degassing the transformer oil a gas fingerprint of this transformer was developed.

#### B. Fuzzy Inference System

K. Tomsovic et proposed a fuzzy information approach to integrate different transformer diagnostic methods. Five gases were considered and detailed analysis of four transformers had been carried out. A fault tree was proposed and there was a framework for performing diagnosis using fuzzy information system. The fuzzy relations were combined with the fault tree to provide best analysis possible. The fact that an older or a heavily loaded transformer will have high concentration of gases that have built up over a time was taken into account. The proposed framework could provide a good foundation for providing diagnosis on variety of power system equipment.

#### C. Artificial Neural Network

Hong-Tzer Yang used Fuzzy Learning Vector Quantization (FLVQ) Networks for condition assessment. Doernenburg's and Rogers Method were compared for 561 numerical samples associated with real time faults. Due to lack of data of high energy partial discharge, low and high energy discharge faults, 150 simulated data were created and mixed with the practical samples. Fuzzy logic and learning vector quantization networks were integrated and the advantages were the linguistic partition properties of fuzzy logic and fast and self learning capabilities of learning vector quantization networks. Also, few samples were needed to construct FLVQ. The learning time needed is extremely short as compared to that required by the Back Propagation.

Artificial Neural Networks (BPANN). The FLVQ networks have highest learning capabilities as compared to fuzzy system and BPANN. With the uncertainties and the limitations existing in DGA approaches, the FLVQ network could greatly improved the diagnosis capabilities of the traditional DGA approach. An intelligent decision support for diagnosis of incipient transformer faults using self-organizing polynomial networks (SOPN) was proposed by Hong-Tzer Yang Data of total 561 numerical samples from 156, 69kV power transformers of Tiawan Electricity Company was used, and simulation data by Monte-Carlo simulation technique for practical samples of high energy

partial discharge, low energy discharge and high energy discharge was also used. In the first type of SOPN the input features (or variables) selected were the ratios while in the second SOPN the input features (or variables) selected were the gases H<sub>2</sub>, CH<sub>2</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>4</sub>, and C<sub>2</sub>H<sub>2</sub>. Two ANN- were built as well using the same sample data by error back propagation training algorithm. SOPNs' proved to be far superior to the existing ANNs' which were adopted as a comparative bench mark..

For diagnosing failed distribution transformers using neural networks A. S. Farag used ANN. Work was done considering 506 overhead and 52 underground transformers. A feed forward neural network was trained to diagnose reasons for failure of distribution transformers. The training algorithm used was back propagation assuming initially a sigmoidal transfer function for networks processing unit. After the network was trained the units' transfer function was changed to hard limiters with thresholds equal to the biased obtained for the sigmoids during training. Six individual ANN were used for six important factors that were; age of the transformer, the weather conditions, damaged bushings, damaged bodies, oil leakage, and winding faults. The six ANN's are combined to one ANN to give recommendations complete diagnosis for working transformers to avoid possible failures. The developed ANN could give complete diagnosis of working transformer and be used as a decision support facilities to the companies for planning and maintenance schedule.

#### D. Artificial Neural Network & Fuzzy Logic

Transformer oil diagnosis using fuzzy logic and NN was proposed by James J. Dukaram using 150 real and synthetic examples. Fuzzy was applied to Key gas analysis, Rogers' ratio method, and nomographs. Feed forward neural network were used. It was concluded that fuzzy logic can be used to automate standard methods of transformer oil DGA. In some cases NN could be used in combination with fuzzy logic to implement more complex diagnostic methods while maintaining a straightforward relation between the enhanced method and the original one. The main obstacle to developing a real diagnostic rule is the lack of sufficient high quality examples with which to train and validate a network. Jingen Wang et al. applied fuzzy classification by Evolutionary Neural Network. The method models the membership functions of all fuzzy sets by utilizing a three layer feed forward network, trains a group of neural networks by combining the modified evolutionary strategy with Levenberg-Marquardt optimization method in order to accelerate convergence and avoid falling into local minima. The method is better than neural network structure, tolerance ability and robustness than any traditional methods.

A hybrid tool for detection of incipient faults in transformers based on DGA of insulating oil was proposed by Diego Roberto Moaris .52 samples of confirmed diagnosis for NN and 20 Transformers with historical datatotaling 212 samples- (180 normal+10 electrical faults+22thermal faults) were used. It is a combination of traditional method, ANN and Fuzzy logic system. Neural Network used was based on a Radial Bias Function (RBF). The proposed analysis included not only the gas levels but also the gas generation rates, the rates that were considered

are Total Generated Gas Level (TGGL), Generation Rate (GR), and Total Gas Generating Rate (TGGR). It was found that this is a more reliable diagnostic due to more than one method being used; the results of NN alone are limited but could be improved with the use of more training data. Fuzzy analysis proved to be highly reliable.

#### E. Genetic Algorithm Approach

Yann-Chang Huang used a new data mining approach to dissolved gas analysis of oil-insulated power apparatus using 820 actual gas records of Taipower Company from 172, 68 kV transformers. The Genetic Algorithm (GA) and ANN (back-propagation) has been compared with Genetic Algorithm Tunes Wavelet Networks (GAWN) for data mining of dissolved gas analysis records and incipient fault detection of oil insulated power transformers. The GAWN's have been tested using four diagnosis criteria, and compared with ANN and conventional methods. The GAWN's have remarkable diagnosis accuracy and require far less learning time than ANN's for different diagnosis criteria.

Wavelet network for power transformers diagnosis using DGA was proposed by Weigen Chen . 700 samples were used; 400 training samples and 300 testing samples. Wavelet Networks (WN's) are an efficient model of nonlinear signal processing developed in recent years. The training and testing samples are processed by fuzzy logic technology comparison and analysis of network training process and simulation results of five WN's. The proposed approach had many important advantages over traditional methods of analysis and interpretation of DGA data. The novel approach does not depend upon any actual fault cases for its modeling, hence it is easy and cost effective to implement. It provides more consistent and convincing diagnosis as the revealed structure actually originates from the real measured DGA records. The feed forward wavelet network used is divided into two types based on different activation functions of the wavelet nodes applied in fault diagnosis of power transformer.

#### F. Discrete Wavelet Transform Method

Karen L. Butler-Purry et al. for identifying transformer incipient events for maintaining distribution system reliability have used Discrete Wavelet Transform (DWT). The approach has been applied to investigate the characteristics of incipient events in single phase transformer. MATLAB program was used to calculate the DWT of the signals. The Daubechies Db-4 type wavelet was used as a mother wavelet. On line incipient fault detection technique for distribution transformer was based on signal analysis. The method used discrete wavelet transform to identify incipient faults in single phase distribution transformers. The simulation method is based on Finite Element Methods (FEM) and ANSOFTs' Maxwell software was used for the circuit analysis. The simulation method takes into account the aging phase and the arcing phase. An experimental setup was made and the simulation methodology was tested. Time-domain results and frequency-domain results were compared for single phase transformer. The data obtained from tests and computer simulations were used to observe the variation. The results show the potential of using DWT-based method for fault

prediction, maintenance and maintaining reliability of transformer.

#### IV. PROPOSED SEQUENTIAL HYBRID SYSTEM

Each of the soft computing methods has been inspired by biological computational processes and nature's problem solving strategies. Each of these techniques, in their own right has provided efficient solutions to fault identification in transformers using DGA. Attempts on wide range of problems belonging to different domains have been made to synergize the three techniques - Fuzzy Logic, Neural Networks and Genetic Algorithm. The objective of synergy or hybridization is to overcome the weakness of one technology during its application, with the strengths of the other by appropriately integrating them. The hybridization of technologies has its pitfalls and should be done with care. The hybrid systems are classified as Sequential hybrid, Auxiliary hybrid and Embedded hybrid. Fig. 1 shows a sequential hybrid system.

When the output of one technology becomes another's input and they are used in pipeline fashion the system is said to be sequential hybrid. Since an integrated combination of the technologies is not present it is one of the weakest forms of hybridization. The Neuro-fuzzy hybrid system is one of the most researched form and has resulted in stupendous quantity of publication and research results. These systems have demonstrated the potential to extend the capabilities of the system beyond either of these technologies when applied individually. There are two ways of looking at this hybridization. One is to endow NN's with fuzzy capabilities, thereby increasing the networks expressiveness and flexibility to adapt to uncertain environment, the other one is to apply neuronal learning capabilities to fuzzy system to make the fuzzy system more adaptive to changing environments. This approach is also known in literature as NN driven fuzzy reasoning.

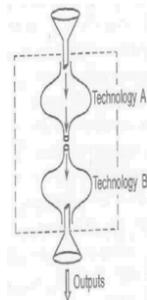


Fig. 1: Sequential hybrid system

It is established that the main difficulty for developing a good diagnostic rule is the lack of sufficient high quality examples with which to train and validate a network. So, as to overcome this in the proposed work real data from research publications [6, 9, 16, 18, 20, 22&27] and test records from utilities has been taken. Of the total samples randomly 60% are taken as training data, 20% as validation data, and the remaining 20% as testing data.

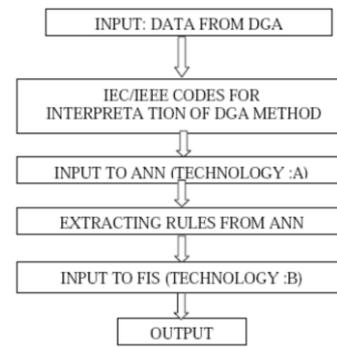


Fig. 2: Scheme of proposed diagnostic system Sequential hybrid system

#### V. CONCLUSION

After study of the AI methods applied for the fault detection in transformers based on DGA methods, it has been found that these can be used to evaluate the condition of the transformer provided sufficient amount of reliable DGA data is available. Each of AI techniques and combination of two of these, in their own right has provided efficient solutions to incipient fault identification. The synergy of ANN and FIS can be a good solution for reliable results for predicting faults because one should not rely on a single technique when dealing with real-life applications.

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