

# Review on Transformer Fault Detection and Diagnosis Algorithms

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**Abstract:** The method of fault diagnosis based on dissolved gas analysis (DGA) is of great importance to detect possible failures in the transformer and to improve the safety of the electrical system. The DGA data of the transformer in the smart grid has the characteristics of a large amount, different types and a low density of values. Since the power transformer is an important type of power supply in the electrical network, this document provides a complete overview of the power transformer and describes how to diagnose faults. Furthermore, on-line monitoring, the method of fault diagnosis and condition-based maintenance strategy decision-making method as also have been described. The paper presents detailed literature on the recent advancements and methods being adopted by various authors on fault detection.

**Keywords:** Power Transformer, DGA, Diagnostics Methods, Monitoring And Transformer.

## I. INTRODUCTION

The fault that occurs in a transformer is divided into two types: external and internal errors. External faults occur outside the transformer: overvoltage, overflow, under frequency, and short circuits of the external system. Internal faults are those that occur inside the transformer: winding from round to round, round to ground, excess. The power grid has grown steadily over the past few decades and progress will continue for years to come. A transformer, which is an integral part of the power system, is an important link between a power plant and a point of use for electricity. The transformer is prone to failures due to various complex loads and their control systems. Internal winding failures in transformers can cause severe damage in a very short time and in some cases the damage can be repaired and approximately 70-80% of transformer failures are caused by

internal failures [1]. Among these faults, it is difficult to monitor and detect a curve-to-curve winding faults, especially when the magnitude of the fault current is smaller. Troubleshooting is therefore a necessary job to repair defective transformers that can be repaired and put back into service.

## II. LITERATURE REVIEW

N.C. Joshi et al. [2] this article introduces the various online and offline techniques associated with fault detection of internal transformer windings. This article also examines and compares the different diagnostic methods based on their pros and cons. This indicates another leeway for purchasing engineers to monitor and diagnose internal winding failures.

XueWanget al. [3] this article applies the stack set policy for troubleshooting. The stratified perceptron, the k-nearest neighbor, the decision tree and the supporting vector machine are used as component students, and the random forest algorithm is used as a combination strategy to build a diagnostic model.

Ibrahim B. M. Tahaet al. [4] this article uses the Fuzzy Logic Transformer Fault Diagnosis System (FLTFDS) as an application of dissolved gas analysis to diagnose the dominant transformer failure created by electrical and thermal voltages. FLTFDS depends on three normal rules: the International Electro-Technical Commission standard (IEC Code Standard), the Central Electric Generating Board (CEGB) standard dependent on the four Roger proportions, lastly the Duval Triangle strategy; these models are utilized to decipher transformer shortcomings in fuzzy logic.

Huo-Ching Sun et al. [5] This investigation looks at Computational Intelligence (CI) ways to deal with the upkeep of oil inundated force transformers by examining chronicled advancements and introducing the most recent shortcoming

determination strategies. IC-based methodologies have arisen as quickly advancing however exceptionally viable ways to deal with utilizing disintegrated gas examination (DGA) information to analyze power transformer failures.

### III. ON-LINE MONITORING TECHNIQUE OF POWER TRANSFORMER

Classical PT detection methods include preventive testing, on-line monitoring, periodical touring detection, including fault synthetic judgement, among others [6]. DGA, pneumatically insulation oil assess, DC resistor as well as insulation resistor of switchbacks, switchbacks deformation analyse, absorption ratio assess, polarisation indices examine, insulating dielectric deficit angle tangent surveillance, insulator pneumatically check, far infrared thermometry supervising, on-load tap customizer characteristics examine, as well as low voltage short circuit capacitive assessment are among the monitoring targets[6].

#### THE TECHNIQUE OF OIL DISSOLVED GAS ANALYSIS

There are numerous approaches to PT fault diagnostics. The transformer DGA assessment is an excellent status detection approach that has been widely employed because the hidden inner fault could be identified early[7]. According to statistics, DGA evaluation results detect approximately 50% of transformer faults in power systems[8]. Whenever a transformer fault happens, the on-line oil dissolved gas approach is used to identify several gases like as H<sub>2</sub>, CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>, CO, as well as CO<sub>2</sub>. This allows for both qualitative and quantitative identification. The principle discovery implies are tone chromatography, infrared chromatography, photograph acoustic spectrometry and sensor cluster [9]. Tone chromatography on-line recognizing method incorporates two key innovations named as oil-gas partition and gas location, in which the generally utilized route for oil-gas division is polymeric membrane, Gas detectors mainly recognize one-component (mostly H<sub>2</sub>) and several component proportion of gas within oil, like the C201-6 on-line including chromatography framework through the Canadian GAJI group as well as the studies conducted by Wang-youyuan at Chong-Qing university .The Palladium grid FETs with catalytic oxidation inductors, and also electrochemistry H<sub>2</sub> inductors, are commonly utilised in one element identification. [10], while the main product is made by Canadian SYPROTEC company, HYDRAN; in multi-component detection, the mainly useful means are thermal conductance sensor, hydrogen flame ionization sensor and semiconductor sensor, etc. [11]. The American Firm AVO's Genuine Gas on-line supervision instrument can identify gases as many as 8, and it is the most effective instrument so far.

(2) By analysing the infrared spectrum, it is possible to determine the gas nature as well as information directly. Its attributes are quick, high exactness rate, non-contact, simple to be kept up, and different gases can be recognized, The Photo-acoustic spectrometry seems to be a type of sensing methodology based here on photo-acoustic impact [12] that detects the potential of gas to accumulate optical energy with in optical-acoustic cabin[13]. This is not sensitive to H<sub>2</sub> and would be too is too costlier. H<sub>2</sub> is detectable and has a high anti-interference capability.

(3) A sensor array is a device that combines multiple gas sensors to detect distinct elements in such a mixed gas[14], hence boosting the detection performance as well as sensitivity of gaseous phase in oil.

#### MEASURING TECHNIQUE OF DC RESISTANCE

Monitoring the DC resistance of the PT winding is crucial. parameter in detecting a transformer. In comprehensive judgment to transformer winding fault (including lead including wire connections, branch switch with winding connections, and etc), DC resistance value and its imbalance gives useful information As indicated in document [15], Mr. Guo-yu and many others conducted considerable study involving DC resistance on-line measuring. Several instances can be checked using a DC resistance assessment, including soldering circumstance of winding contacts, if such a short circuit exists between turns, if somehow the voltage division point connects well, whereas if actual role is just the same as demonstrated, the wire circumstance, and if there are breaks through duplex winding[15]. There seem to be two options. to measure DC resistance: common method and fast measuring. Voltage-ampere relying on ohm law, balancing bridge (single and the double arms) depending on Wheatstone bridge, as well as DC resistance analyzer are all common methods. Fast measurement relies on various essential techniques such as a broader field of view measuring range, higher accuracy, faster speed, little influence by The winding inductance ,will automatically change wrapping groups, as well as evaluate the outcome, including static fast measurements like resistance mutations and bridge mutation, flux pump, short circuit degauss, magnetism assisting, and randomly measuring, two step oscillating and dynamic fast measuring based on identical theory, etc.

#### IV. DISSOLVED GAS ANALYSIS (DGA)

The DGA is among the earliest diagnostic tools for intrinsic winding defects in transformers, having been used for 92 years. This technique was relied on an analysis involving dissolved gases within transformer oil. DGA refers for Dissolved Gas

Analysis as well as being a prominent diagnostic procedure. Due to their high electrical conductivity and improved heat transmission properties, hydrocarbon oils are employed as insulating as well as coolant fluids in transformers. Electrical, thermal, and mechanical stressors cause insulating materials to disintegrate. Decomposition produces a variety of gaseous compounds, that also dissolve into mineral oil and lower its dielectric strengths. Acetylene (C<sub>2</sub>H<sub>2</sub>), ethylene (C<sub>2</sub>H<sub>4</sub>), methane (CH<sub>4</sub>), hydrogen (H<sub>2</sub>), and ethane are the major gases created when dissolved in transformer oil (C<sub>2</sub>H<sub>6</sub>). The proportion of these gases was utilised to distinguish among the transformer's standard and problematic operating conditions. The Dornenberg proportions technique and Rogers's proportions methodology are two commonly used traditional gas ratio approaches. Internal winding defects in transformers have been detected using these two techniques. The DGA data obtained offers detailed statistics about the transformer's status and delivers early warning of emerging issues..

## RESEARCH TENDENCY OF POWER TRANSFORMER

### TECHNIQUE OF IN-DEPTH ASSESSMENT

#### *The Problem with Power Transformers in a Comprehensive Assessment*

This design is set up in such a way that author affiliations aren't repeated for many writers with the same affiliation.. If it's not too much trouble keep your affiliations as concise as could reasonably be expected (for instance, don't separate among branches of a similar association). This layout was intended for two linkages. During the study phase with PT fault diagnosis, DGA judgement is still the most important factor. information source for researching PT condition maintenance and fault diagnosis. Traditional methods and artificial intelligent means exist prominent drawbacks in fault diagnosis and status analysis.

- a) Method immaturity, lesser fault position, and the date detection accuracy all present throughout transformer fault detection, making it simple to cause damage. misdiagnosis and missing diagnosis;
- b) Due to poor distinctive feature indication of constrained bearing capability of PT short circuit with representing status level, both accuracy as well as speed of Intelligent detection and assessment based on DGA data is decreased.
- c) To satisfy fault diagnosis with maintenance plan, expert systems are based on knowledge rules and mimicking experts in experience knowledge, and therefore integrity of judgement

rules and knowledge accumulation is the "bottleneck" difficulty for expert systems to achieve accurate fault diagnostic [16].

- d) Artificial neural networks have a sluggish convergence rate, hence prior knowledge with their net structure and variable setup is required. A key difficulty is determining how to obtain the best network model for a specific application..
- e) When determining the fuzzy membership variable, the fuzzy theory technique uses subjective elements as a master.. The strategy is relatively basic and target compatible believability is scant; the right diagnosing reason of fuzzy complete assessment is to assemble a fuzzy connection grid adjusting to genuine; it is somehow It's challenging to draw a clear line among the cause of the defect and the fault itself. and fault symptom;
- f) While using a genetic algorithm to evaluate PT conditions, there is an issue in that the assessment ratio of status is not taken into account, thus there is a legitimate research topic on how to build up an appropriate assessment model.

### THE FAULT DIAGNOSIS METHOD OF POWER TRANSFORMER

The Fault Diagnosis Method Based on DGA Presently th During transformer fault detection, fault assessment dependent on DGA is extensively employed [17], which is relied on the Hasteed hypothesis. The hypothesis mentioned to carry on thermodynamic analysis for the course of gas status hydrocarbon compounds, considering that for balanced pressure under different temperature the proportion The difference among one hydrocarbon gas includingi another is determined by hot spot temperature, accordingly Hasteed hypothesis formed: assumes that the distinguishing rate of hydrocarbon gases varies with temperature, and that each gas reaches its optimum distinguishing rate at a distinct temperature, and that the relative separating rates at different temperatures are fixed. According to this idea, when the temperature rises, the maximum separation rates in oil dissolved gas would be in the following order: H<sub>2</sub>, CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>. Various scholars have built on this foundation to improve and develop the defect diagnostics relying on DGA: To discriminate between a thermal and an electric defect, Donable devised a two-ratio technique. Davis produced the oxy-hydrogen carbon triangular layout discriminating; Dewey proposed a triangular chart relying on the relative amounts of CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, and C<sub>2</sub>H<sub>2</sub>. Rogers enhanced the third- and fourth methods sequentially. In Japan, an electric-assisted research approach was discovered; The better electric-assisted research was proposed by China. method. Generally the fault analysis ways using DGA could be classified into three categories: the first is based upon the absolute quantity of oil

dissolved gas and the second is based on the pace at which oil dissolved gas amounts arise; and the third is determined by estimating related oil dissolved gas amounts. proportion of different oil dissolved gas [18].

Techniques relying on complete valuation of oil dissolved gas are relied on analysing constrained worth of oil dissolved gas; methods depending on arising rate of oil dissolved gas are relied on limited value of absolute and relative rate of gas manufacturing; methods relying on relative proportion of oil dissolved gas are relied on limited value of terms of absolute rate of gas manufacturing; methods relying on relative proportion of oil dissolved gas are relied on limited value of relative rate of gas manufacturing; methods relying on relative proportion of oil dissolved gas includes coding and no-coding. International Electro-technical Commission (IEC) uses three In China, the enhanced three ratio approach is utilised to make coding diagnoses. Lan-shuli and colleagues used actual quantity of oil dissolved gas, occurring rates of oil dissolved gas, and the three proportion technique, and examples to analyse and judge PT fault kind. method above is correct and feasible[18]. Yang-tingfang and others extended DGA analysis method by introducing BORDA method and increased the accuracy of defect detection [19]. There are a few drawbacks to using the three ratio strategy, like as “lack of coding, coding rule boundary absolution, fault classification vague”. As an outcome, artificial intelligence technologies such as expert systems, neural networks, fuzzy theory, and evolutionary algorithms have lately been utilised in PT fault assessment, with some promising outcomes. This is a novel approach to analysis. the PT fault.

## V. DGA APPROACHES

The research examined into and evaluated by comparing seven current methodologies for diagnosing faults utilising dissolved gas data. type:

- Key Gas Method,
- DoernenburgRatio Method,
- Rogers Ratio Method,
- Nomograph Technique,
- IEC Ratio Method,
- Duval Triangle Method, and
- CIGRE Method.

### A. Key Gas Method

The key gas strategy [20-21] estimates the gases delivered by the protecting oil after a disappointment, which expands the temperature in the force transformer. The presence of the flaw gases relies upon the temperature or energy which upsets the synthetic structure of the protecting oil. This strategy distinguishes mistakes by estimating singular gases instead of ascertaining gas proportions. The significance and extent of gases are classified "key gases". This test is the most significant and most often proceeded as it gives the primary sign of an issue. Despite the reason, stresses cause compound breakdowns in some oil or cellulose particles. The primary deterioration items are gases that disintegrate totally or somewhat in the oil under warm and electrical burden conditions because of flawed flows in the transformers. The hydrocarbon particles of mineral oil deteriorate and structure dynamic hydrogen and hydrocarbon sections, which at that point transform into gases, for example  $H_2$ ,  $CH_4$ ,  $C_2H_2$ ,  $C_2H_4$ ,  $C_2H_6$  etc. Gases that Hydrocarbons and hydrogen ( $CH_4$ ,  $C_2H_2$ ,  $C_2H_4$ ,  $C_2H_6$ ,  $H_2$ ), carbon oxides ( $CO$ ,  $CO_2$ ), and non-faucetinated hydrocarbons ( $CH_4$ ,  $C_2H_2$ ,  $C_2H_4$ ,  $C_2H_6$ ,  $H_2$ ) are all created in transformer oil. It gases ( $N_2$ ,  $O_2$ ).

### B. DoernenburgRatio Method

To facilitate fault diagnosis, gas reporting methods use coding schemes that assign specific code combinations to certain types of faults. The codes are created by computing gas concentration proportions and comparing them to preset values acquired from experience and updated on a regular basis. A malfunctioning situation is recognized when a gas combination matches a specific fault code. The Dornenburg reporting method identifies By examining gas concentration proportions like  $CH_4 / H_2$ ,  $C_2H_2 / CH_4$ ,  $C_2H_4 / C_2H_6$ , and  $C_2H_2 / C_2H_4$ , flaws can be identified. Thermal faults, corona discharges, including electric arcs can all be detected using this method. The concepts of heat deterioration are used in this procedure. Whenever the gas concentrations (in ppm) with  $H_2$ ,  $CH_4$ ,  $C_2H_2$ , and  $C_2H_4$  surpass twice the maximum level specified for each gas, and once the concentrations for  $CO$  as well as  $C_2H_6$  exceeds three times the maximum value set, the proportion approach is declared valid. Each succeeding proportion is compared to predefined values to evaluate the accuracy of the four proportions. Ultimately, if the four criteria are met, consecutive reports for a particular type of fault are within the specified values, the diagnosis is confirmed. This method specified in the IEEE C57.104-2008 [20] standard characterizes the gases dissolved in transformer oil. However, due to incomplete report areas, the method may produce many results without interpretation.

### C. Proportion Technique of Rogers

The Rogers proportion technique, which differentiates more kinds of thermal faults than the Dornenberg proportion mechanism, is the most widely used gas ratio technique. Rogers' technique looks at four different gas ratios:  $\text{CH}_4/\text{H}_2$ ,  $\text{C}_2\text{H}_6/\text{CH}_4$ ,  $\text{C}_2\text{H}_4/\text{C}_2\text{H}_6$ , and  $\text{C}_2\text{H}_2/\text{C}_2\text{H}_4$ . A basic report on interval-based coding technique is used to diagnose faults. The Rogers Ratio is a straightforward chart that uses proportion ranges to diagnose errors. Normal ageing, and partial discharge with or without tracing, and electrical and the thermal defects of various severity seem to be the four identifiable characteristics of such an oil-insulated converter. This approach, which is based on thermal degradation concepts, was included in the IEEE C57.104-2008 standard [20]. This strategy is powerful on the grounds that it relates the consequences of many issue examinations with the gas investigation of each case. Notwithstanding, some report esteems are conflicting with the analytic difficulty codes allotted to different blames in this technique. Likewise, since the technique doesn't believe disintegrated gases to be underneath typical fixation esteems, a precise execution of the strategy can even now confuse the information.

#### D. Nomograph Method

The Nomograph technique improves the exactness of issue conclusion by consolidating shortcoming gas proportions and the key gas edge idea. By introducing the issue gas information graphically, it improves the translation of the issue gas information. A nomograph is a progression of vertical logarithmic scales to speak to the grouping of individual gases as straight lines drawn between neighboring scales. The lines interface focuses that speak to the estimations of individual gas fixations. Straight lines are demonstrative standards for deciding the kind of deficiency. The kinds of shortcomings are distinguished by outwardly contrasting the slants of the line fragments with the keys at the lower part of the nomograph. The seriousness of the deformity is shown by the situation of the lines identified with the fixation scales. The edge estimation of every vertical scale is shown by a bolt. For the slant of a line to be viewed as critical, at any rate one of the two intersection focuses should surpass the edge esteem. The flaw isn't viewed as critical if the association point is more noteworthy than an edge esteem.

#### E. IEC Ratio Method

The IEC ratio technique is identical to the Rogers proportion technique, but it does not take into account the  $\text{C}_2\text{H}_6/\text{CH}_4$  ratio, which implies a narrow decomposing temperature range. The coding ranges for the remaining three gas percentages differ from the Rogers ratio approach [21]. The International

Electrotechnical Commission's defect detection methodology is based on the Rogers approach, with the exception that is  $\text{C}_2\text{H}_6/\text{CH}_4$  proportion. has decreased because it indicates a limited range of temperature decomposition. The four recognized states are normal aging, low and high energy density partial discharges, thermal failures and electrical failures of varying severity. However, thermal and electrical outages are not divided into specific subtypes. The first version of the The first version of the IEC technique (IEC 60599-1978) is dependent upon a simple coding plan, whereas the second version (IEC 60599-1979.-1999) was relied on a more complex coding scheme. directly uses modified ratio ranges. Prior to interpretation, the dissolved gases should be examined for "normal limits" based on the conditions.

#### F. Duval Triangle Method

Duval's triangle method [22-23] uses the values of only The positions of relative three gases  $\text{CH}_4$ ,  $\text{C}_2\text{H}_4$ , as well as  $\text{C}_2\text{H}_2$  on a triangle map. The gases were transformed to triangular dimensions to depict the pyramid. Partial discharges, electrical mistakes (elevated / low energy arcs), and the thermal faults were the three categories of recognised errors. (hot spots of different temperature ranges). While this procedure is easy to perform, careless implementation can lead to misdiagnosis as no area of the triangle is cited as an example of normal aging. Accordingly, prior to utilizing this strategy to investigate transformers that have been in assistance for a long time, it is important to decide the reasonable measure of disintegrated gas. A distinguished issue is analyzed by computing the all out of the three gases in Duval's triangle ( $\text{CH}_4$ ,  $\text{C}_2\text{H}_2$ , and  $\text{C}_2\text{H}_4$ ) and separating the measure of each gas by the complete to discover the level in the average of every gas The relative rates are therefore plotted upon that triangle, yielding the finding.

#### G. Technique of CIGRE

For defect identification, the CIGRE approach examines significant gas proportions including concentrations.  $\text{C}_2\text{H}_2/\text{C}_2\text{H}_6$ ,  $\text{H}_2/\text{CH}_4$ ,  $\text{C}_2\text{H}_4/\text{C}_2\text{H}_6$ ,  $\text{C}_2\text{H}_2/\text{H}_2$ , and  $\text{CO}/\text{CO}_2$  seem to be the five most essential gas ratios examined in this procedure.  $\text{C}_2\text{H}_2$ ,  $\text{H}_2$ , the total of hydrocarbons,  $\text{CO}$ , and  $\text{CO}_2$  seem to be the most significant gas concentrations. Whenever these approaches are applied separately, percentages and concentrations underneath the threshold were considered intact. limit values are obtained. The advantage of this method is that it is possible to detect two or more errors at the same time. By bringing together specialist knowledge and integrating some adaptations, the DGA interpretation CIGRE's technique improves the reliability of defect diagnosis by modifying earlier

interpretation strategies. The CIGRE and the Two-Step Interpretative Mechanism examines key gas concentration proportions and critical gas properties. key gas concentrations and compares them with limit values.

## VI. THE DUVAL PENTAGON

The absolute percentages of the five primary hydrocarbon gases assessed by DGA are first estimated with in new Duval Pentagon depictions. The relative percent of H<sub>2</sub> is calculated as (ppm of H<sub>2</sub>)/(ppm of H<sub>2</sub> + CH<sub>4</sub> + C<sub>2</sub>H<sub>6</sub> + C<sub>2</sub>H<sub>4</sub> + C<sub>2</sub>H<sub>2</sub>).

An example of the Duval-Pentagon representation and the calculations used is shown in Fig. Each peak of the pentagon corresponds to a gas, eg. H<sub>2</sub>. The relative percentage of H<sub>2</sub> is plotted on the axis between the pentagonal center (0% H<sub>2</sub>) and the pentagonal peak for H<sub>2</sub> (100% H<sub>2</sub>). The same goes for each of the other 4 gases [24].

In the example in Figure 1, the DGA results were H<sub>2</sub> = 31 ppm, C<sub>2</sub>H<sub>6</sub> = 130 ppm, CH<sub>4</sub> = 192 ppm, C<sub>2</sub>H<sub>4</sub> = 31 ppm, and C<sub>2</sub>H<sub>2</sub> = 0 ppm. The relative percentage of each gas (8, 34, 50, 8, and 0%, respectively) was plotted on the respective gas axis, with five different points represented by red squares. The center ("center of gravity") of the irregular polygon drawn by these five points was then mathematically calculated as shown below, giving a sixth point, shown in Figure 1 by a blue square. The DGA of such a situation is represented by the last point. example in the pentagonal configuration.

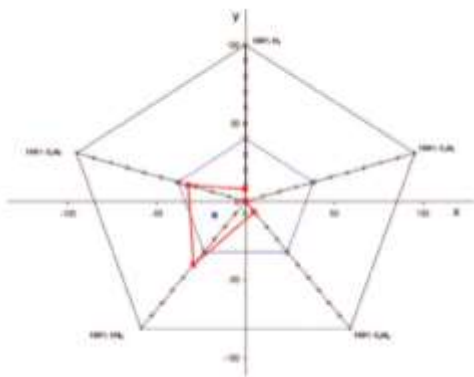


Figure 1. Example of Duval Pentagon representation[24]

## VII. CONCLUSION

The power transformer is an important part of the equipment in the power system. Their reliability affects not only the availability of electricity in the supplied area, but also the economic functioning of a utility company. Determining the health of the transformer is useful for making short-term decisions on operation and maintenance. The primary concern

with impending power transformer failures is that they can affect the electrical and mechanical integrity of the isolation system. This article describes techniques for monitoring power transformers and techniques for analyzing dissolved oil using various algorithms.

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