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External Leakage Current Separation to Determine Arrester Condition Due to Contamination

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A B S T R A C T

Leakage current measurements can be used to determine the aging condition of the ZnO arrester. The leakage current that occurs in the arrester is divided into two, namely external and internal leakage currents. The external leakage current is affected by contamination and the internal leakage current is affected by the aging of the varistor in the arrester. The external and internal leakage currents are measured separately to determine their contribution to the arrester condition. In this study, the effect of salt contamination on the arrester was studied further. The level of contamination used consisted of low, medium and heavy. The obtained leakage current is analyzed using wavelet energy. The results of this study indicate that the wavelet energy of each leakage current is different and can be used as an indicator in further analysis. The conclusion obtained is that the external leakage current is affected by contamination and has a different energy with the internal leakage current due to aging of the varistor arrester components.

INTRODUCTION

A good protection system is needed as a safeguard to protect equipment and electrical power systems against disturbances that arise so that they can distribute reliable electrical energy continuously with good frequency and voltage quality [5, 13, 17]. The distribution of this electric power must be designed with systems and equipment that can work efficiently and function optimally without allowing leakage currents that exceed predetermined standards [8, 10].

Protection against overvoltage disturbances that occur in electrical equipment and power systems, both internally and externally, can be done by using an arrester that works under normal working voltage conditions and during the surge overvoltage disturbance [1, 5, 6, 13]. The arrester which of its functions as a voltage level limiter will be an insulator under working voltage conditions and when a disturbance occurs in the form of a surge overvoltage, then this arrester will be a conductor to flow the fault surge current to the ground without causing interference and does not interfere with the flow of power current. 50 Hz system [18]. Equipment and electrical power systems can be safe if the overvoltage that occurs is still below the level of insulation resistance protection included in the equipment [13].

This test is for the characteristics of the voltage-current leakage of the arrester by examining the condition of the arrester without contaminants and the effects of the contaminants to determine the degradation level of the aging condition of the ZnO arrester.

BASIC THEORY

The use of arresters is an important part of the electric power system [1-23]. Contaminants that arise on the insulation surface of the arrester as an environmental influence due to the placement of the arrester in an open space will cause a failure of the arrester function [3, 6, 18]. Failure of arrester insulation can lead to leakage current which can result in energy losses [8]. The arrester construction as an overvoltage disturbance protection device is made of porcelain and polymer materials with different properties on the surface of the two arresters [13].

ZnO Surge Arrester

The arrester is one of the protective devices used in the electric power system to transmit overvoltage surges that occur to the ground as a function of protection for the electrical power system equipment so that it can withstand the maximum voltage on the 50 Hz frequency system during disturbances and from the effects of aftershocks [1- 23].

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Based on the material of manufacture, the main components of the arrester according to the characteristics of the overvoltage surge consist of Silicon Carbide (SiC) for the arrester with air gap and the arrester without air gap with Zinc Oxide (ZnO) material [13]. The valve arrester element is made of Zinc Oxide, it meets the characteristics of several additive components as the basic material for the compound that makes up the Metal Oxide Surge chip block [14, 17]. This type of arrester has very good conductivity when the discharge working current is passed at intervals of 1-100 kA and when the current passes below that value, the arrester will have high resistance as a capacitor [19, 20]. Arrester with ZnO material is better in protecting power equipment because it does not have a series-interrupted component that is very dependent on the resistance of the block element in the arrester itself [14]. When an overvoltage disturbance occurs, the resistance of this arrester will be very small so that it will provide a very fast response to drain more current to the ground [4]. A fire jump between the gaps will occur when the incoming discharge current reaches the arrester and the discharge voltage reaches the peak [9].

The use of arresters with ZnO material is very dependent on the resistance in the insulator and works because the influence of heat depends on the temperature and humidity of the environment around where the arrester is installed [1]. The performance of the arrester is also affected by the presence of dirt or contamination in the insulation part of the arrester which can reduce the resistance function in the arrester element under normal conditions so that it can cause internal leakage currents in the block part of the arrester element and external leakage currents in the insulation part of the arrester [3]. In Figure 1, the following shows the internal structural design of the block varistor of a ZnO surge arrester made of polymer material with an insulating enveloped active column [17].

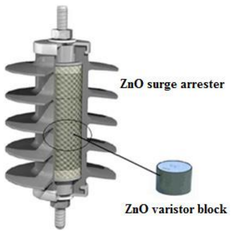

Figure 1. Polymer Insulated ZnO Arrester

The composition of the polymer material is hydrophobic or water repellent and has a small density configuration and is lighter than metal materials [3, 7, 8]. The polymer material used in the isolation of the ZnO arrester is made from organic materials in the form of non-metallic compounds which have an affinity to form macromolecules by sharing electrons to form covalent bonds between two or more atoms of the same or different atoms [3].

The main component of the arrester with ZnO varistor block elements is associated with the temperature at a low current range in providing the desired non-linear resistivity characteristics with some additive components as the basic material for the MOSA block chip which is used is ZnO (~90% by weight), and substances another additive consisting of MnO, B2O3, NiO, Sb2O3, Cr2O3 (~10% by weight) to determine the electrical properties of the arrester element block [17].

Leakage current in the insulation of the arrester that forms a path for the current to the ground can be caused by dirt or contamination caused by the material attached to the insulation layer of the arrester itself, so that the insulation resistance of the arrester with these conditions will be reduced [3, 18]. The increase in the leakage current that occurs with the increase in humidity experienced by the insulation surface of the arrester will cause a higher conductivity value which with its conductive nature can cause the holding conductor to conduct electric current to the ground [3].

A good work function of metal oxide surge arresters must be able to spread the absorbed heat energy to the environment [4]. The temperature conditions of the arrester when working are expected not to exceed the operating temperature limit in the heat release process so as not to lose power [11, 16]. Analysis of the heat balance diagram and the loss of power of the ZnO varistor when removing heat from the insulating part of the arrester to the environment can be used to determine the thermal stability characteristics of the ZnO arrester [8].

ZnO Surge Arrester Leak Current

Contamination of the insulation surface of the arrester due to pollutants attached to the arrester can cause leakage currents [3, 6, 18]. The level of contaminants in the insulation of the arrester depends on the climate and weather conditions, and can also be influenced by the location where the arrester is installed [3, 6, 18]. Conductive electrolytes can occur in the arrester due to the wetting of the contaminant layer by high humidity from the water droplets or wetting of raindrops on the insulation of the arrester which can flow leakage current because the resistance on the insulation surface of the arrester will be small [13].

The leakage current in the ZnO arrester will be related to each other with the temperature conditions in the low conduction area [8, 10, 13]. An increase in temperature conditions that exceed the operating temperature limit of the arrester will experience heat release which causes degradation and increases the value of the resistive leakage current by decreasing the resistance that occurs in the arrester [8, 10, 13, 15]. The leakage current that occurs due to the decrease in resistance in the arrester when the absorption of a large energy surge occurs is due to heat generation which increases the temperature in the ZnO arrester block [10, 16, 23]. In Figure 2 can be seen a simple model representation of the arrester leakage current [3].

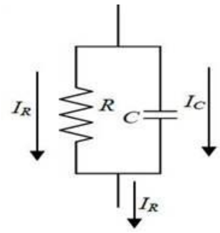

Figure 2. Total Leakage Current Modeling, Resistive And Capacitive

The total leakage current-voltage characteristic of the ZnO arrester flowing is divided into different components the fundamental capacitive leakage current and resistive current [14]. The capacitor current (IC) and the resistance current (IR)

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are directly proportional to the values of the components R and C [17, 22]. Small leakage current in the range of 0.2 - 3 mA continues to flow in the arrester under normal conditions of power system distribution [14]. The type of arrester affects the leakage current threshold in the range of 100 – 500 μA for the maximum level [10, 14]. This leakage current is dominated by capacitive current, while resistive current is in the range of 5% - 20% of capacitive current [14]. Figure 3 shows the nonlinear resistance current-voltage characteristics for resistive currents affected by temperature and voltage, with a typical U (Phase to Ground) operation of the arrester in the range of 50% - 80% of the Ur voltage. For standard ANSI / IEEE C62.11 or IEC 99-4 is used as a variation of the definition [14].

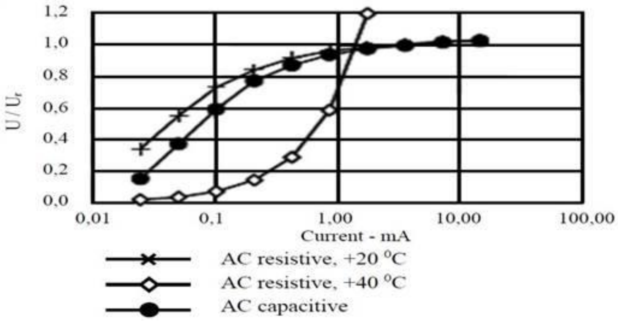

Figure 3. Gapless Metal Oxide Arrester Current-Voltage Characteristic Type

The current and time functions of the block arrester can be seen in the equation below. While I_T, I_R dan I_C can be written as follows:

$$I_T(t) = I_R(t) + I_C(t) \quad (1)$$

so that:

$$I_R(t) = I_T(t) - I_C(t) \quad (2)$$

where $I_T(t)$ is the total leakage current of the arrester, $I_R(t)$ is the leakage current of the resistive component of the arrester, and $I_C(t)$ is the leakage current of the capacitive component of the arrester [3, 22]. The vector diagram shown in Figure 4 below is to illustrate the resistive current component which can be obtained by subtracting the capacitive current component from the total leakage current value [3, 22].

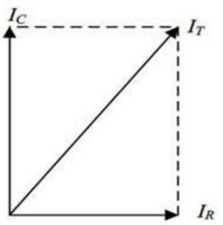

Figure 4. Vector Diagram of I_T, I_R and I_C

ZnO Surge Arrester Degradation

Proactive maintenance activities in monitoring the quality degradation of arresters can be carried out to prevent equipment failure [2, 5]. The combination of pressure from the network and the local environment separately or together will affect the operation of the arrester [5]. Insulating material and protective characteristics affect aging or damage to the degraded arrester block [14].

Degraded operation of the arrester may result in a malfunction of the arrester protection of the equipment [11, 12]. The degradation of the polymer insulated ZnO arrester is a reduction in the weight and length of the polymer molecule which can change the properties of the polymer material due to a reaction that causes the breaking of the main molecular bond chain [18]. Reactions that can cause this degradation to occur due to the influence of chemical substances (water, acid, alcohol, oxygen, etc.), thermal effects (heat, light, radiation), and mechanical influences [6, 10]. The failure of the protection function due to arrester degradation is caused by several factors [14]:

1. Damage to the insulation of the arrester causes the entry of the influence of moisture.
2. Disposal due to contamination on the arrester surface.
3. There is an effect of transient overvoltage resulting in a temporary overload.
4. Lightning arrester specifications do not match the actual system voltage and overvoltage values, causing long-term aging during normal voltage.
5. Internal partial discharge.

The degradation experienced by ZnO arresters without gaps occurs gradually under operating voltage, and electrical or mechanical stress and can also be a problem with the ZnO arrester structure becoming damp [19, 20]. All of these things can cause an increase in the internal leakage current, especially the resistive component of the arrester [9, 21]. The aging rate of the block arrester is affected by the leakage current from the resistive component due to a pure sinusoidal voltage for the fundamental frequency component [3]. The use of several different methods/indicators for monitoring service conditions, diagnosis and assessment of maintenance conditions, as well as predicting the life of the arrester, including visual inspection, calculation of strokes, temperature measurement with thermovision, and leakage current measurement [14].

METHOD

The test in this study was carried out at the High Voltage Laboratory of Electrical Engineering Department, Andalas University to measure the leakage current of the arrester under normal clean conditions and contaminated conditions, on the leakage current-voltage characteristics of the ZnO arrester. This test is carried out by applying a high AC voltage from 12 kV to 24 kV to the tested arrester. The leakage current that occurs in the ZnO arrester is recorded as a result of the measurement due to contamination which will be analyzed to determine its effect on the leakage current-voltage characteristics of the ZnO arrester.

The research begins with case studies and literature conducted by learning from books, the internet, and direct assistance to supervisors. After conducting a case study and literature, then a research process is carried out, such as the preparation of testing equipment and the selection of test equipment for measurements in the laboratory to collect the measurement data needed to obtain the results of the contamination effect that causes leakage currents in the ZnO arrester. After that, processing and analysis of the completeness of the data that has been obtained are carried out. In the next stage, the preparation of a report discussing the final results of the study was carried out.

For further explanation, the stages of the implementation method as well as the steps taken in completing the test and measurement of the leakage current value for the ZnO arrester conditioning in this study, are shown in Figure 5 below.

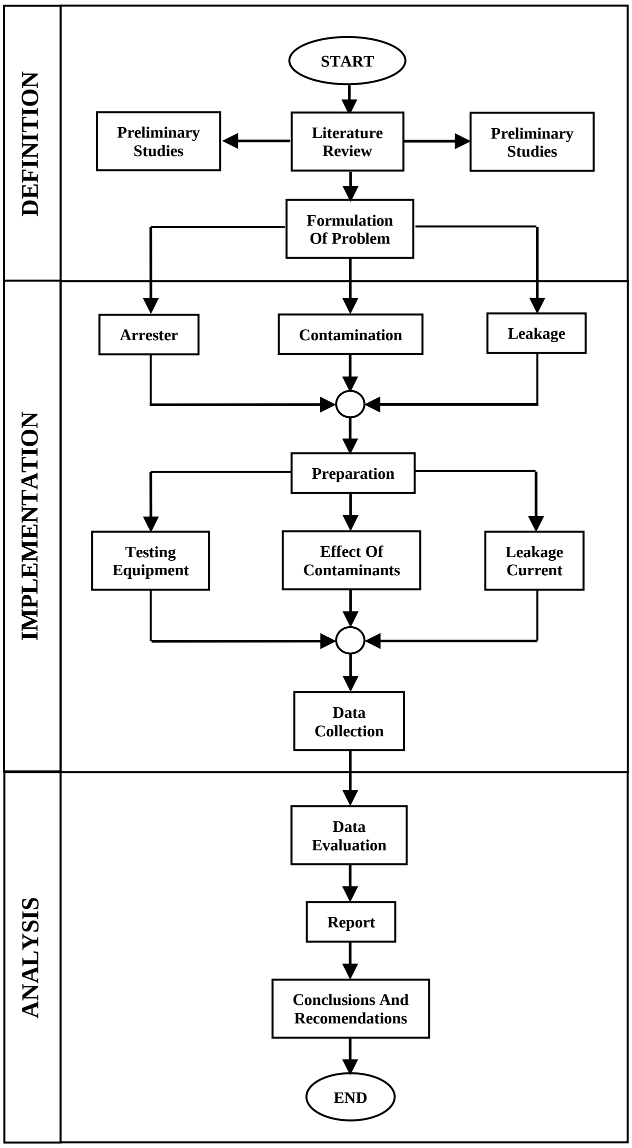

Figure 5. Research Flowchart

In Figure 6, the following describes the experimental circuit to determine the leakage current of the ZnO arrester, where the arrester is connected to an alternating high-voltage generation circuit sourced from 220 V PLN electrical power with a frequency of 50 Hz. The voltage regulator / Automatic Voltage Regulator used is a 0–220 V voltage regulator as the input to the primary side of the step-up transformer to increase the input voltage on the test object. While the second side of the output of the step-up transformer is used as the input voltage for testing the ZnO arrester block.

The input voltage to the arrester is measured using a capacitor divider whose results can be seen on channel 1 of the oscilloscope and the leakage current is obtained by placing a resistance of 1 kΩ on both arrester earth terminals. The leakage current of the arrester isolation is displayed on channel 2 and the leakage current of the arrester block element on channel 3 of the oscilloscope.

To determine the normal conditions and the effect of contaminants on the characteristics of the cylindrical arrester block made from the polymer-insulated Zinc Oxide (ZnO) material used by connecting it to an AC high voltage controlled by testing equipment with a voltage regulator to increase slowly until the voltage is at a value. certain. The arrester block to be tested is placed in a box (chamber) which functions as a simulation place for weather treatment in the field.

Figure 6 also explains that the chamber used is set at room temperature to place the arrester which is the test object to be measured before the arrester is contaminated and when it is conditioned due to the influence of contaminants. For fouling the arrester is made manually with the level of contamination made from several chemical elements into a solution whose levels and processes are adjusted, namely for the level of light contaminants by mixing 40 grams of Kaolin and 100 grams of Calcium Carbonate ($CaCO3$) with 6 liters of clean water, for the level of moderate contaminants by mixing 40 grams of Kaolin and 500 grams of Calcium Carbonate ($CaCO3$) with 6 liters of clean water, and mixing 40 grams of Kaolin and 900 grams of Calcium Carbonate ($CaCO3$) with 6 liters of clean water for heavy contaminants. The arrester which is used as the test object is immersed into the pollutant solution and left for ± 10 minutes and then removed to dry for ± 24 hours in a room so that the contaminant solution can stick to the arrester body to be measured for leakage current.

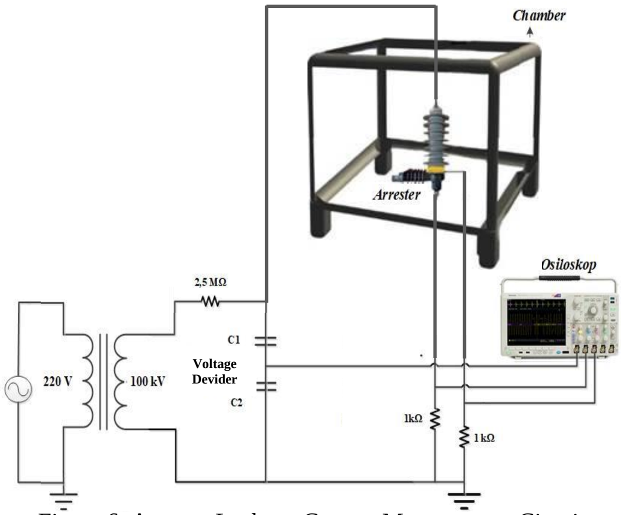

Figure 6. Arrester Leakage Current Measurement Circuit

Table 1. Arrester Technical Specifications

Spesification	Value
System Voltage (kV)	20
Arrester Type: active and housing materials	ZnO Polymer
Status	Used
Rated Voltage (kV)	21
Rated Current 8/20 μs (kA)	10
MCOV (kV)	17
Type of Sheds	Regular
Merk / Brand	Ohio – Brass Made in USA
Top/ bottom shed diameter (mm)	100
Trunk diameter (mm)	62
Axial length (mm)	250
Arcing distance (mm)	20
Creepage distance (mm)	190

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In the test circuit, using a voltage regulator that functions to regulate the value of the output voltage on a 100 kV high voltage transformer will be applied to the arrester as a test object for measuring leakage current. The 2.5 MΩ resistors are used to protect the transformer from a large enough voltage. Capacitors are used as rectifiers from high voltage AC to high voltage DC and dampen hum from AC voltage. To measure the high voltage used a capacitive divider with a ratio of 1:450. As a leakage current sensor, a resistor with a capacity of 1 k is used, which is connected to an oscilloscope.

Figure 7. ZnO Arrester Normal Condition
(Before Contamination)

Figure 8. Test Series ZnO arrester Normal Condition

Figure 9. ZnO arrester with contaminants
(a) Light, (b) Moderate, (c) Heavy.

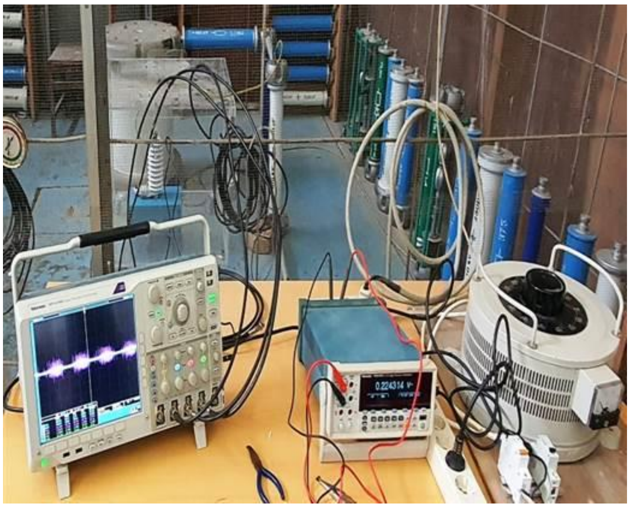

Figure 10. Test Series ZnO Arrester With Contaminants

RESULTS AND DISCUSSION

This research uses a test object in the form of an uninterrupted type of Zinc Oxide (ZnO) arrester material with polymer insulation which describes the normal arrester and the contaminated condition when installed in the field on the 20 kV three-phase electricity system of the PLN network. Tests and measurements were carried out on the insulation of the ZnO arrester to obtain data on the capacitive leakage current as external leakage current and also on the ZnO arrester block element for resistive leakage current as internal leakage current. The leakage current of this arrester will be measured before and after being conditioned due to the influence of contaminants. The data retrieval of the measured leakage current value of the arrester follows the AC alternating high voltage generation circuit as shown in Figure 6 which uses an oscilloscope with a PLN power source voltage of 220 V with a frequency of 50 Hz. The test is carried out using a voltage regulator to apply variations in the input voltage below to above the 20 kV arrester voltage rating and measured at each increase in the given voltage capacity starting from 12, 16, 20, and 24 kV. The results of the measurement of the leakage current of the arrester without contaminants and which are influenced by the level of contamination get an effective value / RMS with the appearance of the voltage and current waveform of the ZnO arrester which is tested in a sinusoidal shape that still contains harmonics. Each characteristic of the obtained voltage and current waveforms is filtered using the Matlab software application.

The measurement data is recorded in a table and presented in a graph in the form of a bar chart which is analyzed to obtain the relationship between one parameter and another to determine the effect of contaminants on the leakage current-voltage characteristics of the arrester in determining the degradation and aging rate of the ZnO arrester condition.

Characteristics of Leakage Current-Voltage of ZnO Arrester Without Contaminants

One of the waveforms of the ZnO arrester measurement results without contaminants is as shown in Figure 11 below with the given voltage according to the 20 kV arrester voltage rating.

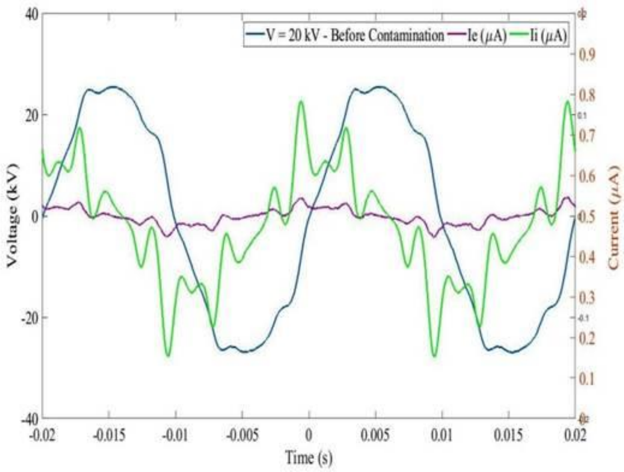

Figure 11. Leakage Current Wave Arrester No Contaminants With 20 kV Input Voltage

The data for measuring the leakage current of the ZnO arrester on the element block and in the isolation of the arrester without contaminants were tested with various input voltages of 12, 16, 20, and 24 kV which are given in the tabulation of the data in the following table.

Table 2. Internal and External Leakage Current of ZnO Arrester Without Contaminants

Applied Voltage (kV)	Arrester Leakage Current (μA)	
	Internal Current (I_i)	External Current (I_e)
12	117	7,25
16	157	8,29
20	197	9,65
24	242	11

The form of a bar chart from the leakage current measurement data in Table 2. above can be seen in the following figure:

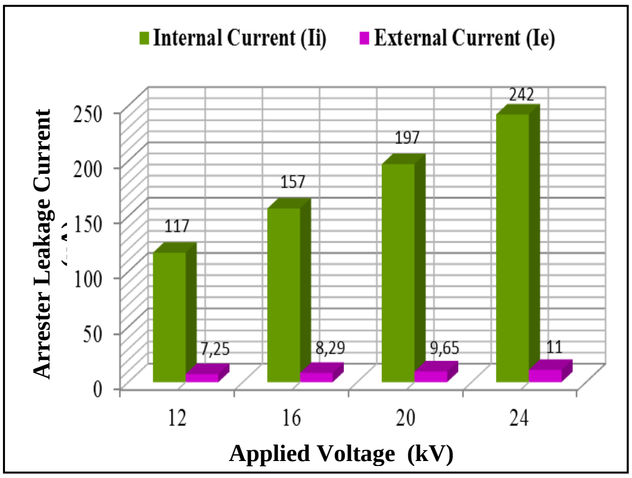

Figure 12. Graph of Leakage Current of ZnO Arrester Without Contaminants

The data in Table 2 and the bar chart in the graph in Figure 12 above, state that for the value of the ZnO arrester leakage current without contaminants, the measurement results using an oscilloscope at any given input voltage variation are directly proportional to the applied voltage supply, i.e. the greater the voltage. the given input, the value of the measured ZnO arrester leakage current also increases. The total leakage current of the ZnO arrester without contaminants measured includes the internal leakage current of the resistive component and for the capacitive component containing the external leakage current. The test results obtained measurement data which stated that there was an increase in the average value of the leakage current of 26.83% for the accumulation of the total leakage current of the arrester with an average value of 42.92 μA at each increase in the variation of the input voltage starting from 12, 16, 20, and 24 kV applied to the test circuit.

Calcium Carbonate and Kaolin Contamination

The measurement of the leakage current of the ZnO arrester due to the influence of these contaminants also follows the series of Figure 6 above with variations in the input voltage of 12, 16, 20, and 24 kV which are connected to an oscilloscope for a high-voltage generation circuit AC source from PLN 220 V with a frequency of 50 Hz. The contamination of this conditioned ZnO arrester is for the influence of light, medium, and heavy contaminant levels using a mixture of the chemical elements Calcium Carbonate (CaCO3) and Kaolin mixed in clean water into a solution whose levels and processes are adjusted.

The leakage current that occurs in the arrester block will be influenced by the level of contamination from the outside which causes a sinusoidal voltage pressure to occur in the arrester which cannot be completely released through polymer insulation because it is covered by contaminants so that it can increase the leakage current in the block of the arrester element caused. For data on the measurement results of the ZnO arrester leakage current which is affected by this level of contamination, on average it also increases when tested using an oscilloscope for each given input voltage variation.

Leakage Current Arrester ZnO Effect of Light Contaminants

The measurement of the leakage current of the ZnO arrester which is conditioned due to the influence of light contaminants begins with the process of fouling the arrester which is made manually by mixing 40 grams of Kaolin and 100 grams of Calcium Carbonate (CaCO3) with 6 liters of clean water. The arrester is then immersed in the pollutant solution and left for ± 10 minutes and then removed to dry for ± 24 hours in the room so that the pollutant solution that is used as a contaminant can stick to the arrester whose leakage current will be measured.

Figure 13. Immersion of the Arrester with Light Contaminant

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The measurement of the leakage current of the ZnO arrester on the element block and in the isolation of the arrester due to the influence of light contaminants was also tested with a given voltage variation of 12, 16, 20, and 24 kV, with the measurement data presented in the following table data.

Table 3. Internal and External Leakage Currents ZnO Arrester Effect of Light Contaminants

Applied Voltage (kV)	Arrester Leakage Current (μA)	
	Internal Current (I_i)	External Current (I_e)
12	119	6,92
16	158	9,04
20	195	11
24	231	13

The bar chart for the data of the arrester leakage current measurement with this light contaminant condition can be presented in the following figure:

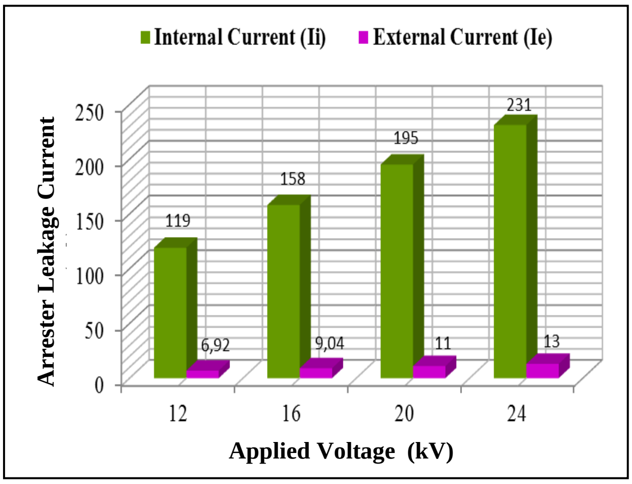

Figure 14. Graph of Leakage Current of ZnO Arrester Due to the Effect of Light Contaminants

The measurement of the arrester leakage current due to the influence of light contaminants, one of which is with an input voltage according to the 20 kV arrester voltage rating also using an oscilloscope which produces a waveform as shown in the following figure below.

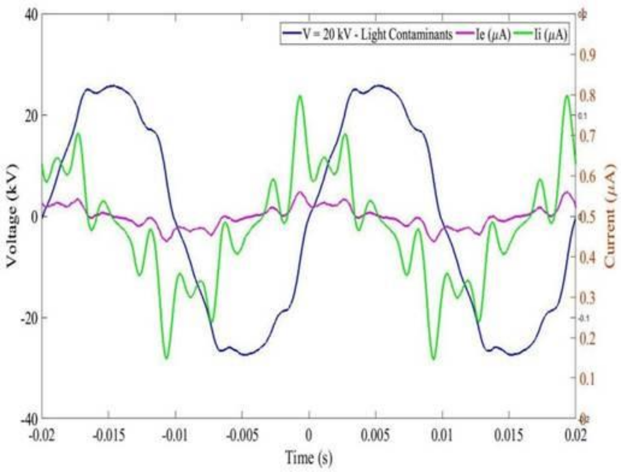

Figure 15. Arrester Leakage Current Wave Effect of Light Contaminants With 20 kV Input Voltage

For the data from the measurement of the leakage current of the ZnO arrester which is affected by this light contamination level, on average it also increases in value when tested using an oscilloscope for each increase in the variation of the input voltage applied to the test circuit. This can be seen in the data in Table 3 and Figure 13 for the results of the measurement of the arrester for the effect of light contaminants.

The total value of the ZnO arrester leakage current measured by light contaminants includes the internal leakage current of the resistive component and the capacitive component containing the external leakage current. The measurement results indicate an increase in the average value of the leakage current of 24.81% for the accumulation of the total leakage current of the arrester with an average value of 39.36 μA at each increase in the variation of the input voltage starting from 12, 16, 20, and 24 kV applied. on the test series.

Characteristics of Leakage Current-Voltage Arrester ZnO Effect of Moderate Contaminants

The measurement of the leakage current of the arrester which is conditioned due to the influence of moderate contaminants begins with fouling the arrester which is made manually by mixing 40 g of Kaolin and 500 g of Calcium Carbonate ($CaCO_3$) with 6 liters of clean water, which is then immersed in the pollutant solution and left for ± 10 minutes and then removed to dry for ± 24 hours in the room so that the solution used as contaminants can stick to the arrester where the leakage current will be measured.

Figure 16. Immersion of the Arrester with Moderate Contaminant

The measurement of the leakage current of the ZnO arrester in the element block and the isolation of the arrester due to the influence of moderate contaminants were also tested for each given voltage of 12, 16, 20, and 24 kV, with the measurement data presented in the data tabulation in the following table.

Table 4. Internal and External Leakage Currents ZnO Arrester Effect of Medium Contaminants

Applied Voltage (kV)	Arrester Leakage Current (μA)	
	Internal Current (I_i)	External Current (I_e)
12	118	8,6
16	156	11,2
20	176	12,7
24	229	16,6

The bar chart for the data of the arrester leakage current measurement with moderate contaminant conditions can be presented in the following figure:

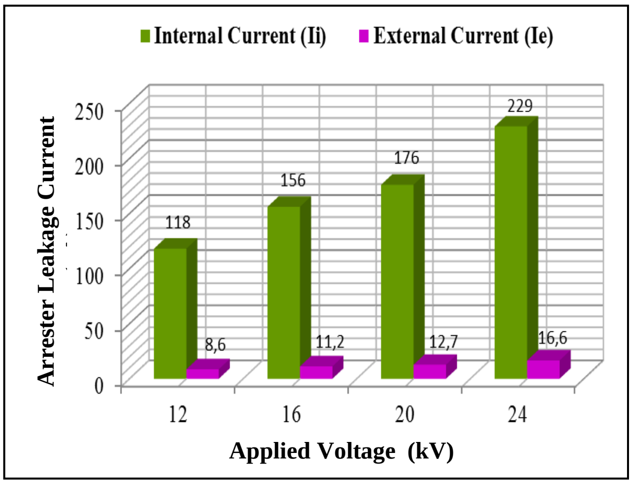

Figure 17. Graph of Leakage Current of ZnO Arrester Effect of Moderate Contaminants

The measurement of the arrester leakage current due to the influence of moderate contaminants, one of which is with an input voltage according to the 20 kV arrester voltage rating also using an oscilloscope which produces a waveform as shown in the following figure below.

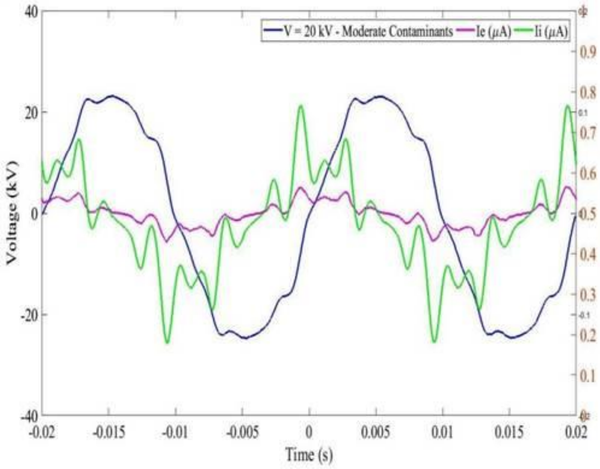

Figure 18. Leakage Current Wave Arrester Effect of Medium Contaminants With 20 kV Input Voltage

The data from the measurement of the leakage current of the ZnO arrester, which is affected by this moderate level of contamination, on average also increased in value when tested using an oscilloscope for each increase in the variation of the input voltage applied to the test circuit. For a description of the data regarding the analysis above, see the detailed data in Table 4 and Figure 17 for the measurement results of the arrester of moderate contaminant effect.

The total value of the measured contaminant effect ZnO arrester total leakage current includes the internal leakage current of the resistive component and for the capacitive component containing the external leakage current. The measurement data for the test results get measurement data which states that there is an increase in the average value of the leakage current of 25.03% for the accumulation of the total leakage current of the arrester with an average value of 39.67 µA at each increase in the variation of the input voltage starting from 12, 16, 20, and 24 kV applied to the test circuit.

Characteristics of Leakage Current-Voltage Arrester ZnO Effect of Heavy Contaminants

The measurement of the leakage current of the arrester which is conditioned due to the influence of heavy contaminants begins with fouling the arrester which is made manually by mixing 40 grams of Kaolin and 900 grams of Calcium Carbonate ($CaCO_3$) with 6 liters of clean water, which is then immersed in the pollutant solution and left for ± 10 minutes and then removed to dry for ± 24 hours in the room so that the solution used as contaminants can stick to the arrester where the leakage current will be measured.

Figure 19. Immersion of the Arrester with Heavy Contaminant

The measurement of the leakage current of the ZnO arrester in the element block and the isolation of the arrester due to the influence of heavy contaminants were also tested for each of the 12, 16, 20, and 24 kV voltages, with the measurement data presented in the data tabulation as shown in the following table.

Table 5. Internal and External Leakage Currents ZnO Arrester Effect of Heavy Contaminants

Applied Voltage (kV)	Arrester Leakage Current (µA)	
	Internal Current (I_i)	External Current (I_e)
12	118	8,09
16	155	10,1
20	199	13
24	230	14,7

The bar chart for the data of the arrester leakage current measurement with this heavy contaminant condition can be presented in the following figure:

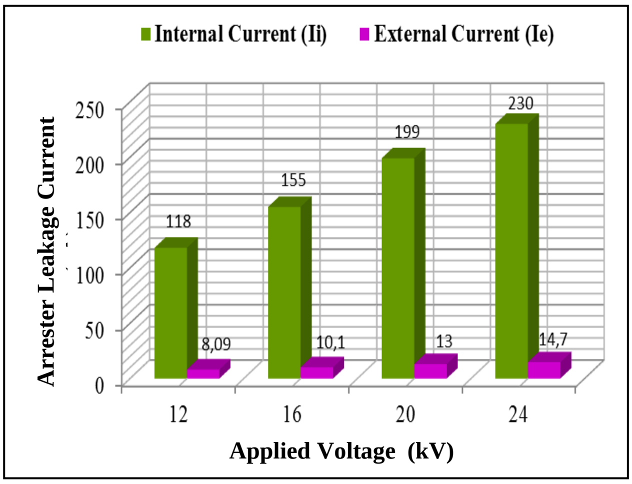

Figure 20. Graph of Leakage Current of ZnO Arrester Due to the Effect of Heavy Contaminants

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The measurement of the arrester leakage current due to the influence of heavy contaminants is one of them with an input voltage according to the 20 kV arrester voltage rating also using an oscilloscope which produces a waveform as shown in the following figure below.

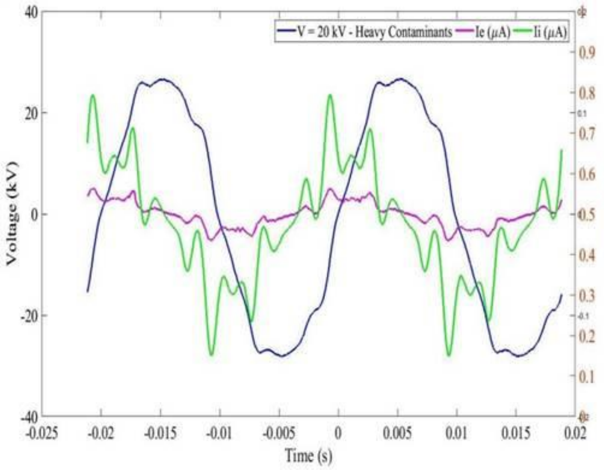

Figure 21. Leakage Current Wave Arrester
Effect of Heavy Contaminants With 20 kV Input Voltage

For data from the measurement of the leakage current of the ZnO arrester which is influenced by this moderate level of contamination, on average it also increases in value when tested using an oscilloscope for each increase in the variation of the input voltage applied to the test circuit. This can be seen in the data in Table 5 and Figure 20 for the measurement results of the arrester effect of heavy contaminants.

The value of the total leakage current of the ZnO arrester the effect of this measured heavy contaminant includes the internal leakage current of the resistive component and for the capacitive component containing the external leakage current. The measurement data indicate an increase in the average value of the leakage current of 24.92% for the accumulation of the total leakage current of the arrester with an average value of 39.54 µA for each increase in the variation of the input voltage ranging from 12, 16, 20, and 24 kV. applied to the test series.

Analysis of the Leakage Current-Voltage Characteristics of ZnO Arrester

The contamination that occurs in this arrester polymer insulation greatly affects the occurrence of leakage currents. This shows that the contamination that occurs in the polymer insulation becomes a medium for leakage current to flow to the ground. To determine the percentage level of the ZnO arrester condition due to the contribution of leakage current, it is necessary to separate the internal leakage current and external leakage current. For waveforms and harmonic spectrums with small amplitudes compared to the fundamentals, the leakage current of the arrester is clean without contaminants and due to the effect of this level of contamination, it can be assumed as a basic reference for the condition of installing the arrester in the field in the electric power system network. Another influence is from the factor of the voltage source system consisting of PLN grids with a frequency of 50 Hz, a control table, a test transformer, a measuring capacitor, test resistors, and others.

If the voltage that must be held by an arrester exceeds the ability of the arrester, there will be a current flow called leakage current. The leakage current is initiated by a conductive layer on the surface of the arrester body. The conductive layer is formed due to the presence of salt compounds and insoluble materials in the air as pollutants that become contaminants attached to the surface of the arrester body. In the clean state, the arrester surface has a large electrical resistance. The formation of a conductive layer is caused by contamination on the surface of the arrester element, causing a decrease in the resistance value on the surface of the arrester. This decrease causes a leakage current to occur on the surface of the arrester.

The waveform and the value of the leakage current measured on the insulation surface of the arrester are strongly influenced by the environment in which it is installed and the surface conditions of the ZnO arrester polymer insulation used to analyze the condition of the arrester. Diagnosing the insulation condition of the arrester, it can be done by determining the changes in the amplitude and harmonic content of the arrester leakage current that occurs. The effect of contaminants on the surface of the polymer insulation of the arrester can cause internal heating and an increase in resistive current leakage which also causes power loss, resulting in the arrester failing to function because the accumulated energy exceeds the energy capability of the arrester which can cause heat inside the ZnO arrester element block.

The technique of measuring leakage current before determining the level of aging of the arrester must first take into account the effect of the condition of the arrester, one of which is caused by contaminants attached to the insulation surface of the arrester. The percentage increase in the total leakage current is calculated from the resistive component of the leakage current which can be associated with the increase in the resistive component of the leakage current which is affected by the increase in the level of contaminants in the capacitive component of the leakage current. The results of the measurement of the leakage current of the ZnO arrester from the test in this study will be used as a study of the method and analysis mechanism in determining the degradation factor for the percentage level of aging and condition of the arrester. The equivalent circuit-based extraction method can be used to extract the resistive component of the total leakage current. A high increase in leakage current can cause degradation of the ZnO arrester due to overvoltage pressure on the insulation surface of the arrester. Changes in the insulating properties of the arrester lead to a decrease in the effectiveness of surge protection. Due to the degradation of this arrester, it is necessary to predict the remaining useful life of the ZnO arrester as a reference for scheduling the replacement or repair of the ZnO arrester.

Various methods can be applied to monitor the condition of the arrester leakage current, both in the field and in the laboratory, including the resistive current waveform-based method applied using programs in Matlab and LabView, an artificial neural network method to capture thermal images and leakage current from the arrester. without polymer insulated gaps. Finite element analysis can be used to determine the conductivity of a material which affects the leakage current significantly under different applied voltages, wet conditions, and pollution conditions. The resistive leakage current in surge protection is an important indicator to characterize the aging rate of the arrester. The corrective resistive leakage current measurement can be done using the polynomial regression method and extracting the weak resistive component of the arrester can be done by the enhanced phase current shift method.

Based on the description above, there are several ways to monitor the condition of the ZnO arrester that has been used for the analysis of measuring resistive leakage current which is the main indicator of arrester damage. In this study, the analytical study uses an arithmetic equation as an algorithm formula for measuring resistive leakage current by removing the capacitive current from the total leakage current.

CONCLUSIONS

Several things can be concluded from the results of the analysis and discussion of the test and measurement data that have been carried out in this study, including the matter of measuring the leakage current of the normal ZnO arrester in clean conditions and which is influenced by the level of contamination. The internal leakage current from the resistive component in the block section of the arrester element is part of the total value of the ZnO arrester leakage current which can be caused by the capacitive component in the polymer insulation section of the arrester containing external leakage current due to contaminants and will affect the estimated life and degradation conditions of the arrester. To find out the increase in the value of the internal leakage current that occurs in the arrester element block, the influence of this external leakage current needs to be separated by reducing the total value of the arrester leakage current with the amount of leakage current that occurs in the polymer insulation of the arrester. For the measurement of the total leakage current of the arrester which will be tested in further research, it is necessary to improve the methods and mechanisms that are carried out, to obtain more accurate data as a result of the measurement of the leakage current of the arrester which will be used in determining the degradation factor for the percentage level of age and condition of the ZnO arrester.

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