Analysis of Losses Due to the Effect of Noise on Dry Transformers at Artg Port Belawan

Imam Wahyudi, Rahmaniar, Parlin Siagian

Abstract
This study aims to analyze the losses and effects of noise on dry transformers at ARTG Port Belawan. The method used is quantitative with a field study approach. The test was carried out with a voltage variation of 90%–110% of the nominal voltage and a load of 25%–110%. The parameters analyzed included no-load loss, load loss, current, temperature, and noise level. The test results showed that the no-load loss increased from 1,185 kW at 90% voltage to 1,884 kW at 110%, while the noise level increased from 57.8 dB(A) to 68.5 dB(A). In the load test, the loss increased from 0.46 kW at 25% load to 3.87 kW at 110% load. These results show that the increase in voltage increases the core magnetization activity which affects the noise, while the increase in loading leads to an increase in the loss and temperature of the transformer. Therefore, voltage control and loading are necessary to maintain the efficiency and reliability of the dry transformer.

Keywords: Dry transformer, Loss, Noise, Magnetostriction, Loading.

Imam Wahyudi
Electrical Engineering Studies, Faculty of Science and Technology, Construction Panca Budi University Medan
Surel: imamwah93@gmail.com
Rahmaniar,parlin siagian
e-mail:imamwah93@gmail.com,
rahmaniar@dosen.pancabudi.ac.id,parlinsiagian@dosen.pancabudi.ac.id
2nd International Conference on Islamic Community Studies (ICICS) Theme: History of Malay Civilisation and Islamic Human Capacity and Halal Hub in the Globalization Era
https://proceeding.pancabudi.ac.id/index.php/ICIE/index

Introduction

In an era of growing industry and economic growth, the need for electrical energy has increased significantly. Electricity is not only a basic need of the community, but also a strategic component in supporting national development and social welfare.[1] Therefore, the power generation and distribution system must be able to be key in the electric power distribution system, serving to channel energy from medium to low voltage networks based on the principle of electromagnetic induction.

Transformers are one of the main equipment in the electric power system that functions to change the voltage level according to the needs of the system. In its operation, transformers not only undergo electrical processes, but also produce heat, vibration, and noise. In dry transformers, these conditions need to be considered because the characteristics of the load and heat discharge process can affect the performance and life of the equipment[2]. Core losses and winding losses that occur during operation also generate heat that can affect the working conditions of the transformer.[3]

Noise in transformers is basically related to vibrations that occur in the core and windings. One of the main sources of noise is the phenomenon of magnetostrictation in the transformer core, which is a change in the dimensions of the core material due to changes in the magnetic field. These changes cause mechanical vibrations that then produce sound. In addition to magnetostriction, vibration can also be affected by electromagnetic forces in the winding, especially when the transformer works under load.[4]

Noise that occurs during the operation of a dry transformer is not only a problem of the working environment, but can be used as an indicator to determine the condition of the transformer. Changes in noise level or frequency characteristics can indicate changes in electromagnetic and mechanical conditions in the transformer. Therefore, noise measurement needs to be associated with other operating parameters, such as current, voltage, load level, temperature, and power loss.[5]

ARTG Port Belawan is one of the container loading and unloading equipment facilities used to support the operational activities of the Belawan Container Terminal. The existence of ARTG as an equipment that operates intensively requires a reliable electrical system, including transformers as one of the supporting components of its electric power system. The condition of the transformer is important because the disruption or decrease in performance in the electrical system can potentially affect the operational continuity of loading and unloading equipment. Therefore, observation of noise in dry transformers used in the operational environment of ARTG Port Belawan is important to find out the actual condition of the equipment and potential losses related to its operation.

Based on these conditions, an analysis of the effect of noise on dry transformers at ARTG Port Belawan is needed to determine the characteristics of the noise produced during the transformer operation and its relationship with the condition and losses of the transformer. This analysis is expected to provide an overview of the relationship between noise level and loading, temperature, and transformer losses so that it can be used as material for evaluating the operating and maintenance conditions of dry transformers at ARTG Port Belawan.

Literature Review

1. Transformer

Transformer is a static electromagnetic electrical equipment that functions to transfer and convert electrical power from one electrical circuit to another with the same frequency through a magnetic coupling based on the principle of electromagnetic induction. In general, a transformer consists of a core made of coated iron and two coils, namely the primary coil and the secondary coil. The ratio of voltage change depends on the ratio of the number of windings in the two coils. Transformer coils are generally made of copper wire wrapped around the core legs of the transformer[6].

Transformers are electrical equipment that functions to distribute power/power from high voltage to low voltage or vice versa. Transformers consist of two coils, namely (primary and secondary) which are inductive. These two coils are separate but are connected magnetically through a path that has reluctance (*reluctance*) low. Transformers or better known transformers are electromagnetic components that can convert high voltage to low voltage or vice versa in the same frequency.[7].

A simple transformer basically consists of two insulated coils or coils, namely primary and secondary coils. Most transformers have an insulated coil coil wrapped around a piece of iron called a core[8]. Transformers consist of several main parts that have different functions and support each other in the process of transferring electrical energy. These parts include[9]:

a. Iron Core
   Serves as a magnetic flux path generated by the coil. Iron cores generally use silicon steel lamination to reduce eddy current losses.
b. Transformer Coil
   It consists of primary and secondary coils that function to receive and distribute electrical energy through electromagnetic induction. The comparison of the number of windings determines the voltage change.
c. Tertiary Coil
   It is an auxiliary coil used for specific needs, such as auxiliary load supply, system stabilization, and reduction of harmonic influence.
d. Oil Transformer
   It functions as an electrical insulation medium as well as cooling to help reduce the heat generated by the core and coils.
e. Bushings
   It serves as a connection to the electrical conductor from the inside of the transformer to the outside grid while providing insulation to the tank.
f. Tanks and Conservators
   The tank functions to protect the internal components of the transformer, while the conservator functions to accommodate the expansion and shrinkage of oil due to temperature changes.

Transformer Types and Functions

Based on the operating voltage, it can be differentiated into 500/18 kV transformers called Generator Transformers/Main transformers (GT), 150/10 kV transformers called *Standby Service Transformers* (SST), 18/10 kV transformers called Unit Auxilliary Transformers (UAT) and 6300/400 V transformers called PDC Transformers. The neutral point of the transformer is grounded according to the needs for the security/protection system, for example the 500/18 kV and 150/10 kV transformers are grounded directly on the neutral side of 500 kV and 150 kV while the neutral side of 10 kV is grounded with low resistance.

Transformer Parts

The transformer consists of several parts that have their own functions, namely: Iron Core, Transformer Coil, Transformer Oil, Bushing, Tank and Conservator, Tap Changer, NGR (*Neutral Grounding Resistor*), Respirator (*dehydrating brether*) and Indicator.

2. Efficiency of the transformer

Transformers or transformers are never ideal, when used a transformer always produces heat energy. Thus, the electrical energy that enters the primary winding is always greater than the energy that comes out of the secondary winding. As a result, the primary power is greater than the secondary winding. In an ideal transformer, the power of the primary winding is equal to the power of the secondary winding power[10]. The efficiency of the power transformer is 90 - 95 %; however, power losses are always present in the entire transformer.[11]

a. These losses can be classified into two major categories: 1. Copper *losses*
b. Rugi inti (*core losses iron losses*)

This is caused by the heat generated in the coil due to resistance. Copper losses vary according to the load current. This is known as I2R loss. This current is divided into three categories, namely:

a. Resistive loss in conductor and lead windings
b. Eddy current loss in conductor windings
c. Eddy current loss in tanks and steel structures

3. Noise Transformer

Transformers, in addition to causing unwanted electrical impacts, also produce heat and noise that can interfere with the performance and life of the equipment. Overheating can damage windings, so it needs to be reduced through proper construction planning, such as preventing core saturation, reducing eddy currents, and avoiding over-loading windings[12]. In addition, the use of a cooling system on a power transformer is necessary to control temperature, while core vibrations due to magnetic narrowing can cause noise. Therefore, a proper cooling system is essential to prevent overheating while reducing noise in the transformer.[13]

a. Causes of Transformer Noise

Noise in transformers is mainly caused by magnetostriction, which is the change in the shape of ferromagnetic materials when exposed to a magnetic field. These changes cause the transformer core to vibrate and produce sound. In addition to causing noise, magnetostriction can also cause energy loss in the form of heat in the transformer core

b. Types of Noise

The noise caused by electronic devices varies a lot because the noise is actually caused by several different consequences. Judging from the source, Noise can be distinguished into two main classifications, namely: [14]

1) *Internal Noise* The noise generated by the internal components of a communication system is referred to as internal noise. Thermal noise, gunshot noise, flicker noise, and transit-time noise are examples of internal noise.
2) *External Noise* is noise that comes from a source other than an electrical circuit. It is not from electronic or electrical components or circuit components that generate noise. External Noise consists of Atmospheric Noise, Industrial Noise, and External Noise.

Research Methods

The research method used is a quantitative method with a field study approach carried out at ARTG Port Belawan, Medan Belawan, Medan City, North Sumatra. The object of the research is a three-phase dry transformer with a capacity of 1,600 kVA with a high voltage side voltage of 20 kV and a low voltage side voltage of 400 V. The research began with a literature study on dry transformers, transformer losses, core magnetization, magnetostriction, and noise levels in the transformer. Furthermore, data on the specification and operating conditions of the transformer were collected. Specification data included rated power, number of phases, frequency, voltage, nominal current, vector group, cooling system, insulation class, impedance, and year of installation. Operating condition data includes primary and secondary voltages, primary and secondary currents, active power, reactive power, pseudo-power, power factor, load level, winding temperature, surface temperature, and noise level.

1. Weightless Loss Testing

The no-load loss test is performed by assigning a voltage in stages of 90%, 95%, 100%, 105%, and 110% of the nominal voltage of the low-voltage side of 400 V. At each voltage variation, the secondary voltage loss, no-load loss (P_0), and no-load current (I_0) measurements are made. The no-load loss is obtained from the measured power when the transformer is operating without load. The percentage increase in no-load loss from the initial condition to the final condition is calculated by the equation:

$$\%\Delta P_0 = \frac{P_{0,akhir} - P_{0,awal}}{P_{0,awal}} x100\%$$

The change in current without load is calculated by the equation:

$$\%\Delta P_0 = \frac{P_{0,akhir} - P_{0,awal}}{P_{0,awal}} x100\%$$

The calculation results are used to determine the change in no-load and no-load current losses due to the increase in excitation voltage.

2. Weighted Loss Testing

The load loss test was carried out by providing load variations of 25%, 50%, 75%, 100%, and 110% of the transformer's nominal capacity. At each load level, load current, input power, and output power were measured. Load losses were calculated based on the difference between input power and output power with the equation:

$$PLL=Pin-Pout$$

Description:
PLL = load loss (kW)
Pin = input power (kW)
Pout = output power (kW)
To find out the nominal current of a transformer, the equation is used:

$$I_N = \frac{S_N}{\sqrt{3 \times V_N}}$$

with S being the transformer's rated power and V being the transformer's low side voltage. The test results data were then used to analyze the relationship between the load level, load current, and load loss in the transformer[2].

3. Noise Level Measurement

Noise level measurement is carried out using *sound level meter* at a fixed measurement position against the transformer. Measurements were made under no load with voltage variations of 90%, 95%, 100%, 105%, and 110% of the nominal voltage. At each test condition, the noise level in units dB(A) was recorded. The noise level measurement results were then compared with the no-load loss and no-load current values to determine the tendency of the relationship between voltage change, core magnetization activity, and transformer noise level[15].

Research Results

1. Data on Specifications and Operating Conditions of Dry Transformers

The dry transformer specification data used as the research object includes capacity, phase count, frequency, voltage, current, vector group, cooling type, and transformer impedance. The dry transformer specification data used in the study is presented in Table 1.

Table 1. Specification of Dry Transformer

Specification	**Dry Transformer**
Identifying Power	1,600 kVA
Number of Phases	3
Frequency	50 Hz
Vector Group	Dyn5
Tegangan HV	20 kV
Tegangan LV	400 V
Arus HV	46,19 A
Arus LV	2.309,40 A
Types of Transformers	Dry Type

Cooling System	AN/AF
Insulation Class	F
Impedances	6,0 %
Year of Installation	2022

Based on Table 1, the dry transformer that is the object of the study has a rated power of 1,600 kVA with a three-phase system and an operating frequency of 50 Hz. The transformer has a high-voltage side voltage of 20 kV and a low-voltage side voltage of 400 V. Based on this capacity and voltage, the nominal current on the high-voltage side is 46.19 A, while on the low-voltage side is 2,309.40 A.

The transformer uses an AN/AF cooling system, which is cooling with natural air circulation and forced air assistance when operating conditions require greater heat dissipation. Insulation class F indicates the ability of the insulation system to withstand certain operating temperatures. Meanwhile, an impedance value of 6.0% indicates the characteristics of the transformer impedance related to the condition of the short-circuit current and voltage regulation. Furthermore, to determine the operating condition of the transformer at the time of the study, observations were made of electrical parameters which included voltage, current, active power, reactive power, pseudo-power, power factor, and load level.

Image 1 Energy Measuring Instrument and Electrical Parameters in Dry Transformers

Figure 1 shows an energy measuring device used to monitor the electrical condition of the transformer in *real time*. The tool can provide information about electrical energy in kWh units as well as power parameters consisting of active power (P), reactive power (Q), and pseudo-power (S). This information is used to determine the condition of the transformer load and as a basis for analyzing energy losses in dry transformers.

Table 2. Dry Transformer Operating Conditions

Parameter	**Value**
Primary Voltage	19.85 kV
Secondary Voltage	398.6 V
Primary Current	38.72 A
Arus Seconds	1,936.40 A
Active Power (P)	1,280 kW
Reactive Power (Q)	545 kVAR

Pseudo-Power (S)	1,391 kVA
Power Factor	0,92
Baby Transformer	83,9 %
Temperature Belitan	82.5 °C
Surface Temperature	67,8 °C
Noise Level	64,8 dB(A)

Based on Table 2, the dry transformer operates at a load of 83.9% of the nominal capacity of 1,600 kVA. The apparent power value of 1,391 kVA indicates that the transformer is operating at a fairly high load level, but it is still below its nominal capacity. The power factor of 0.92 indicates that the use of electrical power is relatively good as most of the pseudo-power supplied is used as active power.

The primary voltage of 19.85 kV and the secondary voltage of 398.6 V indicate that the voltage condition of the transformer is relatively stable to its nominal value. The secondary current of 1,936.40 A also indicates a considerable load on the low voltage side. This load condition can cause an increase in temperature in the winding due to increased *copper losses.*

From the thermal side, the winding temperature of 82.5 °C is higher than the surface temperature of the transformer of 67.8 °C. The temperature difference indicates the heat generated during the electrical energy transformation process. The greater the current flowing through the winding, the greater the potential for I^2R losses that produce heat.

In addition to generating heat, the magnetization process of the transformer core can also cause vibrations through the phenomenon of magnetostriction. The vibration then produces a humming sound that can be measured as a noise level. In these operating conditions, a noise level of 64.8 dB(A) was obtained. Thus, the specification and operating condition data in this section are the basis for further analysis, especially in examining the transformer losses, noise levels, and the relationship between the loading conditions and the noise effect on dry transformers.

2. Weightless Loss test results

The no-load loss test was performed to determine the amount of power lost in the dry transformer when the transformer was given voltage under no load. The test was carried out by gradually providing a voltage of 90%, 95%, 100%, 105%, and 110% of the nominal voltage of the low-voltage side (LV) of 400 V. At each test point, measurements were made of the secondary voltage, no-load loss (P_0), and no-load current (I_0). No-load losses are mainly related to transformer core losses which include hysteresis losses and eddy current losses. The test results are presented in Table 3.

Table 3. Weightless Loss Test Results

Test Voltage	Secondary Voltage	Loss Without Load (P_0)	Load Current (I_0)
90%	360 V	1,185 kW	2,84 A
95%	380 V	1,268 kW	3,02 A
100%	400 V	1,365 kW	3,26 A
105%	420 V	1,589 kW	3,71 A
110%	440 V	1,884 kW	4,38 A

The no-load loss is obtained from the power read on the measuring instrument when the transformer is energized under no load. At a nominal voltage of 100% or 400 V, the measurement results show a no-load power of 1,365 kW. The 400 V voltage is used as a reference condition because it is the nominal voltage on the low voltage (LV) side of the transformer, so the no-load loss value at this point describes the condition of the transformer when operating at a nominal voltage without any load connected to the secondary side. The measured power at this condition is mainly the core loss of the transformer.

P0=1,365 (100% or 400V voltage)

To convert kW to W is used:

1 kW=1,000 W

So:

P0=1,365×1.000

P0=1.365 kW

To determine the increase in no-load loss due to voltage increase from 90% to 110%. The voltage range of 90% to 110% is used to determine the change in no-load loss at voltage conditions below, equal to, and above the nominal voltage. With a nominal voltage of 400 V (100%), tests at 90% and 95% indicate conditions below nominal, while 105% and 110% indicate conditions above nominal. This range is used as a basis to see the tendency to increase no-load losses as the voltage increases. The formula used to calculate the percentage of increased no-load loss is as follows:

$$\%\Delta P_0 = \frac{P_{0,akhir} - P_{0,awal}}{P_{0,awal}} x100\%$$

$$\%\Delta P_0 = \frac{1{,}884\ - 1{,}185}{1{,}185} x100\% = 58{,}99\%$$

Based on these results, the no-load loss increased by 58.99% when the voltage was increased from 90% (360 V) to 110% (440 V). Furthermore, the change in no-load current was calculated using the equation:

$$\%\Delta I_0 = \frac{I_{0,akhir} - I_{0,awal}}{I_{0,awal}} x100\%$$

$$\%\Delta I_0 = \frac{4{,}38\ - 2{,}84}{2{,}84} x100\% = 54{,}23\%$$

Based on the test results, it can be seen that the increase in voltage leads to an increase in no-load loss and no-load current. No-load loss increases from 1,185 kW at 360 V voltage to 1,884 kW at 440 V voltage. At the same time, no-load current increases from 2.84 A to 4.38 A.

This increase indicates that the increase in excitation voltage causes an increase in magnetization activity in the transformer core. At higher voltages, especially when the voltage exceeds the nominal condition, the transformer core is getting closer to the saturation condition so that the magnetization current increases and the core losses also increase. This condition is one of the factors that need to be considered in analyzing the increase in noise in dry transformers, because the increase in core magnetization can cause vibrations due to the phenomenon of magnetostriction which further produces higher noise levels.

3. Weighted Loss Test Results

Load loss testing is carried out to determine the amount of power loss in the dry transformer due to the load current flowing through the transformer coil. The test is carried out by providing load variations of 25%, 50%, 75%, 100%, and 110% of the nominal capacity of the transformer. In each load condition, measurements are made of the load current, input power, and output power. The load loss is obtained from the difference between input power and output power, with the equation:

PLL=Pin−Pout

Description:

PLL = load loss (kW)

Pin = input power (kW)

Pout = output power (kW)

Table 4 Results of Load Loss Test on Dry Transformers

Load	Load Current (A)	Daya Input (kW)	Daya Output (kW)	Load Loss (kW)
25%	902,11	615,42	614,96	0,46
50%	1.804,22	1.228,76	1.227,82	0,94
75%	2.706,33	1.842,31	1.840,54	1,77
100%	3.608,44	2.455,68	2.452,49	3,19
110%	3.969,28	2.698,41	2.694,54	3,87

Based on Table 4, it can be seen that the load loss tends to increase as the transformer load rate increases. At 25% load, the load loss is 0.46 kW, then increases to 0.94 kW at 50% load, 1.77 kW at 75% load, and reaches 3.19 kW at 100% load. When the transformer is operated at 110% load, the load loss increases to 3.87 kW. The increase in load losses occurs because the greater the load served, the greater the current flowing through the transformer coil. Assuming the coil resistance is relatively constant, the increase in current will cause an increase in copper losses. Therefore, the higher the load rate of the transformer, the greater the power loss will be generated. At 100% load, the load current reaches 3,608.44 A. This value is the current used as a reference for the nominal load condition of the transformer at a low side voltage of 400 V for a three-phase system. The nominal current can be calculated using the equation:

$$I_N = \frac{S_N}{\sqrt{3 \times V_N}}$$

Sn = daya semu nominal transformator (VA)

Anonymous = nominal voltage (V)

In = arus nominal (A)

$\sqrt{3}$ = factor for a 3-phase system

$$S_N = \sqrt{3} \times V_n \times I_n$$

$$S_N = \sqrt{3} \times 400 \times 3.608{,}44$$

$$= 2.500.000 \text{ VA}$$

The value of I_n is:

$$I_N = \frac{2.500.000}{\sqrt{3 \times 400}} = 3.608{,}44\ A$$

Thus, the load currents at 25%, 50%, 75%, 100%, and 110% respectively indicate the appropriate level of load to the nominal current of the transformer. At 110% loading, the current increases to 3,969.28 A or about 110% of the nominal current. Under these conditions, the load loss increases to 3.87 kW, higher than the 100% nominal load condition which results in a loss of 3.19 kW. This increase indicates that operating the transformer above nominal capacity causes power losses to be greater. In addition, the increase in current can lead to an increase in heating in the coil because copper losses have a square relationship to the current. Therefore, the operation of dry transformers needs to pay attention to the load capacity limit so that power losses and operating temperatures are controlled. Load conditions above nominal capacity, such as at 110% loading, need to be treated because they result in higher load losses than nominal conditions.

The results of this load loss test can then be used as supporting data in analyzing the relationship between load conditions, power losses, and noise levels in dry transformers at ARTG Port Belawan. By comparing the change in load loss with the results of noise level measurement in each load condition, it can be determined the tendency of the relationship between the increase in load and the change in the *noise characteristics* of the transformer.

4. Noise Level Measurement Results

Noise level measurement was carried out to determine the change in sound level produced by the dry transformer at ARTG Port Belawan under different operating conditions. The test was carried out in conjunction with the no-load loss test, namely by providing a voltage of 90%, 95%, 100%, 105%, and 110% of the nominal voltage of the low voltage side (LV) of 400 V. Noise level was measured using a sound level meter at a fixed measurement position against the transformer. Measurements were made at the condition of the transformer being unloaded so that the observed noise level change was mainly related to the magnetization condition of the transformer core. The data from noise level measurement is presented in Table 5.

Table 5. Dry Transformer Noise Level Measurement Results

Test Voltage	Secondary Voltage	Loss Without Load (kW)	Load Current (A)	Noise Level dB(A)
90%	360 V	1,185	2,84	57,8
95%	380 V	1,268	3,02	59,1
100%	400 V	1,365	3,26	61,3
105%	420 V	1,589	3,71	64,7
110%	440 V	1,884	4,38	68,5

Based on Table 5. The noise level of dry transformers shows a tendency to increase as the voltage is applied. At a voltage of 90% or 360 V, the noise level is recorded at 57.8 dB(A). When the voltage is increased to 95%, the noise level increases to 59.1 dB(A). At a nominal voltage of 100% or 400 V, the noise level reaches 61.3 dB(A). A greater increase is seen when the voltage is raised above the nominal condition. At a voltage of 105% or 420 V, the noise level increases to 64.7 dB(A), while at a voltage of 110% or 440 V it reaches 68.5 dB(A). Thus, there is an increase in noise level by 10.7 dB(A) from the 90% to 110% of the nominal voltage condition.

The increase in noise level is related to the magnetization process of the transformer core. When voltage is applied to the coil, a magnetic flux is formed in the core. Periodic changes in magnetic flux cause magnetostriction, which is a change in the mechanical dimensions of the core material due to the magnetization process. These changes produce vibrations in the core and construction parts of the transformer which are then heard as noise. The relationship between voltage increase, no-load loss, and noise level is also seen from the test results. At 90% voltage, the no-load loss is 1.185 kW with a noise level of 57.8 dB(A). At a nominal voltage of 100%, the no-load loss increases to 1.365 kW and the noise level to 61.3 dB(A). Furthermore, at 110% voltage, the no-load loss increases to 1.884 kW, while the noise level reaches 68.5 dB(A).

These results show a tendency to have a positive relationship between the increase in no-load losses and noise levels. The higher the excitation voltage, the greater the core magnetization activity, so that core losses and magnetic vibrations tend to increase. This condition causes the noise level produced by dry transformers to also be higher. Thus, the measurement results show that the increase in operating voltage can be one of the factors that contribute to the increase in noise in dry transformers at ARTG Port Belawan. Operating conditions above nominal voltage need to be considered because in addition to increasing no-load losses, it can also increase the vibration and noise level of the transformer.

Discussion

Based on the results of research on dry transformers at ARTG Port Belawan, it is known that the operating conditions of the transformer have a relationship with the amount of loss and

loss and the level of noise produced. The test results show that when the voltage and load of the transformer increase, the value of losses also tends to increase.

Under no load, the test voltage is increased from 90% to 110% of the nominal voltage. At 90% or 360 V voltage, the no-load loss is 1,185 kW and increases to 1,365 kW at a nominal voltage of 400 V. When the voltage is increased to 110% or 440 V, the no-load loss increases to 1,884 kW. Based on the test results, there is an increase in no-load loss of 58.99% from 90% to 110% of the nominal voltage condition. This condition shows that the voltage increase causes an increase in core losses due to the higher magnetization process in the transformer core.

The increase in no-load loss is also followed by an increase in no-load current, from 2.84 A at 90% to 3.26 A at 100% and reaches 4.38 A at 110%. The increase in no-load current indicates that the increase in excitation voltage leads to an increase in magnetization activity in the transformer core. The higher the voltage given, the greater the magnetizing current required by the transformer core.

This condition is clearly seen in the results of noise level measurement. At 90% voltage, the noise level is 57.8 dB(A), then increases to 61.3 dB(A) at 100% nominal voltage, and reaches 68.5 dB(A) at 110% voltage. This means that the voltage increase from 90% to 110% causes the noise level to increase by 10.7 dB(A).

The increase in noise occurs because the magnetization process in the transformer core causes magnetostriction. When the core undergoes continuous changes in the magnetic field, the core material undergoes a dimensional change that produces mechanical vibrations. The vibration then produces a buzzing sound in the transformer. Therefore, when the voltage is increased and the magnetization activity increases, the level of vibration and noise produced also increases.

The test results also showed a tendency to associate the increase in no-load loss with the noise level. At 90% voltage, the no-load loss was 1,185 kW with a noise level of 57.8 dB(A). At 95% voltage, the no-load loss increased to 1,268 kW and the noise level to 59.1 dB(A). At a nominal voltage of 100%, the no-load loss increased to 1,365 kW with a noise level of 61.3 dB(A). Furthermore, at 105%, the no-load loss reached 1,589 kW and the noise level increased to 64.7 dB(A). At 110% voltage, the no-load loss reached 1,884 kW and the noise level was 68.5 dB(A). The data showed that the increase in no-load loss was followed by an increase in the noise level of the transformer.

Meanwhile, the results of the load test showed that the load loss increased as the transformer load rate increased. At 25% load, the load loss was 0.46 kW, then increased to 0.94 kW at 50% load, 1.77 kW at 75% load, and reached 3.19 kW at 100% load. When the transformer was operated at 110% load, the load loss increased to 3.87 kW.

The increase in load losses occurs because the greater the load served, the greater the current flowing through the transformer coil. The increase in current causes copper losses to be greater. Theoretically, copper losses have a square relationship to current. Therefore, the higher the load level of the transformer, the greater the power losses produced.

At 100% loading, the load current reaches 3,608.44 A. This value indicates the nominal load condition of the transformer. At 25%, 50%, and 75% loading, the load current is 902.11 A, 1,804.22 A, and 2,706.33 A, respectively. Meanwhile, at 110% loading, the current increases to 3,969.28 A. The increase in current causes the load loss to increase from 3.19 kW at 100% load to 3.87 kW at 110% loading.

The increase in load loss also causes more electrical energy that turns into heat in the transformer winding. This condition needs to be considered because the increase in temperature in the winding can affect the insulation condition and reliability of the transformer if it takes place continuously. Based on the observation results, the winding temperature reaches 82.5 °C. This condition shows that the operation of the transformer at high load needs to be considered so that the operating temperature remains controlled.

When comparing the results of the no-load and no-load tests, it can be seen that each has different loss-loss characteristics. No-load loss is more related to the magnetization process in the transformer core, while the weighted loss is more related to the current flowing in the transformer winding. Therefore, the voltage increase mainly affects the core loss and noise level, while the load increase has a greater influence on the load loss and winding heating.

The results of this study are in line with the research conducted by Hakim, Sibatuara and Nur[1] which states that *Noise* The transformer comes from the magnetostriction effect, which is a change in the physical dimensions of the core material when undergoing a magnetization cycle. The higher the flux, the greater the change in core dimensions due to magnetostriction so that the noise becomes high.

Thus, in dry transformers at ARTG Port Belawan, noise can be one of the supporting indicators in seeing changes in transformer operating conditions. The voltage condition of 110% shows the highest value, namely a loss without load of 1,884 kW, a no-load current of 4.38 A, and a noise level of 68.5 dB(A). Meanwhile, at 110% loading, the load loss reaches 3.87 kW with a load current of 3,969.28 A. These results show that voltage control and transformer loading are important to keep losses, temperature, vibration, and noise levels under controlled operating conditions.

Conclusion

Based on the results of the study, the increase in voltage and load on the dry transformer at ARTG Port Belawan led to an increase in losses and noise levels. In the no-load test, the no-load loss increased from 1,185 kW at 90% to 1,884 kW at 110%, while the noise level increased from 57.8 dB(A) to 68.5 dB(A). In the load test, the loss increased from 0.46 kW at a 25% load to 3.87 kW at a 110% load. These results showed that the increase in voltage had an effect on magnetization and noise, while the increase in load increased the losses and temperature of the transformer.

The voltage and load of the transformer should be kept close to nominal conditions to reduce losses, temperatures, and noise levels. Regular monitoring of losses, current, temperature, and noise also needs to be carried out to maintain the reliability and operating conditions of the dry transformer.

References

[1] X. Zhao, F. Gui, H. Chen, L. Fan, And P. Pan, “Applied Sciences Life Cycle Cost Estimation And Analysis Of Transformers Based On Failure Rate,” *Mdpi Appl. Sci.*, 2024.

[2] A. Sampe, "Analysis of Power Losses Due to Load Imbalance in 20 Kv/380 V Distribution Transformers at City House Feeders," *J. Science and Technology.*, Vol. 1, No. 2, Pp. 106–123, 2022.

[3] A. Saiful and A. Ektianto, "Analysis of Load Imbalance in Distribution Transformers at Pt. Pln (Persero) Rayon Cepu," *Simetris*, Vol. 15, No. 1, Pp. 35–42, 2021.

[4] Yusiran and Hasanuddin, "Analysis of the Effect of Load Imbalance on Power Loss and Efficiency of 20 Kv/400 V Step Down Transformers," *J. Researcher. Inov.*, Vol. 5, No. 3, Pp. 2113–2120, 2025.

[5] X. Yang, X. Zhao, X. Shen, Y. Wang, And C. Xu, “Intelligent Predictive Maintenance Of Dry-Type Transformer Based On Vibration,” *Hindawi Wirel. Commun. Mob. Comput.*, 2022, doi: 10.1155/2022/2796167.

[6] M. A. Maulana and G. Budiono, "Analysis of the Effect of Load Imbalance on Transformer Efficiency at Pdam Surya Sembada Surabaya," *Jupiter Publ. Engineering Science Ind. Tek. Electrical and Inform.*, Vol. 2, No. 2, Pp. 1–10, 2024.

[7] L. Hakim, H. Sibatuara, and T. Nur, "Analysis of the Effect of Magnetization on Noise and Efficiency in Crgo and Amorphous Iron Core Transformers," *J. Elektr. Borneo*, Vol.

11, No. 2, Pp. 116–121, 2025.
[8] H. Setijasa And Triyono, "Calculation of Transformer Efficiency," *Orbith*, Vol. 19, No. 3, Pp. 315–323, 2023.
[9] J. Siburian, "Transformer Characteristics," *J. Technology. Energy Uda*, Vol. VIII, no. 21, pp. 21–28, 2019.
[10] Mustari, R. Kurniawan, and Ramlan, "Analysis of Transformer Efficiency in Power Plants at Pt. Pln Indonesia Power Updk Keramasan," *J. Researcher. Science*, Vol. 26, No. 2, Pp. 137–142, 2024.
[11] P. Harinda, L. S. Patras, and N. Tulung, "Analysis of Power Transformer Conditions Based on Noise Measurement at Transformers at PLTU Sulut-3," 2024.
[12] Q. Fang, Z. Ye, And C. Chen, "A Review Of Power Transformer Vibration And Noise Caused By Silicon Steel Magnetostriction," *Electronics*, Vol. 12, No. 1, Pp. 1–10, 2024.
[13] Indah and Munnik, "Analysis of the Impact of Harmonic Current on Loss and Derating in a 167 MVA Transformer Using the Harmonic Current Spectrum Matrix Method in Branch Gazette," *Jteus J. Tek. Electro*, Vol. 1, No. 1, Pp. 1–12, 2025.
[14] D. H. Darmawan, "Maintenance of Generator Excitation Transformer to Prevent Recurrence of Fan Damage Due to Dust Accumulation at Pt Pln Nusantara Power Up Paiton 1 & 2," Surabaya Aviation Polytechnic, 2025.
[15] H. Hamzah, M. N. Agriawan, and M. R. Kadir, "Noise Level Analysis Using Microcontroller-Based Sound Level Meter," *J. Fis. Papua*, Vol. 1, No. 2, Pp. 46–51, 2022.
[16] Rahmaniar, R., Khairul, K., Junaidi, A., & Fahreza, "ANALYSIS AND CALCULATION OF ELECTRICITY TRANSMISSION: GMR AND GMD APPROACHES.*Tahta Media*,2025.
[17] A. Siagian, M. E. Dalimunthe, and Z. Tharo, "Analysis of the Reliability of the 20 KV Feeder Network Configuration System at PT. PLN (Persero) ULP Pakam Kota Based on Matlab," Journal of Sriwijaya Electrical Engineering, vol. 5, no. 1, pp. 18-31, 2023
[18] S Mendrofa, ME Dalimunthe, R Rahmaniar, "The Analysis of Performance Reliability Electric Power System in 20 Kv Distribution Network in PT. PLN," Journal of Computer Science, Information Technology, 2025.