Analysis of Transformer Conditions using Triangle Duval Method

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Abstract. Electrical or thermal failure that occurred in the transformer oil can produce a dangerous gas called gas fault. By indicating the content of dissolved gases in the transformer oil, can be obtained information about what happened to the oil so it can be estimated indication of the type and cause of the failure in the transformer. The method used to identify and analyze the dissolved gases in oil is called Dissolved Gas Analysis (DGA). In this study conducted by the DGA Duval Triangle method for transformer oil used in geothermal power plant UPJP Kamojang PT. Indonesia Power. The results using Duval Triangle method produces thermal failure and partial discharge.

1. Preliminary
In the electric power transformer system is one of the vital parts, which serves to distribute electrical energy to the low voltage and high voltage to, the delivery takes place within the same frequency. This function is known as the term step-up and step-down, As electrical devices, transformers must never be separated from failures, especially the failure of thermal and electrical failure or what we call electrical breakdown. The failure of the type that usually occur in the transformer, namely: Arcing, Sparking, heat disorders and Partial Discharge [1].

Therefore, the reliability of the transformer also need to be maintained, and the necessary preventive measures to determine the condition of the transformer. One method often used is the method of DGA (Dissolved Gas Analysis). Methane (CH₄), Ethane (C₂H₆), Ethylene (C₂H₄), acetylene (C₂H₂) and Air (H₂O) [2].

2. DGA Testing

2.1 Sampling Process Oil

The sampling process oil in the transformer is divided into stages, due to prepare the equipment for oil sampling and sampling procedures of the oil in the transformer. For the first part is a tool that is used for sampling are: Syringe, oil flushing units, buckets, gloves, wipes and vials.[3] In the next stage of the sampling process transformer oil and gas extraction process to determine the gas content in the transformer.
2.2 Gas Extraction Process

a. Gas Chromatograph is a technique for separating substances - certain of a joint compound, usually substances - are separated by evaporation rates (volatility).[4]

![Figure 1. Method Chromatograph](image)

b. Photoacoustic Spectroscopy (PAS), (hydrogen, methane, oxygen, and others) basically have the ability to absorption of electromagnetic radiation that is unique and distinctive. This capability is usually applied to the infra-red spektokopis method to produce an effect of photo acoustic. Absorption of electromagnetic radiation by gases will increase the gas.[5]

![Figure 2. Photoacoustic Spectroscopy Method](image)

Results obtained from the extraction of gas will be used as input to the gas content analysis or DGA. DGA analysis of the calculation results can be obtained an indication of the failure of the transformer is likely to emerge.[6]

2.3 Analysis of Data From Extraction

After the gas is separated from the oil sample through the extraction process, it can be data in the form of gas contained in the sample, then the data is analyzed using Dissolved Gas Analysis. The method used is:
2.3.1 Limit IEEE / Total Dissolved Combustible Gases. TDCG is one type of Dissolved Gas Analysis method to classify the type of combustible gas, the higher the gas content obtained it must do further tests. [7]

Table 1. Standar TDCG

| Level | Concentration (Ppm) | Description TDCG |
|-------|---------------------|-------------------|
| 1     | <= 720              | Indications that the normal transformer operation |
| 2     | 721 - 1920          | Indications high starting a gas composition, there arises the possibility of failure, prevention of the symptoms do not continue. |
| 3     | 1921 - 4630         | Indications decomposition of a high level of insulation. The failure may have occurred. Make prevention of disorder does not continue. |
| 4     | > 4630              | Indications of deterioration are very high and the decomposition / damage to the insulator is already widespread. Imminent damage to the transformer. Soon |

2.3.2 Key Gas. Key gas is defined as gas - gas that is formed in the transformer oil coolers are quantifiable and can determine the type of failure occurs yan, based on the type of gas that is typical or dominant formed at various temperatures. [7]

Table 2. Standar Key Gas

| Fault                | Key Gas    | Criteria                                                                 | Gas Percent Amount |
|----------------------|------------|---------------------------------------------------------------------------|--------------------|
| Arcing               | Acetylene  | Large amount of and (and minor quantities of (CO), and may also exist if cellulose is involved) | (H₂) : 60% (C₂H₂) : 30% |
| Corona (Low Energy PD) | Hydrogen  | Large amount of some, with small quantities of (CO) and may be comparable if cellulose is involved | (H₂) : 85% (CH₄) : 13% |
| Overheating of Oil   | Ethylene   | Large amount of (less amount of (CO) and some quantities of (C₂H₆)(CH₄)(H₂)) | (C₂H₄) : 63% (C₂H₂) : 20% |
| Overheating of Cellulose | Carbon Monoxide | Large amount of CO and Hydrocarbon gases may exist | CO : 92% |

2.3.3 Roger Ratio. Roger Ratio method is one of the DGA methods by comparing the value / amount of gas that is different by dividing the gas with other gases. [8]. Comparison of the gas used by themselves have some reference standards starting from IEC Standards, CEGB Standards and ASTM Standards. Type of gas used as a comparison, namely: Hydrogen (H₂), Methane (CH₄), Ethane (C₂H₆), Ethylene (C₂H₄) and acetylene (C₂H₂). [9]

2.3.4 Triangle Duval. This method uses a triangular plot for analyzing interference, Methane (CH₄), Ethylene (C₂H₄) and acetylene (C₂H₂). When using the Triangle Duval necessary to determine the existence of a problem or not, how to determine the existence of a problem or not the gas is contained in the transformer oil is to ensure at least one of hydrocarbons or hydrogen should be at the level of L1. [10]

In addition, Duval triangle method was created to help method - other analytical methods. This method is a closed system (closed system) is different from the method of Key Gas and Gas Ratio which is (open system), so that this method can reduce the percentage of cases outside the analytical criteria.[11]
Table 3. Limit L1

| Gas | Limit L1 ppm |
|-----|--------------|
| H₂  | 100          |
| CH₄ | 75           |
| C₂H₂| 3            |
| C₂H₄| 75           |
| C₂H₆| 75           |
| CO  | 700          |
| CO₂ | 7000         |

Now that we know that we obtain the data entered in L1 criteria, then the data previously obtained we calculated by using a calculation formula Duval Triangle, namely:

\[
\% CH_4 = \frac{CH_4}{CH_4 + C_2H_4 + C_2H_2} \times 100\%
\]

\[
\% C_2H_2 = \frac{C_2H_2}{CH_4 + C_2H_4 + C_2H_2} \times 100\%
\]

\[
\% C_2H_4 = \frac{C_2H_4}{CH_4 + C_2H_4 + C_2H_2} \times 100\%
\]

Function formula above is to determine the value of (X, Y, Z) which represent the value of the proportion of CH₄, C₂H₄ and C₂H₂, from 0% to 100%, the first assumption in all three grades, namely: (CH₄ + C₂H₄ + C₂H₂) = S in ppm, then calculation of the third value in percent of the gas is X = CH₄ % CH₄ = 100 (A / S), Y = C₂H₄ % C₂H₄ = 100 (B / S), Z = C₂H₂ % C₂H₂ = 100 (C / S). So the value in (CH₄ + C₂H₄ + C₂H₂) must equal 100%. C₂H₄ [12]

Figure 3. Triangle Duval
Table 4. Types of Disorders of the Duval Triangle

| Symbol | Fault examples |
|--------|----------------|
| PD     | Partial discharge of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper |
| D1     | Partial discharges of the sparking type, inducing pinholes, punctures in carbonized paper. Low energy arcing carbonized inducing perforation or surface tracking of paper, or the formation of carbon particles in oil. |
| D2     | Discharges in paper oil, with the power of follow-through, the resulting in extensive damage to paper or large formation of carbon particles in the oil, metal fusion, tripping of the equipment and gas alarms. |
| T1     | Thermal Fault, evidenced by turning brownish paper (> 200°C) or carbonized (> 300°C). |
| T2     | Thermal Fault, carbonized of paper, the formation of carbon particles in oil. |
| T3     | Thermal fault, extensive formation of carbon particles in oil, metal coloration (800°C) or metal fusion (1000°C). |

3. Result and Discussion

This study uses data derived from geothermal power plant UPJP Kamojang PT. Indonesia Power. The data in the form of content of the extracted gas in transformer oil, gas content in transformer oil is used as a sample calculation is the gas content in transformer oil T31 during the period 2012 - 2017. The sample is what will be used as the calculation in Duval Triangle methods of analysis.

Prior to the Duval triangle analysis on the data obtained, first do data matching with the limit L1, because not all types of data acquired is at the limit L1. Adjustment function here is the first step in the analysis process, it is undeniable that the limit L1 is one of the conditions required in the analysis of Duval Triangle as the minimum limit indication of failure on the transformer.

Table 5. Data Transformer T31

| date      | $H_2$ ppm | $C_2H_4$ ppm | CO ppm | $CO_2$ ppm | $C_2H_6$ ppm | $C_2H_2$ ppm |
|-----------|------------|---------------|--------|-------------|---------------|---------------|
| 11/27/12  | 32         | 5             | 243    | 2405        | 1             | 8             | 0             |
| 11/12/2012| 32         | 1             | 243    | 2300        | 6             | 10            | 0             |
| 03/07/2013| 45         | 6             | 511    | 5944        | 1             | 10            | 0             |
| 12/16/2013| 34         | 5             | 379    | 6188        | 7             | 8             | 0             |
| 03/20/2014| 5          | 2             | 4      | 64          | 1             | 1             | 0             |
| 07/24/2014| 48         | 6             | 336    | 3406        | 1             | 6             | 0             |
| 25/09/2014| 54         | 7             | 462    | 4460        | 1             | 5             | 0             |
| 11/06/2014| 90         | 13            | 525    | 5588        | 1             | 7             | 21.6          |
| 07/11/2014| 33         | 11            | 348    | 4257        | 1             | 69            | 0             |
| 11/12/2014| 42         | 7             | 500    | 5384        | 1             | 8             | 0             |
| 01/22/2015| 44         | 10            | 551    | 6744        | 2             | 7             | 0             |
| 07/04/2015| 49         | 9             | 548    | 7476        | 5             | 8             | 0             |
| 16/10/2015| 55         | 14            | 641    | 10395       | 5             | 6             | 0             |
| 12/04/2015| 48         | 11            | 633    | 11025       | 5             | 13            | 0             |
| 01/19/2016| 52         | 9             | 633    | 11819       | 5             | 12            | 0             |
| 03/08/2016| 51         | 10            | 601    | 11 865      | 3             | 16            | 0             |
| 26/07/2016| 39         | 11            | 641    | 13835       | 13            | 5             | 0             |
| 19/12/2016| 22         | 1             | 36     | 209         | 3             | 3             | 0.5           |
| 29/05/2017 | 38         | 4             | 132    | 419         | 2             | 3             | 0.5           |
Table 6. Data transformer T31 is at L1 Limit

| Date       | H₂ ppm | CH₄ ppm | CO ppm | CO₂ ppm | C₂H₄ ppm | C₂H₆ ppm | C₂H₂ ppm |
|------------|--------|---------|--------|---------|----------|----------|----------|
| 11/06/2014 | 90     | 13      | 525    | 5588    | 1        | 7        | 21.6     |
| 07/04/2015 | 49     | 9       | 548    | 7476    | 5        | 8        | 0        |
| 16/10/2015 | 55     | 14      | 641    | 10395   | 5        | 6        | 0        |
| 12/04/2015 | 48     | 11      | 633    | 11025   | 5        | 13       | 0        |
| 01/19/2016 | 52     | 9       | 633    | 11819   | 5        | 12       | 0        |
| 03/08/2016 | 51     | 10      | 601    | 11865   | 3        | 16       | 0        |
| 26/07/2016 | 39     | 11      | 641    | 13835   | 13       | 5        | 0        |

Table 6 shows the data transformer T31 is at the limit L1, can be seen on the vulnerable 04-07-2015 to 26-07-2016 gas CO₂ content in transformer oil contains very high, CO₂ exceeding the limit on Limit L1 of 7000 ppm, because it should be noted rise on CO₂ can also affect the temperature rise in cellulose. On April 11 -06-2014, gas content increased in C₂H₂ the transcend limit L1. The increase in C₂H₂ the type of failure can cause Arcing.

3.1 Triangle Duval

Duval triangle method using three gas in the process are: CH₄, C₂H₂, and C₂H₄. The third gas present value (X, Y and Z) on. X for the value% CH₄, C₂H₄% Y for value, and Z value% C₂H₂. If it is assumed further that the value - the value of determination serves as a meeting point in determining the type of interference on Duval Triangle.

Data on April 11 -06-2014 indicates that the value of H₂ = 90 ppm CH₄ = 13 ppm, CO = 525 ppm CO₂ = 5588 ppm C₂H₄ = 1 ppm C₂H₆ = 7 ppm, and C₂H₂ =21.6 ppm, said to be worth using because the Duval triangle method has a C₂H₂ value that exceeds the limit L1, the final result of these data are:

\[
\% CH₄ = \frac{13}{13+9+21.6} \times 100\% = 35.519\%
\]

\[
\% C₂H₂ = \frac{21.6}{13+9+21.6} \times 100\% = 59.02\%
\]

\[
\% C₂H₄ = \frac{1}{13+9+21.6} \times 100\% = 5.464\%
\]
Table 7. Analysis on Transformer T3 using Triangle Duval Method

| Date       | $H_2$ ppm | $CH_4$ ppm | CO ppm | $CO_2$ ppm | $C_2H_4$ ppm | $C_2H_6$ ppm | $C_2H_2$ ppm | Fault |
|------------|-----------|------------|--------|------------|--------------|--------------|--------------|-------|
| 11/06/2014 | 90        | 13         | 525    | 5588       | 1            | 7            | 21.6         | D1    |
| 07/04/2015 | 49        | 9          | 548    | 7476       | 5            | 8            | 0            | T2    |
| 16/10/2015 | 55        | 14         | 641    | 10395      | 5            | 6            | 0            | T3    |
| 12/04/2015 | 48        | 11         | 633    | 11025      | 5            | 13           | 0            | T2    |
| 01/19/2016 | 52        | 9          | 633    | 11819      | 5            | 12           | 0            | T2    |
| 03/08/2016 | 51        | 10         | 601    | 11 865     | 3            | 16           | 0            | T2    |
| 26/07/2016 | 39        | 11         | 641    | 13835      | 13           | 5            | 0            | T3    |

The results of the analysis can be seen in Table 7, that the transformer T31 has the possibility of symptoms - symptoms of failure are diverse ranging from Partial Discharge, Thermal Fault $300 < T < 700^\circ\text{C}$, and Thermal fault $T > 700^\circ\text{C}$. This is because in some cases have increased activity in the $C_2H_2$ and $CO_2$, where the gas is a gas trigger of failure - the failure.

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