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Feasibility Test Analysis of Insulation Resistance Based on Polarization Index and Delta Tangent On Transformator 30-40 MVA

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Abstract

This research present the feasibiity insulation test of 30-40 MVA transformer at 150/20 KV substation with the aim of ensuring the quality of the insulation resistance value. The model is determined as a feasibility test of the transformer by conducting an insulation resistance test on a 30-40 MVA transformer. Parameters determined include: polarization index and delta tangent data which are then calculated and compared with IEEE 43-2000 and ANSI C 57.12.90 standards. The method used is polarization index and delta tangent which are used to evaluate the quality of insulation in electrical equipment. As the research site was chosen PT. Asia Pacific Fiber, Kendal, Indonesia. The results show that the polarization index on the measurement data of the 30-40 MVA transformer a: 1.772-1.098-1.091 and the calculation results: 1.760-1.200-1.100. The results show that the delta tangent to the measuring data of a 30-40 MVA transformer a: 0.5%-4.3%-1.2% and the calculation results: 0.3%-2.0%-0.8% . The test and measurement results are compared with the appropriate standard values for the polarization index of 1.25-2 and the delta tangen value is ≤0.5%, this is based on the IEEE 43-2000 and ANSI C 57.12.90 standard the 40 MVA transformer is appropriate while the transformer 30-35 MVA is not suitable so further repair and maintenance steps are required.

Keywords: *Feasibility Test of Transformer Insulation Resistance, Polarization Index, Delta Tangent*

1. Introduction

The function of the power transformer is to change electrical power from high voltage to medium voltage or vice versa [1]. PT Asia Pacific Fibers (PT. APF), Kendal, Indonesia is a spinning company that has a 150/20 KV substation with a transformer capacity of 30-40 MVA which has been operating for almost 40 years working continuously for 24 hours with a peak load of 70% [2]. The problems that occur in the 30-40 MVA transformer are: overvoltage, high humidity and temperature factors. This is because the equipment is used continuously. The impact is a decrease in insulation resistance and causes short circuit disturbances in the transformer [3]. To ensure that the transformer is in normal condition, evaluation, testing or maintenance needs to be carried out on a routine scale so that the transformer can operate according to its maximum usage period. Several previous studies discussing the test of insulation on transformers have been carried out, including: analysis of insulation resistance testing based on the breakdown voltage ratio test [5], using the fuzzy-based dissolve gas analysis (DGA) method [6], insulation resistance test method with directional polarization, and test method with delta tangent measurement [7], high voltage electrical equipment [8], repair of transformer insulation resistance of 60 MVA using the delta tangent method [9]. This study focuses on the analysis of the feasibility test of insulation resistance based on polarization index and delta tangent on 30-40 MVA transformers at 150/20 KV substations. The results of the due diligence values were compared with the IEEE 43-2000 and ANSI C 57.12.90 standards.

2. Research Methods

Feasibility test insulation resistance based on polarization index and delta tangent on a 30-40 MVA transformer using a power transformer research model at a 150 KV substation at PT APF Kendal by testing the insulation resistance on the windings. The transformer research model is shown in Fig. 1. Insulation resistance testing can be done using several methods such as polarization index, delta tangent, time resistance method (absorption test), and portal discharge test (testing using low frequency voltage) [3]. The value in the insulation resistance test can be affected by temperature, humidity, and leak paths or dirt in the bushings or insulation, therefore in this study the polarization index and tangent delta testing method was chosen.

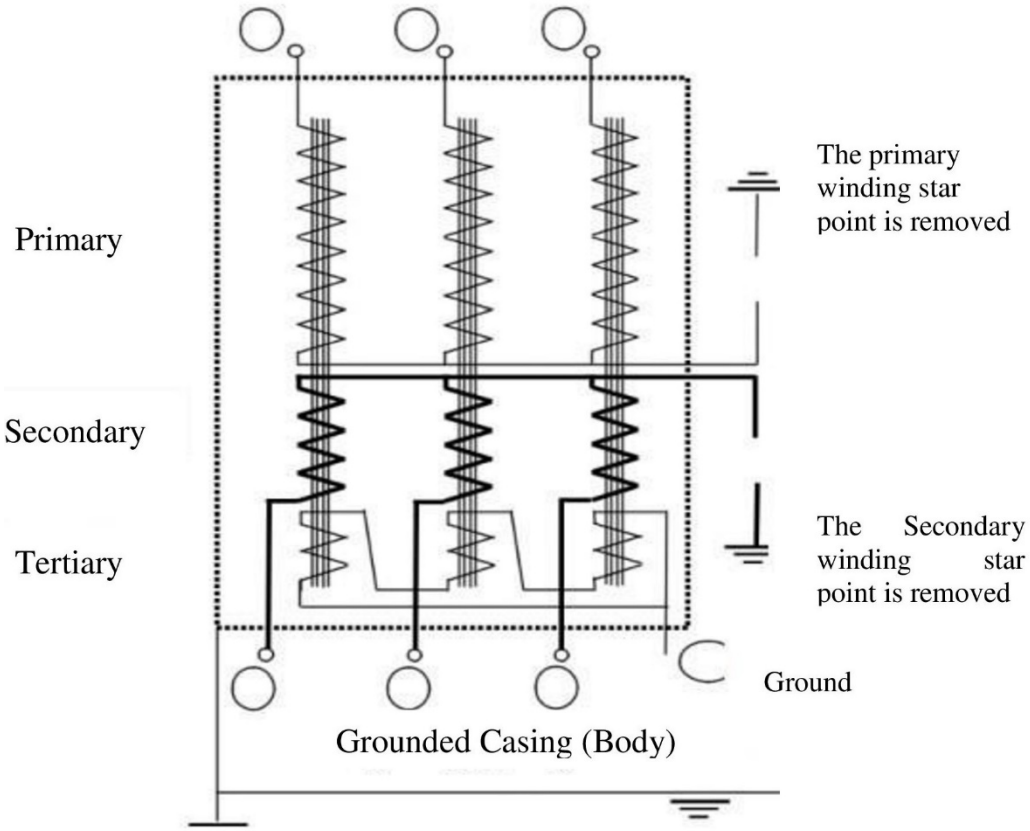

Fig. 1 Transformers Research Model.

2.1 Polarization Index (PI)

The polarization index (PI) is a test method used to measure the insulation integrity of electrical equipment. The purpose of this test is to evaluate the extent to which the insulation on electrical equipment can maintain resistance to leakage currents for a certain period of time. In PI testing, a DC (direct current) voltage is applied to the equipment under test, such as a transformer, electric motor, generator, or cable. The PI is a comparison between the value of the insulation resistance in the 10th minute and the 1st minute. The leakage current through the insulation or the leakage channels on the outer surface determines the rated insulation resistance. Temperature, humidity, and dirt adhering to the insulation have an impact on damage to the path causing surface leaks. Although current leakage cannot be prevented, the leakage that occurs must be less than the existing standards and must comply with the relevant terms and conditions. The PI calculation is shown as Eq. (1).

$$PI = \frac{R_{10}}{R1} \qquad (1)$$

with: *PI*= Polarization Index, R_{10}= the test was carried out at 10 minutes, R_1= the test was carried out in the 1st minute.
Calculation of the PI value performs calculations based on Eq. (1) to obtain the value of an insulation resistance, the category of isolation conditions based on the results of the PI value test has a standard value which can be concluded that an insulation resistance value is still in good or bad condition, the provisions of the value obtained from testing or calculation of insulation resistance using the PI method refers to Table 1 which shows a provision for the value of insulation resistance in the PI test method in accordance with the IEEE 43-2000 standard [7] standard explaining insulation requirements, tools used, test procedures, interpretation of test results and limit values fulfilled.

Table 1: Standard polarization index (PI) IEEE 43-2000 [7]

Test Result	Information	Recommendation
<1,0	Dangerous	Investigation
1,0 – 1,10	Bad	Investigation
1,10 – 1,25	Questionable	Tangent Delta Test
1,25 – 2,0	Good	-
>2,0	Very Good	-

The polarization indeks (PI) is the ratio between the insulation resistance at a longer time and the insulation resistance at a shorter time. A high PI value indicates good insulation, as the insulation resistance remains high over time. Conversely, if the PI value is low, it can indicate an insulation leak or damage to the equipment. PI testing provides an early indication of the insulation quality of equipment and can be used to detect potential problems before failure or damage occurs. This method is commonly used in preventive maintenance and monitoring of electrical equipment to ensure the reliability and safety of the power system operation.

2.2 Delta Tangen (DT)

Delta Tangen (DT) or commonly known as loss angle or dissipation factor test is an electrical diagnostic method used to evaluate the quality of insulation in electrical equipment. This method is also known as dielectric power factor testing or loss factor testing. Basically, the DT method involves measuring the power factor or loss factor of the insulating material. An ideal insulating material has a very low power factor, indicating that the insulation has a high resistance to leakage current. The DT testing process involves applying an AC voltage to the equipment or component to be tested, such as a transformer, cable, or capacitor. During the test, the applied AC voltage produces a leakage current through the insulation. This test compares the phase between the voltage and current flowing through the insulation to measure the power factor or loss factor. In the DT method, measurements are made at specified frequencies and voltages, and the results are used to evaluate the state of the insulation. If the power factor or insulation loss factor exceeds the specified limit, it can indicate damage or leakage in the insulation. DT testing is a useful method for identifying problems with the insulation of electrical equipment and monitoring insulation quality over time. This helps in preventive maintenance, early detection of insulation leaks, and proper maintenance to prevent further damage to electrical equipment. The isolation system in a transformer generally consists of an isolation winding with ground and two parts of the winding with insulation: primary–ground, secondary– ground, tertiary–ground, primary–secondary, secondary–tertiary, primary–tertiary.

The equivalent circuit of the insulation and the phasor diagram of the capacitance current and resistive current of an insulation, Ir/Ic measurements can predict the quality of the insulation. Perfect isolation has angles close to zero. Increasing the angle will increase the resistive current that is passed through the insulation, this means that there is contamination in the insulation. Increasing the angle will worsen the condition of an insulation, in this explanation it can be exemplified as shown in Fig. 2.

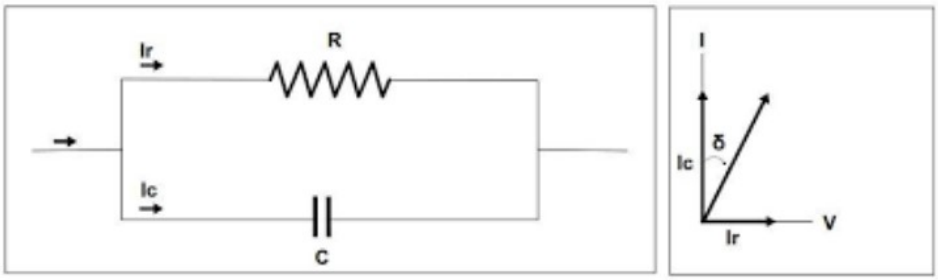

Fig. 2 Isolation equivalent circuit and phasor diagram.

General steps in delta tangent (DT) testing using equivalent circuits: Prepare the necessary equipment, connect the equipment to be tested with the DT measuring equipment and an AC voltage source. The test configuration determines the appropriate frequency and voltage for the test based on the characteristics of the equipment to be tested. Set the DT

measuring equipment according to the test parameters. Building an equivalent circuit that reflects the insulation characteristics of the equipment to be tested, this circuit consists of resistive and capacitive components that represent the insulation resistance and capacitance of the equipment. The testing process by applying AC voltage to the equipment to be tested. DT measuring equipment will measure the current and the phase between the voltage and current in an equivalent circuit. Record the results of the DT measurements for each stress tested. Perform analysis and evaluation of DT measurements to evaluate the quality of insulation on the equipment being tested. Compare the DT value with the specified limits to identify abnormal insulation conditions or insulation leaks that may occur. DT measurement results into useful information about insulation quality and equipment condition. Identify possible problems or need for further maintenance based on the test results. If the test results indicate a problem with the insulation, take the necessary repair or maintenance steps to improve the condition of the insulation and prevent further damage to the equipment. The equivalent circuit is further clarified by an illustrated tangent delta test scheme as shown in Fig. 3.

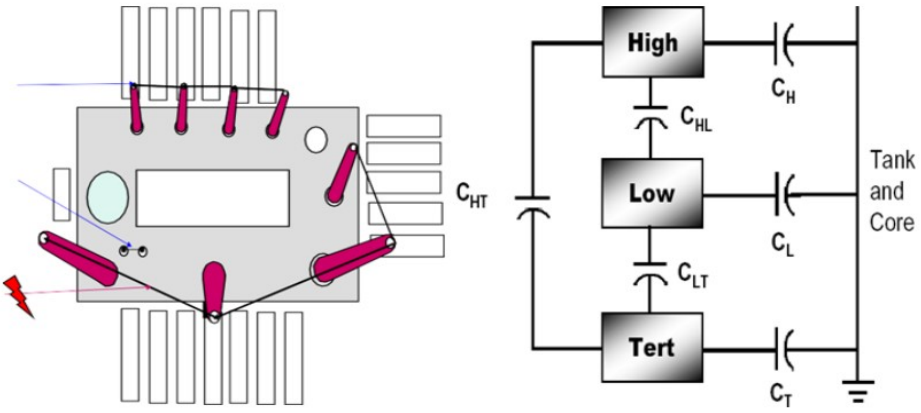

Fig. 3 Transformer isolation equivalent circuit and tangent delta test scheme.

The state of isolation in the transformer can be determined by the results of the delta tangent (DT) test. Data interpretation of the test results refers to the ANSI C57.12.90 standard [7] standard rules. Eq. (2) and (3) show the calculation of DT (S) distance and (Z) impedance.

$$S = \frac{V^2}{Z} \quad (2)$$

$$Z = \frac{V^2}{S} \quad (3)$$

Finding the value of a capacitive reactance (Xc) as shown in Eq. (4) and (5):

$$Xc = \frac{V^2}{Q} \quad (4)$$

$$Xc = \frac{1}{\dot{\omega}C} \quad (5)$$

Where from Eq. (4) and (5) the equation for calculating energy (Q) is obtained which is shown in Eq. (6) to (8).

$$Q = \frac{V^2}{XC} \quad (6)$$

$$Q = \frac{V^2}{\frac{1}{\dot{\omega}C}} \quad (7)$$

$$Q = V^2\dot{\omega} \quad (8)$$

So the tangent delta value is obtained according to Eq. (9).

$$Tan\ \delta = \frac{P}{V^2\ C} \quad (9)$$

with: δ= delta, P= power (watts), V= voltage (volts), C= capacitance (f) dan $\dot{\omega}$= 2πf.

Eq. (9) explains that the insulation resistance test using the delta tangent (DT) method obtains a standard to refer to the measurement results obtained from an insulation resistance, the standardization of the DT uses the ANSI C 57.12.90 standard [7] concerning the requirements for insulation quality values in electrical equipment used as a standards are met. Testing the tangent delta with a good yield value ensures that a transformer is feasible to operate if the test value meets the standard, namely ≤0.5% and if an insulation resistance test shows a value of more than 0.5%, it means that the transformer

has begun to experience a decrease in the quality of insulation resistance. and it is recommended to carry out further checks and repairs in order to repair the damage that arises due to the poor insulation resistance value. as shown in Table 2.

Table 2: Standard tangent delta using ANSI C 57.12.90 [7]

Test results	Condition
≤0,5 %	Good
0,5 % - 0,7 %	Starting to experience a decline
≥ 1,0%	Bad

The flowchart of the research steps in the analysis of the test of insulation resistance based on the polarization indeks (PI) and delta tangent (DT) on a 30-40 MVA transformer is shown in Fig. 4.

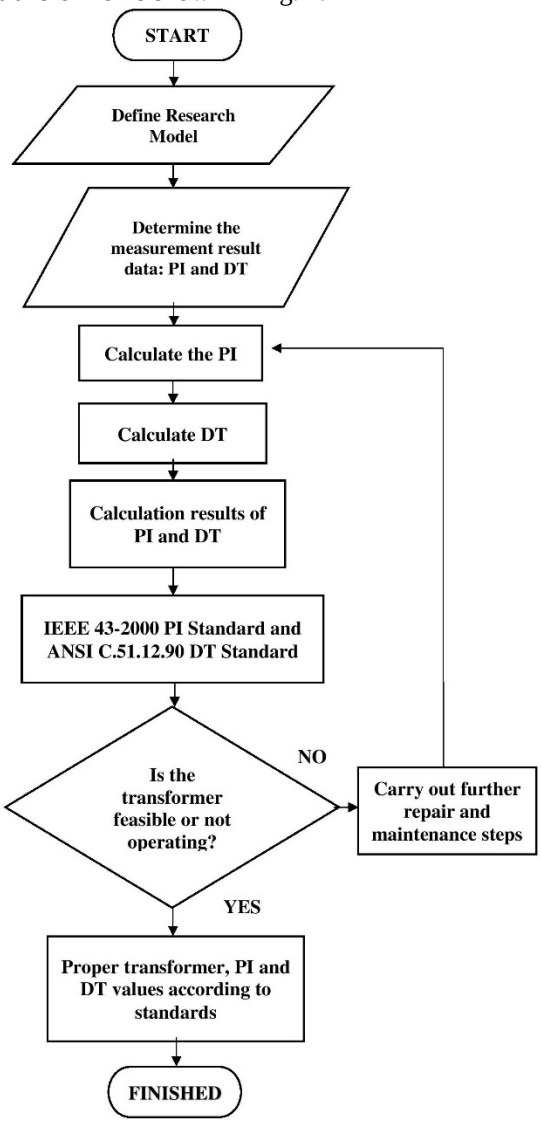

Fig. 4 Research flowchart.

The initial steps for carrying out the research were: observing the research site, seeking information related to transformers and determining transformer insulation resistance data. Data specifications for 30-40 MVA transformers are determined based on the name plate of each transformer at the 150/20 KV substation as shown in Table 3.

Table 3: Data transformer 30-40 MVA substation 150/20 KV

Rating	30 KVA	35 KVA	40 KVA
Serial Number	38761	38932	38933
Year Of Manufacture	1995	1998	1998
Ref. Standard	IEC–60076 / BS 171	IE–60076 / BS 171	IEC–60076 / BS 171
Frequency	50 HZ	50 HZ	50 HZ
Phases	3	3	3
Cooling	ONAN / ONAF	ONAN / ONAF	ONAN / ONAF
HV Side	150 KV	150 KV	150 KV
LV Side	20 KV	20 KV	20 KV
Rated HV	136.01 Amperes	134.719 Amperes	181.135 Amperes
Rated LV	867.05 Amperes	1010.39 Amperes	1154.73 Amperes
Temperature Rise Oil	50 ºC	50 ºC	50 ºC
Temperature Rise Wdg	55 ºC	55 ºC	55 ºC
Vector Group	Ynyn – 0	Ynyn – 0	YNyn – 0
MASS/Vol. of Oil	15000 Kg / 17000 L	6400 Kg / 18500 L	17600 Kg /19600 L
Untanking MASS	31000 Kg	32200 Kg	34900 Kg
Total MASS	61000 Kg	65000 Kg	71000 Kg
Ambient Temperature	50 ºC	50 ºC	50 ºC
Tank Type	Conservaton	Conservaton	Conservaton

3. Results and Discussion

3.1 Calculation of Insulation Resistance Polarization Indeks (PI)

Table 4 describes the measurement data of a 30-40 MVA transformer for insulation resistance that has been measured using the polarization indeks (PI) method.

Table 4: Polarization index data for 30-40 MVA transformers in 2022

Transformator Daya	30 MVA	35 MVA	40 MVA
Channel	CH1	CH1	CH1
Capacitance @ 50 Hz	4, 319 nF	5, 204 nF	5, 393 nF
Capacitance @ 60 Hz	4, 316 Nf	5, 201 nF	5, 392 Nf
Tan δ / power factor @ 50 Hz	0, 96 % / 0, 96 %	0, 61 % / 0, 61 %	0, 26 % / 0, 26 %
Tan δ / power factor @ 60 Hz	0, 90 % / 0, 90 %	0, 58 % / 0, 58 %	0, 25 % / 0, 25 %
C (10 mHz) / C (50 Hz)	1, 574	1, 238	1, 500
Barriers (X)	60 %	60 %	22 %
Spacers (Y)	14 %	10 %	16 %
Polarization Index	1, 097	1, 098	1, 772
Dar	1, 091	1, 037	1, 249
Primary–Sekunder (1 min)	10900	9987	6730
Primary–Sekunder (10 min)	12050	12010	11900

Referring to the research model according to Fig. 1. and the data from the insulation resistance test results from the 30-40 MVA transformer in Table 4 a calculation is obtained through Eq. (1), then the calculation of the polarization indeks (PI) on the primary–secondary transformer 30 MVA:

$$\text{PI} = \frac{12050}{10900} = 1,\ 10$$

Calculation of the PI on the primary–secondary transformer 35 MVA:

$$\text{PI} = \frac{12010}{9987} = 1,\ 20$$

Calculation of the PI on the primary–secondary transformer 40 MVA:

$$PI = \frac{11900}{6730} = 1,\ 76$$

After obtaining the measurement data and calculations on the insulation resistance of the 30-40 MVA transformer using the PI method, a test result obtained adheres to the IEEE 43-2000 standard [7] standard, as shown in Table 5.

Table 5: The results of the insulation resistance test using the polarization index (PI) method.

Transformer	Measurement Data	Calculation Data	Standard Value IEEE 43-2000	Information
30 MVA	1,091	1,10	1,10-1,25	Questioned
35 MVA	1,098	1,20	1,10-1,25	Questioned
40 MVA	1,772	1,76	1,25-2,0	Good

3.2 Calculation of Delta Tangent (DT) Insulation Resistance

Delta tangent (DT) testing on transformers is carried out using several test equipment from several vendors, such as using magger, omicron, doble, tettex and so on. Insulation resistance testing in this study uses the tangent delta method with the omicron tool. The tests that have been carried out obtained the value of insulation resistance on transformers of 40-30 MVA using the DT method, as shown in Table 6.

Table 6: Tangent delta data for 30-40 MVA transformers in 2022

Transformer	Measurenment Capacitance	Test Mode	Vout (KV)	Cap. Meas (pF)	Watt Losses	Tangen Delta %	
						DF Meas	DF Corr
30 MVA	ICH + ICHL	GST	10	8066, 4	2,239	1,20	0, 82
	ICH	GSTg-A	10	3750, 0	3,666	1, 57	1, 21
	ICHL	UST - A	10	4316, 5	2,316	0, 88	0, 68
Cross ceck : Calculated ICHL				-	-	-	-
35 MVA	ICH + ICHL	GST	10	9616, 6	5,839	4, 3444	3, 4744
	ICH	GSTg-A	10	4349, 7	7,299	6, 2899	5, 0284
	ICHL	UST - A	10	5203, 7	1,921	0, 5816	0, 4652
Cross ceck : Calculated ICHL				5266, 8	1,898	2, 7363	-
40 MVA	ICH + ICHL	GST	10	8066, 4	2,239	1,20	0, 82
	ICH	GSTg-A	10	3750, 0	3,666	1, 57	1, 21
	ICHL	UST - A	10	4316, 5	2,316	0, 88	0, 68
Cross ceck : Calculated ICHL				5392, 4	1,854	0, 2547	-

The following is a description of the Capacitance Measurement based on Table 6
ICHL : Injeks Capasitance High Low
ICH : Injeks Capasitance High
There are various terms when DT measurements are carried out including:
UST : Ungrounded Speciment Test
GST : Grounded Speciment Test
GSTg : Grounded Speciment Test with guard

Referring to the research model according to Fig. 1. and data from the insulation resistance test results on the three 30-40 MVA transformer units using the delta tangent (DT) method in Table 6, the calculation of the DT is through Eq. (9). The value obtained from the calculation of insulation resistance on a 30-40 MVA transformer:

Transformer 30 MVA

$$Tan\ \delta = \frac{2{,}239}{10000^2 \times 2 \times 3{,}14 \times 50 \times 8066{,}4 \times 10^{-12}} \times 100\ \%$$
$$Tan\ \delta = \frac{2{,}239}{10^{-4} \times 6{,}28 \times 8066{,}4} \times 100\ \%$$
$$Tan\ \delta = \frac{2{,}239 \times 10.000}{2.532.850} \times 100\ \%$$
$$= 0{,}8\ \%$$

Transformer 35 MVA

$$Tan\ \delta = \frac{1{,}039}{10000^2 \times 2 \times 3{,}14 \times 50 \times 9616{,}6 \times 10^{-12}} \times 100\ \%$$
$$Tan\ \delta = \frac{1{,}039}{10^{-4} \times 6{,}28 \times 480.830} \times 100\ \%$$
$$Tan\ \delta = \frac{1{,}072 \times 10.000}{3.019.614} \times 100\ \%$$
$$= 2{,}0\ \%$$

Transformer 40 MVA

$$Tan\ \delta = \frac{1{,}072}{10000^2 \times 2 \times 3{,}14 \times 50 \times 9328{,}8 \times 10^{-12}} \times 100\ \%$$
$$Tan\ \delta = \frac{1{,}072}{10^{-4} \times 6{,}28 \times 466.410} \times 100\ \%$$
$$Tan\ \delta = \frac{1{,}072 \times 10.000}{2.929.054{,}8} \times 100\ \%$$
$$= 0{,}3\ \%$$

The data values obtained and the calculation of insulation resistance on a 30-40 MVA transformer using the delta tangent (DT) method ICH+ICHL mode which adheres to the standard rules of ANCI C 57.12.90 standard [7] obtained the results of the insulation resistance test as shown in Table 7.

Table 7: Insulation resistance test results with the tangent delta (DT) method %.

Transformer	Measurement Data	Calculation Data	Standard Value ANCI C 57.12.90	Information
30 MVA	1,20 %	0,8 %	≥ 1,0%	Bad
35 MVA	4,3 %	2,0 %	≥ 1,0%	Bad
40 MVA	0,41 %	0,3 %	≤0,5 %	Good

4. Conclusions

Based on the results of the feasibility test analysis of insulation resistance based on the polarization index (PI) and delta tangent (DT) on a 30-40 MVA transformer at the PT APF 150/20 KV substation, the following conclusions can be drawn:

1. The results of the 30 MVA transformer test using the polarization index method on the measurement data are 1.091 and the calculation results are 1.100 and the results of the delta tangent test on the measurement data are 1.2% and the calculation results are 0.8%. The two results are compared with the appropriate standard values for the polarization index of 1.25-2 and the delta tangent value is ≤0.5%, so the values obtained are not in accordance with the IEEE-2000 and ANSI C 57.12.90 standard.
2. The results of the 35 MVA transformer test using the polarization index method on the measurement data are 1.098 and the calculation results are 1.200 and the results of the delta tangent test on the measurement data are 4.3% and the calculation results are 2.0%. The two results are compared with the appropriate standard values for the polarization index of 1.25-2 and the delta tangent value is ≤0.5%, so the values obtained are not in accordance with the IEEE-2000 and ANSI C 57.12.90 standard.
3. The results of the 40 MVA transformer test using the polarization index method on the measurement data are 1.772 and the calculation results are 1.760 and the results of the delta tangent test on the measurement data are 0.5% and the calculation results are 0.3%. The two results are compared with the appropriate standard values for the polarization index of 1.25-2 and the delta tangent value is ≤0.5%, the values obtained are in accordance with the IEEE-2000 and ANSI C 57.12.90 standard.

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