# ANALYSIS ON THE QUALITY OF THREE-PHASE TRANSFORMER OIL

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***Abstract: Tangent delta is an electrical diagnostic method to determine the condition of the insulation. One of the insulations to know is transformer oil being a liquid insulation. In a transformer, insulation is an important part to know from the beginning as a reference to determine the life of the insulation. To ascertain or know the effect of transformer oil on tangent delta, this study is conducted against transformer oil before filtering and after filtering. An instrument used for testing tangent delta testing is Megger Delta 2000. This instrument has several testing methods namely GST, GSTg, and UST.***

***Keywords: Transformer, Tangent Delta, Liquid Insulation***

## I. INTRODUCTION

### 1.1 BACKGROUND

Transformer plays a very vital role to distribute electrical energy in an electric machine. Transformer is an electric machine that can transform electrical energy from an electrical circuit to another one through a magnet coupling based on the magnetic induction principle. In general, transformer is used for changing an electrical energy from one voltage level to another one. One of the most critical parts of transformer is insulation and one of the insulations is transformer oil. Its condition is not certainly good due to a lot of dirt and water content on transformer oil. If the transformer oil is put into the transformer and the transformer is operated in such a condition, insulation failure and aging transformer insulation due to bad transformer oil will occur. A testing needs to be conducted to know the condition from the beginning. The testing is called tangent delta. The purpose of the testing is to know if the condition of transformer oil insulation is good.

### 1.2 THE PURPOSES OF THE STUDY

The purposes of the study are:

1. *To determine and indicate the values of tangent delta on transformer oil before and after purification.*
2. *To obtain tangent delta measurement results on transformer oil since the beginning as a reference in case of insulation trouble in a transformer.*
3. *To know the effect of transformer oil on tangent delta testing results.*

### 1.3 SCOPE OF PROBLEM

1. The testing is conducted only in a distribution transformer oil.
2. The brand of the tested transformer oil is Apar TU 60.
3. The condition of the tested transformer oil is before purification and after purification.
4. Rated voltage of the transformer oil used as a testing material in the transformer is 50kV.
5. The instrument used for testing tangent delta is Megger Delta 2000.

***Several researches used as references and comparisons are among others:***

1. *S. J. Tee; Q. Liu; Z. D. Wang; G. Wilson; P. Jarman; R. Hooton; D. Walker; P. Dyer, (2016) who Analysis An early degradation phenomenon identified through transformer oil database analysis[1].*
2. *Daniel Martin; Jaury Wijaya; Nick Lelekakis; Dejan Susa; Nick Heyward, (2014) who Analisys Thermal analysis of two transformers filled with different oils[2]*
3. *C. T. Dervos; C. D. Paraskevas; P. Skafidas; P. Vassiliou, (2005), who Analysis Dielectric characterization of power transformer oils as a diagnostic life prediction method[3]*
4. *Fu Wan; Weigen Chen; Caisheng Wang; Qu Zhou; Jingxin Zou; Zhaoliang Gu, (2014), who Analysis "Using a sensitive optical system to analyse gases dissolved in samples extracted from transformer oil [4]*

Therefore this research will Analysis On The Quality Of Three-Phase Transformer Oil, The value of tangent delta can be calculated on formulation basis to ensure the testing results and The value of tangent delta on transformer oil is determined by the existing $I_C$ and $I_R$ currents in the transformer leading to shift of δ angle and α angle.

## II. THEORETICAL BASIS

### 2.1 DEFINITION AND WORKING PRINCIPLE OF TRANSFORMER

Transformer is a statis electromagnetic electrical equipment functioning to transfer / change electrical energy from one electric circuit to another one, at the same frequency and with the certain transformation ratio in distributing the power where the current will flow in the primary coil resulting in the change of magnetic flux in iron core if the primary coil is connected to AC voltage source [5].

### 2.2 MAIN PARTS AND FUNCTIONS OF TRANSFORMER

**1. Iron Core**

Iron core functions to facilitate the flux resulting from electric current passing through the coil. It is made of thin iron plates insulated by silicon to reduce the heat (as iron losses) resulting from eddy current.

**2. Winding**

Winding consists of insulated copper or aluminium surrounding the iron core where the iron core will be inducted and a magnetic flux will occur when the AC current flows in the winding.

**3. Bushing**

Connector between the transformer coil and the external network through the terminal is called bushing, namely a conductor veiled by an insulator simultaneously functioning as an insulator between the conductor and the transformer tank.

**4. Tank and Radiator**

Transformer tank functions as a place to put the winding and the transformer oil. Transformer tank is connected to radiator. Radiator is a fin surrounding the transformer and functions as a cooling media in the transformer. The fin construction can radiate the heat on transformer oil and distribute the heat from the transformer oil to the air.

**5. Definition and Function of Transformer Oil**

Transformer oil is a liquid produced from crude oil refining process. In addition, the oil also originates from organic materials, for example piranol oil and silicon.Transformer oil is one of the liquid insulating materials used as insulator and cooler in the transformer. As an insulator, it must be able to withstand voltage breakdown and as a cooler, it must be able to reduce the heat generated.

### 2.3 TRANSFORMER OIL STANDARD

As a cooler, the viscosity of transformer oil may not be too high for easy circulation and the relative viscosity of transformer oil may not exceed 4.2 at a temperature of 20ºC and 1.8 and 1.85 and maximum 2 at a temperature of 50ºC. The requirements to fulfil by transformer oil are [6]:

**1. Clarity**

The insulating oil may not contain suspension or sediment.

**2. Density**

The density is limited so that the water can be separated from the insulating oil and does not float.

**3. Kinematic viscosity**

Viscosity plays an important role in the cooling, namely to determine the class of transformer oil.

**4. Flash point**

Low flash point indicates the contamination of flammable gabar substance.

**5. Pour point**

Pour point is used for identifying and determining the types of equipment to use insulating oil.

**6. Neutrality figure**

Neutrality figure is a figure to indicate a shrinking acid oil and can detect oil contamination and indicate the tendency of chemical changes in the additives.

**7. Sulphur corrosion**

Sulphur corrosion is possibly produced from free sulphur or volatile sulphur compounds in the insulating oil.

**8. Voltage breakdown**

Too low voltage breakdown indicates a contamination, such as water, dirt or conductive particles in oil.

**9. Water content**

Water content in the insulation results in reducing voltage breakdown and insulating oil resistance will accelerate the damage to the insulating paper.

### 2.4 TRANSFORMER TANGENT DELTA TESTING

Tangent delta is an electrical diagnostic method to determine the condition of the insulation. If the insulation is free from defect, the insulation will be capacitive perfect in nature as an insulator between two electrodes in a capacitor. In a perfect capacitor, voltage and phase current shift 90º and the current passing through the insulation is capacitive.

If, the contamination in the insulation, for example the moisture in the transformer, is too high, the resistance value of the insulation reduces and leads to high resistive current passing through the insulation, so that the current angle preceding the voltage is not $90^0$ anymore but shifts to less than $90^o$. The high difference of the shift from $90^o$ represents the level of contamination in the insulation [7]. Equivalent circuit drawings and phasor diagram of capacitance current and resistive current of an insulation are described herein below. The quality of the insulation can be predicted by measuring $I_R$ / $I_C$ value. In a perfect insulation, the angles approaches zero. The increasing angle indicates the increasing resistive current passing through the insulation meaning that a contamination occurs. The bigger the angle the worst the condition of the insulation.

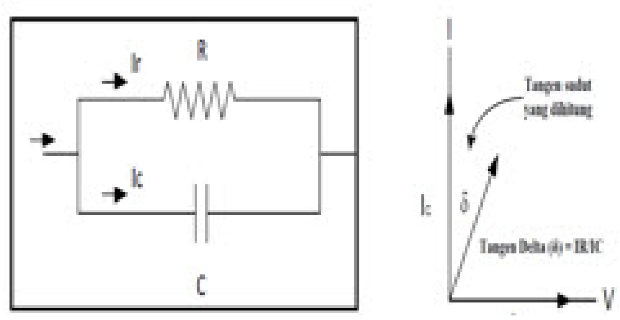


*Figure 1 Equivalent circuit isolation and testing current phasor diagrams tangent delta*

### 2.5 .MEASUREMENT MODES USED IN TANGENT DELTA TESTING

**1 GST (Grounded Specimen Test) Mode**
It is the capacitance of the object to test with the ground. For example, a testing between the secondary side and the ground or between the primary side and the ground.

**2 GSTg (Grounded Specimen Test Guard) Mode**
It is object capacitance to test with the ground and limit (guard) the capacitance of the other objects influencing the capacitance of the tested object.

**3 UST (Ungrounded Specimen Test) Mode**
It is the capacitance between the two objects not absolutely connected to the ground.

**4 Hot Collar**
It is a measurement mode to find out the cracks on porcelain, contamination on the bushing surface.

### 2.6. INSULATION FAILURE MECHANISM ON TRANSFORMER OIL

Several factors influencing failure mechanism are [8]:

**1 Particles**
Dust particles or cellulose fibres of the surrounding solid dielectric are always left behind in the liquid.

**2 Water**
Water here is different from moist particles. The water itself will exist on oil in operation. However, in a normal operation condition, the equipment tends to limit the moisture of less than 10%.

**3 Bubble**
The existing field in a bubble exceeds the steam power producing more steams and bubbles so as to form a bridge in all cracks resulting in a perfect release.

### 2.6 TRANSFORMER OIL PURIFICATION

Several transformer oil purification methods are:

**1 Boiling**
In this process, the oil is heated to boiling point and the water in the oil will evaporate because the boiling point of the oil is higher than that of the water.

**2 Centrifugal device**
The oil is rotated quickly in the centrifugal device. The dirt will be pressed to the side of the vessel by the centrifugal force and the clean oil will remain in the middle of the vessel.

**3 Filtering**
With this method, the oil is filtered through a filtering paper so that the dirt cannot pass through small filtering pores.

**4 Regeneration**
Regeneration is the last alternative if the methods above cannot reduce the aging in the oil.


 

## III. TANGENT DELTA TESTING METHOD AND STANDARD

### 3.1 TRANSFORMER TANGENT DELTA TESTING STANDARD

This time, the author does not yet find guideline and procedure for tangent delta testing but only finds those for transformer oil testing. Therefore, the method used is (*Breakdown Voltage)* test bowl. The author assumes that the bowl is like oil in the transformer, namely there are two electrodes within 2.5 mm as the minimum distance between the part with voltage and the part without voltage. The distance is in accordance with *IEC 60422* and *IEC 156* standards on breakdown voltage testing for the rated voltage of 50kV. Meanwhile, the bowl is made of resin for insulator in dry type transformer. Only ANSI standard that discusses tangent delta testing standard while PLN standard or another standard such as IEC does not contain tangent delta testing.

### 3.2 TESTING EQUIPMENT

Equipment used for the testing are:

1. Transformer oil Appar TU 60 before and after purification.
2. Tangent delta testing equipment Megger Delta 2000.

*Figure 2 megger delta 2000*

3. Bowls BDV

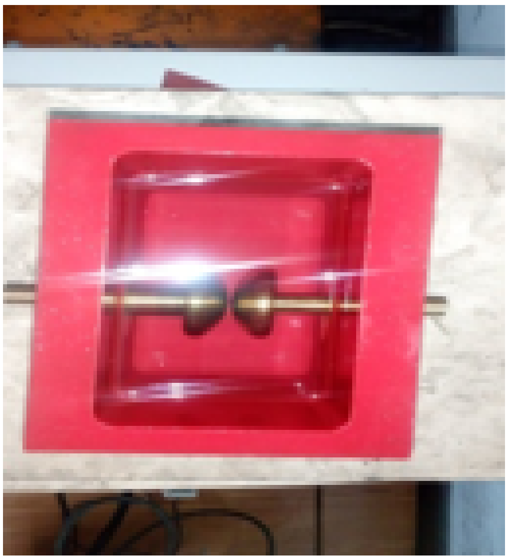

*Figure 3 Bowls BDV*

### 3.3 Transformer Oil Sampling Procedure

Principally, there should be no bubbles on oil in transformer oil sampling. Otherwise, there would be voltage flash over and in the testing and invalid testing result.

### 3.4 .Tangent Delta Testing Procedure

Tangent delta testing measures with one of the testing equipment namely Megger Delta 2000 are described as follows:

1. *Install grounding cable to the equipment and ensure that the grounding system is correct and connect the same as in the testing diagram drawing.*

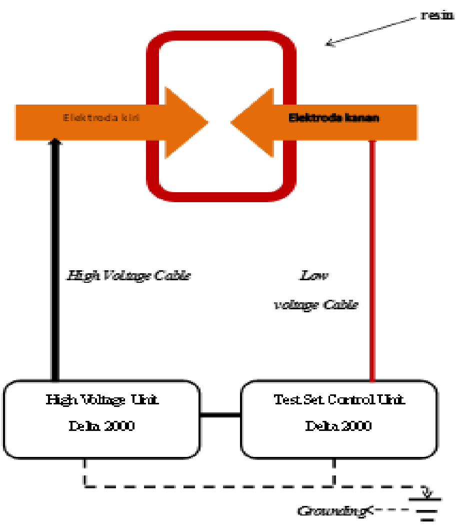


*Figure 4 Diagram Testing Tangent Delta Transformer Oil*

2. *Turn on "POWER" button to "ON" position.*
3. *Check "OPEN GROUND" light in the equipment if it still turns on. If it does, it means the ground system in the equipment or on the transformer needs to be rechecked.*
4. *After "OPEN GROUND" light is off, press menu in accordance with the configuration in the specimen to test (GST no Guard) and then choose "New Test"*
5. *Press the both interlock buttons and then choose "High Voltage ON" to start the testing.*
6. *Turn right "High Voltage Control" potensio until the voltage reads 10kV on the screen and then choose "Measurement".*
7. *Wait for several times until the results are shown on the screen.*
8. *Record the testing results comprising power, current, voltage, tan δ, and capacitance.*

## IV. DATA AND ANALYSIS

### 4.1 Tangent Delta Testing Data

The testing is conducted in two conditions, namely in conditions before purification and after purification of transformer oil. Tangent delta testing results are as follows:

From the table above, the values can be calculated with the formula as follows:

Table 1 Results of Testing Tangent Delta

| Condition | Mode | Voltage (kV) | Tan δ | Power (watt) | Current (mA) | Capacitance (pF) |
|---|---|---|---|---|---|---|
| Before | GST | 10 | 0,76 | 0,35 | 0,057 | 18,49 |
| After | GST | 10 | 0,24 | 0,129 | 0.054 | 16,48 |

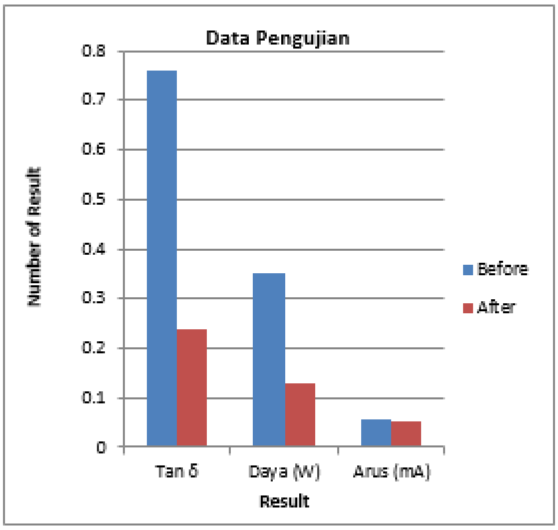


*Figure 5 Bar Chart Data Testing Transformer Oil*

1. Condition before purification

$0{,}35W = 10000V \times 0{,}057 \times 10^{-3} A \times \sin\delta$

$\sin\delta = \frac{0{,}35}{10000 \times 0{,}057 \times 10^{-3}}$

$\sin\delta = \frac{0{,}35}{0{,}57} = 0{,}614$

$\delta = \sin^{-1} 0{,}614 = 37{,}88^{o}$

The magnitude of the current IC can be calculated to be:

$I_C = 0{,}057 \times \cos 37{,}88^{o}$

$I_C = 0{,}045$ mA

The magnitude of the current IR can be calculated to be $0{,}057 = \sqrt{IR^2 + 0{,}045^2}$

$I_R^2 = 0{,}057^2 - 0{,}045^2$

$I_R^2 = 0{,}003249 - 0{,}002025$

$I_R^2 = 0{,}001224$

$I_R = \sqrt{0{,}001224}$

$I_R = 0{,}035$ mA

After knowing of $I_C$ and $I_R$ currents, the value of tangent delta (δ) can be calculated as follows:

tangent delta (δ) $= \frac{0{,}035}{0{,}045} = 0{,}78$

After knowing δ angle, $I_C$ current, $I_R$ current, the phasor can be described as follows:

The magnitude of the angle α be = $90^{o} - \delta = 90^{o} - 37{,}88^{o} = 52{,}12^{o}$

Condition after purification

$0{,}129W = 10000V \times 0{,}054 \times 10^{-3} A \times \sin\delta$

$\sin\delta = \frac{0{,}129}{10000 \times 0{,}054 \times 10^{-3}}$

$\sin\delta = \frac{0{,}129}{0{,}54} = 0{,}239$

$\delta = \sin^{-1} 0{,}239 = 13{,}83^{o}$

The magnitude of the current Ic becomes:

$I_C = 0{,}054 \times \cos 13{,}83^{o}$

$I_C = 0{,}0524$mA

The magnitude of the current IR can be calculated to be

$0{,}054 = \sqrt{IR^2 + 0{,}0524^2}$

$I_R^2 = 0{,}054^2 - 0{,}052^2$

$I_R^2 = 0{,}002916 - 0{,}002746$

$I_R^2 = 0{,}00017$

$I_R = \sqrt{0{,}00017}$

$I_R = 0{,}01304$ mA


 

After knowing $I_C$ and $I_R$ currents, the value of tangent delta (δ) can be calculated as follows:

Tangenss delta (δ) = $\frac{0{,}01304}{0{,}0524}$ = 0,25

After knowing δ angle, $I_C$ current, and $I_R$ current, the phasor can be described as follows:

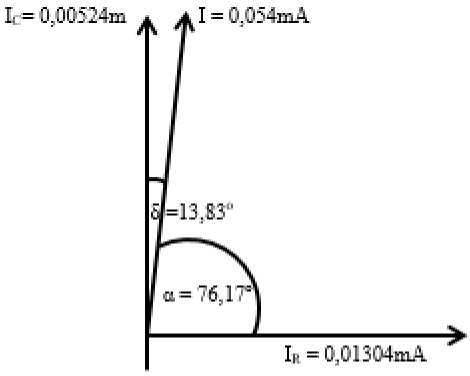


*Figure 6 phasor diagrams*

From the testing phasor calculation and diagram, it is concluded that the value of tangent delta angle after improvement by purification is significant with the shrinking δ angle from 52.12º to 76.17º. In addition, $I_R$ and $I_C$ currents decline. It will certainly change the value of tangent delta after purification on transformer oil than before purification.

## V. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSION

1. *The value of tangent delta can be calculated on formulation basis to ensure the testing results.*
2. *The value of tangent delta on transformer oil is determined by the existing $I_C$ and $I_R$ currents in the transformer leading to shift of δ angle and α angle.*
3. *After testing and analysing the value of tangent delta before and after purification, the value of tangent delta is highly different.*
4. *In addition, δ angle increases and α angle decreases before purification.*

### *5.2* SUGGESTIONS

1. *Tangent delta testing on transformer oil should serve as a reference in the subsequent tests and can serve as a reference in the testing of transformer used.*
2. *Other tests namely DGA (Dissolved Gas Analysis) and BDV (Breakdown Voltage) test are required for more perfect condition of transformer oil insulation*

## BIBLIOGRAPHY

[1] S. J. Tee; Q. Liu; Z. D. Wang; G. Wilson; P. Jarman; R. Hooton; D. Walker; P. Dyer, (2016). “An early degradation phenomenon identified through transformer oil database analysis”, 2016 IEEE Transactions on Dielectrics and Electrical Insulation.

[2] Daniel Martin; Jaury Wijaya; Nick Lelekakis; Dejan Susa; Nick Heyward, (2014). “Thermal analysis of two transformers filled with different oils”, 2014 IEEE Electrical Insulation .

[3] C. T. Dervos; C. D. Paraskevas; P. Skafidas; P. Vassiliou, (2005). “Dielectric characterization of power transformer oils as a diagnostic life prediction method” 2005 IEEE Electrical Insulation.

[4] Fu Wan; Weigen Chen; Caisheng Wang; Qu Zhou; Jingxin Zou; Zhaoliang Gu, (2014). "Using a sensitive optical system to analyze gases dissolved in samples extracted from transformer oil” 2014 IEEE Electrical Insulation.

[5] Arismunandar 1990. *High Voltage Engineering*: Pradnya Paramita, Jakarta

[6] Danikas M.G (1990).”*Breakdwon of Transformer* Oil” 1990 IEEE Electrics Insulation

[7] Kind,Deter 1993. *Introduction to high voltage experimental engineering*: ITB Bandung

[8] L.Tobing, Bonggas. , 2003. *High Voltage Equipment*, Jakarta: PT Gramedia Pustaka Utama


 