

Technical Analysis of Lightning Arrester Replacement to Improve Customer's Power Grid Reliability

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Abstract

The reliability of the power distribution network in the tropics is particularly vulnerable to thunderstorm disturbances, which can cause asset damage and service interruptions. Lightning arrester (LA) as a primary protection component experiences performance degradation over time due to environmental factors, which has the potential to cause protection failure to thermal runaway. This study aims to conduct a technical analysis of the urgency of replacing existing LA units through a quantitative evaluation of isolation prisoners and a comparison of technical specifications with modern LA. The research methodology refers to the standard testing of insulation resistance with high DC voltage (2.5 kV - 5 kV), where values below the critical threshold of 1 Giga Ohm (GΩ) are identified as indicators of insulation failure after corrective cleaning measures are ruled out. The researchers analyzed that the value below the standard indicated a significant risk of leakage current that could trigger catastrophic failure of the Metal Oxide Varistor (MOV) block. The results of this analysis are expected to provide a strong technical justification for predictive maintenance policies, in order to improve surge protection capabilities, reduce the rate of disturbances, and ultimately strengthen the reliability of the electrical system comprehensively.

Keyword: *Lightning Arrester, Lightning Protection, Overvoltage, Power Network Treatment.*

I. INTRODUCTION

The structure and reliability of the power grid are fundamental aspects that underpin all social and economic activities (De Conti and Leal, 2026). Continuity of energy supply is a must, and therefore, the integrity of the distribution system must be maintained from various threats (Silakhori, Mirzaie and Ahmadi, 2025). One of the most significant threats in tropical climates, such as Indonesia, is lightning strikes. This natural phenomenon can trigger an extraordinary voltage surge (surja), potentially damaging crucial components such as transformers, control panels, and customer meters (Souto, Taylor and Wilkinson, 2023). The consequences of this damage are not only limited to material losses, but also lead to service interruptions that harm the wider community and the industrial sector (Widagdo *et al.*, 2025).

To overcome this threat, lightning arresters (LA) or lightning arresters act as the front line in the protection system. The device is designed to provide a low-impedance path for lightning currents, flowing them directly into the earthing system. Thus, the LA is able to keep the voltage in the equipment within safe limits and prevent damage (Xue *et al.*, 2023). However, it's important to note that LA isn't a permanent solution. Constant exposure to extreme environmental conditions, such as corrosion, material aging, and internal damage due to repeated operations, may lead to performance degradation (Zhao *et al.*, 2022). Over time, degraded LA loses its ability to effectively protect the system, potentially even becoming a new source of disruption in the event of an internal failure (Ritonga, Taringa and Arzya, 2022).

Given this urgency, an in-depth technical study of the condition and urgency of LA's replacement is crucial (Wadie, 2023). This study is designed to conduct a comprehensive analysis of the urgent need to replace an already installed LA. The methodology used focuses on comparing the technical specifications between old devices and new devices that have adopted more advanced technologies. This evaluation includes not only technical data, but also an assessment of overall functionality and protection capabilities, to gauge the extent to which new devices can improve protection effectiveness (Utomo *et al.*, 2025).

This analysis will specifically prove that LA replacement is not just a routine maintenance measure, but a strategic investment to optimize the protection of electrical assets. By implementing a more reliable and efficient LA, it is hoped that there will be a significant decrease in the frequency of power outages caused by lightning strikes. A further impact of this increased protection is the extended life of the network infrastructure, which directly reduces long-term operational and maintenance costs.

The results of this study will be a strong scientific foundation for the development of more effective maintenance policies. The resulting data and findings will provide the necessary justification for LA replacement priorities, ensuring optimal resource allocation. Ultimately, the implementation of these recommendations is expected to comprehensively improve the reliability of the electricity system, support energy supply stability, and strengthen the foundation for sustainable economic growth.

II. THEORY

In its crucial role, the lightning arrester has a contradictory but vital dualism of function: it must act as a perfect insulator under normal voltage conditions and transform into an ideal conductor instantaneously when a voltage surge occurs, such as a lightning strike (Castro *et al.*, 2022). It is this paradox that makes it an interesting subject of research. A proficient researcher not only understands this theory, but also has the ability to verify its performance with high precision (Napolitano *et al.*, 2023).

One of the most fundamental verification methods is the insulation resistance test, often referred to as the Megger test (Sabiha and Alkhammash, 2023).1 This test is specifically designed to evaluate the first function of a lightning rod, namely its ability as an insulator. By applying a high DC voltage, such as 2.5 kV or 5 kV, this test measures the insulation resistance of the device. This is an important step to ensure that lightning rods can effectively isolate the system from the ground under normal operational conditions (Reski *et al.*, 2024).

A competent researcher knows that the results of these tests are a direct indicator of the internal condition of the lightning rod (Boukhouna, Nekhoul and Khelifi, 2024). A high insulation resistance is a positive signal, indicating that the leakage current flowing through or on the surface of the device is very small (Grebović *et al.*, 2023). This means that the insulation material is still intact and there are no unwanted conductive paths. This is proof that the lightning rod is in prime condition to protect the system.

In contrast, low insulation resistance is a warning of danger. These results indicate the presence of conductive pathways that should not be present, such as cracks in porcelain, surface contamination, or internal degradation in varistors (Silakhori, Mirzaie and Ahmadi, 2025). These paths can cause significant leakage currents, which not only threaten operational safety but also indicate damage that reduces or even eliminates the device's ability to function as an insulator (Dolník and Šárpatakyľ, 2023). Thus, researchers can conclude that the lightning rod is no longer able to carry out its isolation role effectively and requires further attention (Dong, Yao and Zhao, 2025).

Referring to SPLN D5.006:2013 Arrester Selection Guidelines for 20 kV Distribution Networks, the standard Insulation resistance for physical lightning rods is more than 1 Giga Ohm (GΩ). If it is less than 1 Giga Ohm (GΩ), cleaning of the cable connection can be done. If it is not stated to be more than 1 Giga Ohm (GΩ), then the lightning rod unit needs to be replaced. The determination of the 1 GΩ threshold is based on several crucial technical reasons.:

A. A value above 1 GΩ indicates that the external insulating material (both porcelain and polymer) and the internal components are in excellent condition, dry, and clean.
B. Significant leakage current (due to low insulation resistance) can heat the internal block of the Metal Oxide Varistor (MOV). This continuous heating can trigger a fatal condition called thermal runaway, where heat lowers the resistance of the MOV, which then increases the leakage current and heat further, eventually causing the LA to explode catastrophically.
C. A value below 1 GΩ is often the first indication of impending trouble. It serves as an early warning system for technicians.

III. METHOD

To ensure the reliability of the customer's power grid, the technical analysis of the lightning rod replacement must be carried out with a strict and structured methodology. As a skilled researcher, this study by comparing the results of testing the lightning rod units before and after the replacement work. This approach allows for an immediate evaluation of the impact of the actions taken. The data collected includes not only the physical condition of the unit, but also the vital electrical parameters measured in the field.

The basis of this research methodology is sourced from the guidelines and standards set by PT. PLN (Persero). Guided by these regulations, the researcher ensures that every analytical step taken by the researcher is relevant and in accordance with applicable industry practices. The object of this research is specifically the lightning protection unit operating in the work area of PT. PLN (Persero) ULP Ngagel, which allows for in-depth case studies and focus on areas with specific needs.

The tests carried out include a series of diagnostic tests, such as insulation resistance tests, which aim to identify potential weaknesses in the old unit. The results of this pre-replacement test serve as a solid basis for justifying replacement actions. Once the new unit is installed, similar testing is performed again to verify that the new unit is functioning optimally and meets all required performance standards. This comparison of data provides empirical evidence regarding the effectiveness of replacement.

In the end, the findings of this analysis make a significant contribution to improving the reliability of electricity distribution in the work area of PT. PLN (Persero) ULP Ngagel. By identifying and mitigating the risk of lightning rod failure, we can reduce potential power outages, minimize economic losses, and improve customer satisfaction. This research is not just a replacement of components, but a proactive strategy to strengthen the power grid infrastructure and ensure a stable energy supply.

The steps of technical analysis that are carried out in a simple way can be described as follows:
Data Collection
1. Network: Where the feeder position of the lightning arrester.
2. Equipment: Data protection tool.
3. Insulation value: The insulation resistance value(R) on the lightning arrester as protective equipment.

Starting the technical analysis process
1. The data is collected completely, namely data before and after the unit replacement is carried out.
2. Calculating current leakage that occurs due to the insulation resistance value that has been collected previously

Steps for the work are shown in Figure 1 which shows the process from where the data is obtained until the measurement is carried out.

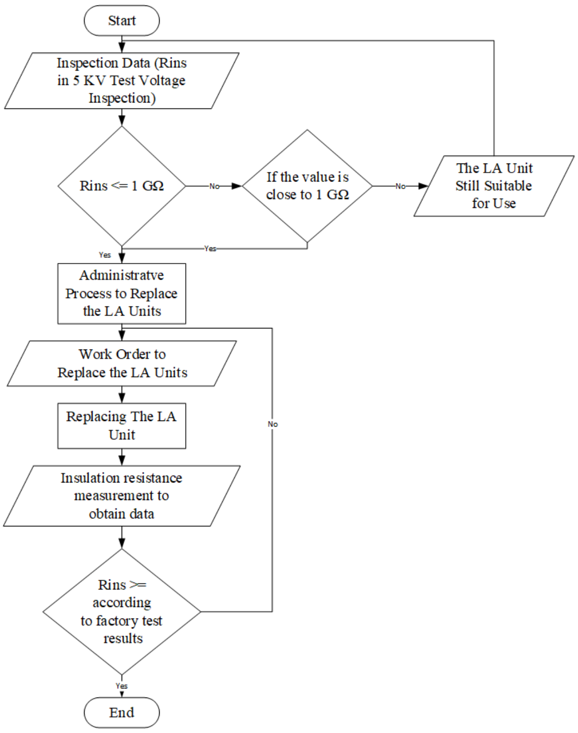

Figure 1. The Lighting Arrester replacement work process PT. PLN (Persero) ULP Ngagel

Comparisons are needed to analyze how much change occurs between the lightning arrester before and after the equipment replacement is performed.

In this case, there is a basic equation that will be used, namely the calculation of current leakage which can be calculated simply with the following equation (1) :

$$I = \frac{V}{R} \quad (1)$$

Information:
I = Large current leakage
V = Nominal voltage
R = Resistansi unit *lightning arrester*

For the calculation of current leakage, a comparison is required between the maximum allowable current leakage data and the data before and after the lightning arrester replacement.

IV. RESULT AND DISCUSSION

Lightning arrester replacement interventions are not carried out randomly, but rather through a measurable strategic approach. Location prioritization is based on the analysis of historical data on network points that show high frequency of disturbances as well as mapping areas with significant levels of lightning strike density (isokeraunic level). This proactive approach aims to mitigate the risk of system failure on the most vulnerable assets, so that the allocation of resources for maintenance becomes more effective and the impact on improving network reliability can be maximized.

The execution process in the field follows a series of methodical stages designed to guarantee system integrity and occupational safety. The initial stage involves quantifying existing operational parameters, namely measuring the output voltage and load current of the transformer to obtain baseline data. After that, a planned temporary power outage is carried out, followed by the process of dismantling the old lightning arrester unit and installing the new unit with precision. Every step in this procedure is carried out in accordance with standard operational protocols to minimize the duration of outages and potential technical risks.

The final stage is the verification and validation phase, which is crucial to confirm the success of the intervention. Comprehensive testing was carried out on the customer-serving LVMDP (Low Voltage Main Distribution Panel) panel, including post-installation voltage and current re-measurements. More importantly, insulation resistance testing is performed, which is a critical parameter for assessing the health of the protective device. The purpose of this final validation is to ensure the conformity of the functionality of the device with the established safety and operational reliability standards, so that it can be ensured that the system is back in optimal and safe operation.

Figure 2. The Lighting Arrester replacement work was carried out by the HAR-C team PT. PLN (Persero) ULP Ngagel

Figure 3. Lightning Arrester isolation detention measurement

After the replacement, monitoring of the network performance is carried out to evaluate the effectiveness of the lightning arrester replacement.

From the Lightning arrester replacement activities, there is measurement data before and after the work on the values of voltage, current, and insulation resistance. Below is the data presented in a table containing the values of voltage, current, and insulation resistance, as follows table 1:

TABLE I
Lightning arrester replacement work measurement data

Type	Point	Before			After		
		R	S	T	R	S	T
V	P-N	232	230	235	232	232	232
V	P-P	395	392	398	395	395	395
Current	P-N	30	32	31	30	31	33
R Ins Cable (10kV)	P-G	100 MΩ	100 MΩ	100 MΩ	200 MΩ	200 MΩ	200 MΩ
R Ins Cable (10kV)	P-N	190 MΩ	230 MΩ	190 MΩ	250 MΩ	250 MΩ	250 MΩ
R Ins Cable (10kV)	P-P	200 MΩ	250 MΩ	200 MΩ	300 MΩ	300 MΩ	300 MΩ
R Ins LA (5kV)	Up-G	2 GΩ	2,5 GΩ	2,3 GΩ	35 GΩ	31 GΩ	32 GΩ

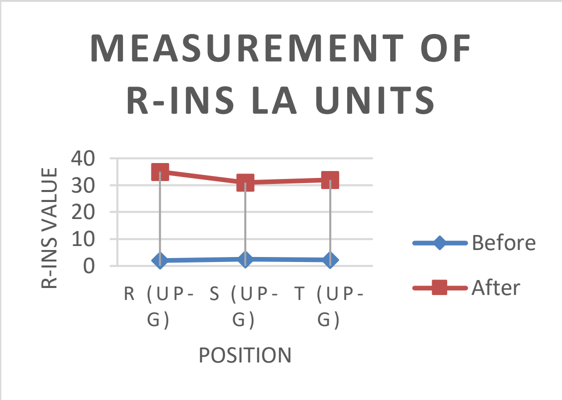

Figure 4. The Lighting Arrester measurement result after replacement work was carried out by the HAR-C team PT. PLN (Persero) ULP Ngagel

This chart compares the insulation resistance (R-Ins) values of the Lightning Protection (LA) unit at three positions R (UP-G), S (UP-G), and T (UP-G) measured before and after maintenance or testing. The Before measurements (blue line) show consistently low R-Ins values, approaching 1 GΩ at all positions, indicating relatively higher leakage or lower insulation quality before the intervention. Conversely, the After measurements (red line) show a significant increase in R-Ins values, ranging between 28 MΩ and 32 MΩ, reflecting increased insulation resistance after maintenance or replacement activities and meeting or exceeding the typical factory standard of 25 GΩ.

The overall trend indicates that post-treatment, all three phases (R, S, and T) experienced significant improvements in insulation characteristics, indicating successful restoration of the lightning protection capability of the lightning protection unit. The uniformity of the After data also indicates balanced performance across phases, which is essential for maintaining system reliability and minimizing the risk of insulation damage.

From the measurement data obtained from the replacement of the lightning arrester, a comparative count is needed to confirm that the work can be said to be successful or needs to be re-evaluated. The calculation can be done in the following steps:

A. Maximum current leakage with minimum allowable resistance

Based on the study theory, it can be concluded that PT. PLN (Persero) has set a minimum insulation resistance threshold for lightning rods, which is 1 GΩ. This value is not without basis, but is based on strict security and reliability standards of the system. This resistance ensures that the leakage current flowing through the lightning rod is at a very low limit.

The minimum resistance value of 1 GΩ directly correlates with the maximum permissible leakage current limit, which is 20µA, specifically for medium-voltage networks. This very small leakage current is crucial to maintain the integrity of the insulation and prevent progressive damage to the lightning rod itself. By limiting leakage current to a very low level, the risk of insulation failure can be significantly minimized.

This statement is not just a theory, but can be proved through simple calculations using Ohm's law. With a nominal operating voltage and a minimum insulation resistance set, the resulting leakage current can be calculated. The results of this calculation will consistently show that the measured leakage current value is below the permissible 20µA threshold, validating PLN's technical decision and confirming the importance of insulation resistance testing in ensuring the reliability of the power grid. The calculation can be explained as follows:

Known:

1. Nominal Voltage = 20 kV (Medium Voltage Network)
2. Minimum isolation detention = 1 GΩ

Asked : How much current leakage is allowed?

Answer:

$$I = \frac{V}{R}$$
$$I = \frac{20\text{ kV}}{1\text{ G}\Omega}$$
$$I = 0{,}02\text{ mA}$$
$$I = 20\ \mu\text{A}$$

B. With the same theory and equation, for calculation before the lightning arrester replacement work can be described as follows:

Known:

1. Nominal Voltage= 20 kV (Medium Voltage Network)
2. Lightning Arrester insulation resistance in phasa R = 2 GΩ
3. Lightning Arrester insulation resistance in phasa S = 2,5 GΩ
4. Lightning Arrester insulation resistance in phasa T = 2,3 GΩ

Asked: How much of the current leakage occurred before the lightning arrester unit replacement work was carried out?

Answer:

$I_R = \frac{V}{R}$

$I_R = \frac{20\ kV}{2\ G\Omega}$

$I_R = 0{,}01\ mA$

$I_R = 10\ \mu A$

$I_S = \frac{V}{R}$

$I_S = \frac{20\ kV}{2{,}5\ G\Omega}$

$I_S = 0{,}008\ mA$

$I_S = 8\ \mu A$

$I_T = \frac{V}{R}$

$I_T = \frac{20\ kV}{2{,}3\ G\Omega}$

$I_T = 0{,}0087\ mA$

$I_T = 8{,}7\ \mu A$

C. With the same theory and equation, for calculation before the lightning arrester replacement work can be described as follows:

Known:

1. Nominal Voltage= 20 kV (Medium Voltage Network)
2. Lightning Arrester insulation resistance in phasa R = 35 GΩ
3. Lightning Arrester insulation resistance in phasa S = 31 GΩ
4. Lightning Arrester insulation resistance in phasa T = 32 GΩ

Asked: How much current leakage occurred after the lightning arrester unit replacement work was carried out?

Answer :

$I_R = \frac{V}{R}$

$I_R = \frac{20\ kV}{35\ G\Omega}$

$I_R = 0{,}547\ \mu A$

$I_R = 547\ nA$

$I_S = \frac{V}{R}$

$I_S = \frac{20\ kV}{31\ G\Omega}$

$I_S = 0{,}645\ \mu A$

$I_S = 645\ nA$

$I_T = \frac{V}{R}$

$I_T = \frac{20\ kV}{32\ G\Omega}$

$I_T = 0{,}625\ \mu A$

$I_T = 625\ \mu A$

The comparative graph (Figure 4) shows that the post-replacement R-Ins values exhibit uniformity across all three phases, signifying balanced insulation performance. This uniformity is essential for ensuring consistent protection levels and reducing the likelihood of insulation breakdown due to uneven voltage stress distribution. The improvement in insulation resistance indicates the effectiveness of the replacement intervention in restoring the arrester's operational reliability.

Based on Ohm's Law, the relationship between voltage, resistance, and leakage current can be used to evaluate the arrester's performance quantitatively. For a nominal system voltage of 20 kV and a minimum insulation resistance of 1 GΩ (as specified by PT PLN standards), the corresponding maximum permissible leakage current is 20 μA. This threshold ensures the arrester operates safely within acceptable insulation limits.

Before the replacement, calculated leakage currents for phases R, S, and T were approximately 10 μA, 8 μA, and 8.7 μA, respectively still within permissible limits but approaching the upper range. After the replacement, the leakage currents were substantially reduced to 547 nA, 645 nA, and 625 nA, respectively, confirming the improved insulation performance of the new units.

V. CONCLUSION

Based on data analysis and calculations, the replacement work of the lightning arrester (LA) unit on the 20 kV medium voltage network (JTM) can be declared significantly successful.

This conclusion is based on a comparison of conditions before and after replacement, with reference to the standards set by PLN:

A. Success Standard: PLN specifies that the minimum insulation resistance for lightning arresters is 1 GΩ, which is equivalent to the maximum allowable leakage current limit of 20 μA to maintain system reliability.

B. Conditions Before Replacement: The old LA insulation resistance is at values of 2 GΩ to 2.5 GΩ. Although this value is still above the minimum threshold, it results in a leakage current of 8 μA to 10 μA.

C. Conditions After Replacement: After the new LA unit is installed, there is a drastic improvement in performance. The insulation resistance jumped to 31 GΩ to 35 GΩ. This increase causes a substantial decrease in the leakage current to the figure of ~0.547 μA to ~0.645 μA.

Thus, the resistance value of the new LA insulation far exceeds PLN minimum standard, and the resulting leakage current is very small, i.e. well below the maximum limit of 20 μA. This confirms that the replacement of the LA has succeeded in improving the safety and reliability of the electrical system.

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