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Tesis

# Impact of Installing Lightning Arresters on Low Voltage Networks in Areas with High Lightning Incidence per Kilometer

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# Impact of Installing Lightning Arresters on Low Voltage Networks in Areas with High Lightning Incidence per Kilometer

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***Abstract*—The concession area of Sociedad Eléctrica del Sur Oeste S.A. (SEAL) faces a significant challenge due to the high incidence of atmospheric discharges, ranging from 12 to 30 lightning strikes per square kilometer annually. These discharges result in critical failures in transformers and electrical networks. Current medium-voltage protections are insufficient to effectively mitigate electrical surges that damage secondary windings, leading to increased maintenance costs, service interruptions, and reduced system reliability. The presented article addressed these shortcomings through the implementation of Surge Protective Devices (SPDs), a technology already validated in Europe and Brazil. In critical areas such as Chuquibamba, Valle del Colca, Chococo, Orcopampa, and Huancarama, 1,300 SPDs were installed, distributed across three-phase and single-phase networks. The results demonstrated a significant reduction in failures, preservation of transformers, and low implementation costs—approximately $89.22 per three-phase SED and $44.61 per single-phase SED—totaling an investment of $28,119.00, which significantly reduces losses caused by the problem. Financial analysis confirmed the project's profitability, with an Internal Rate of Return (IRR) of 14.9%, a Net Present Value (NPV) of $61,298.84, and a payback period of seven years. This viable and effective model reinforces the company's commitment to innovation and energy efficiency, setting a precedent for expansion into other critical areas.**

***Keywords—Lightning Protection, Surge Protective Devices (SPDs), Electrical Network Reliability, Cost-Effective Solutions y High Lightning Incidence Areas***

## I. Introduction

The increasing frequency and intensity of atmospheric discharges pose a critical challenge to the reliability and safety of electrical distribution and transmission networks. In regions with high lightning incidence, such as specific electrical concession areas in Ecuador and other high-activity zones, these discharges cause transient overvoltages that severely damage transformers, burn windings, and lead to recurrent equipment failures.[1][2]

Atmospheric discharges, whether direct or indirect, significantly impact both the operators of electrical systems and end-users, who experience constant service interruptions and incur high costs from damaged electrical equipment. Data from atmospheric discharge protection projects in Ecuador reveal that lightning density in certain areas exceeds 15 strikes per square kilometer annually, underscoring the urgent need for adequate protective measures.[2] Technologies such as metal oxide surge arresters and surge protection devices (SPDs) have emerged as key solutions to mitigate these effects, but their implementation and efficiency vary depending on environmental and operational factors.[1]

Despite technological advances, the effectiveness of current protection solutions faces several challenges. Ground resistance is a critical factor for surge arrester performance; elevated resistance values can significantly diminish the systems' ability to dissipate overvoltages, resulting in persistent failures. Studies in Malaysia have shown that high ground resistance exacerbates overvoltages in power lines, severely impacting performance. Furthermore, deficient geometric configurations in distribution and transmission lines can amplify the adverse effects of overvoltages.[3], [4]

Another significant challenge is inadequate installation practices or the absence of clear strategies for locating surge arresters. Recent investigations highlight that improperly positioned protective devices not only limit their effectiveness but also increase maintenance and repair costs for electrical networks.[5]

The economic impact of atmospheric discharge-related failures is substantial. Studies indicate that costs associated with service interruptions, equipment repairs, and energy losses can reach millions of dollars annually for power system operators. The lack of efficient protection system designs not only raises these costs but also limits companies' ability to ensure quality electrical service.[6]

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Conventional methods, such as the installation of shield wires and reducing resistance at tower bases, have proven either insufficient or economically unfeasible in many cases. This has led to growing interest in innovative technologies, such as metal oxide surge arresters, which offer superior performance at a more reasonable cost.[7]

The urgency to develop comprehensive solutions to address these limitations is evident. These solutions should include dynamic analysis of transient phenomena, traveling wave modeling, and advanced tools like EMTP-RV software to simulate real scenarios and predict overvoltage behavior. Moreover, integrating probabilistic models and statistical analyses can enhance risk assessment precision and optimize the placement of protective devices.[8]

The implementation of efficient technologies has not only technical and economic implications but also social and environmental ones. Reducing service interruptions improves users' quality of life and reinforces trust in system operators. On the other hand, protecting electrical networks also contributes to environmental sustainability by preventing energy wastage caused by system failures.[8], [9]

The problem of atmospheric discharges and their impacts on electrical systems demands innovative, economically viable, and technically robust solutions. These solutions must be supported by detailed studies, advanced modeling, and a strategic implementation tailored to specific regional conditions. Effectively addressing this issue will not only ensure greater continuity and quality of electrical service but also establish a precedent for sustainable management of electrical networks in the future.[10]

The concession area of Sociedad Eléctrica del Sur Oeste S.A. (SEAL) is highly exposed to frequent atmospheric discharges, ranging from 12 to 30 lightning strikes per square kilometer annually, as identified by the isokeraunic map provided by Osinergmin. These discharges, whether direct or indirect, significantly impact the electrical systems, causing overvoltages that can severely damage transformers and other components within the distribution network.

While Medium Voltage (MV) Distribution Substations (SEDs) are equipped with lightning arresters connected to grounding systems, these protections are insufficient to mitigate electrical surges. These surges propagate to the Low Voltage (LV) side of the transformer, leading to critical failures such as the burning of secondary windings. This issue not only increases maintenance and repair costs but also undermines the quality of the electrical service by causing frequent interruptions and reducing system reliability.[11]

This lack of adequate protection in Low Voltage networks poses a substantial challenge for SEAL, particularly in areas with high lightning activity, including Chuquibamba, Valle del Colca, Chococo, Orcopampa, and Huancarama. Implementing an effective and cost-efficient solution to prevent damage from these discharges is essential to ensure service continuity, safeguard company assets, and enhance customer satisfaction.

Thus, there is a pressing need to assess and deploy innovative technologies, such as Surge Protective Devices (SPDs), which have proven effective in other international contexts, to mitigate the consequences of atmospheric discharges on SEAL's Low Voltage distribution networks.

## II. METHODOLOGY

The study was conducted in SEAL's concession area, whereregions with high lightning incidence were identified based on isokeraunic maps provided by Osinergmin. These areas, including the Chuquibamba, Valle del Colca, Chococo, Orcopampa, and Huancarama substations, experience between 12 and 30 lightning strikes per km² annually. The types of atmospheric discharges (direct and indirect) and their associated damages were evaluated, including overvoltages affecting transformers in medium and low-voltage networks. A protection scheme was designed using Surge Protection Devices (SPDs), also known as low-voltage lightning arresters, which have been previously tested in Europe and Brazil.

### *A. Types of Discharges*

Atmospheric discharges impacting the medium-voltage network affect the transformers of the MV/LV substations. These discharges can be either direct or indirect.

The number of discharges for the medium-voltage networks of the CHUQUIBAMBA substation, VALLE DEL COLCA substation, CHOCOCO substation, ORCOPAMPA substation, and HUANCARAMA substation has been determined using the isokeraunic map provided by Osinergmin, which is shown
11 below:

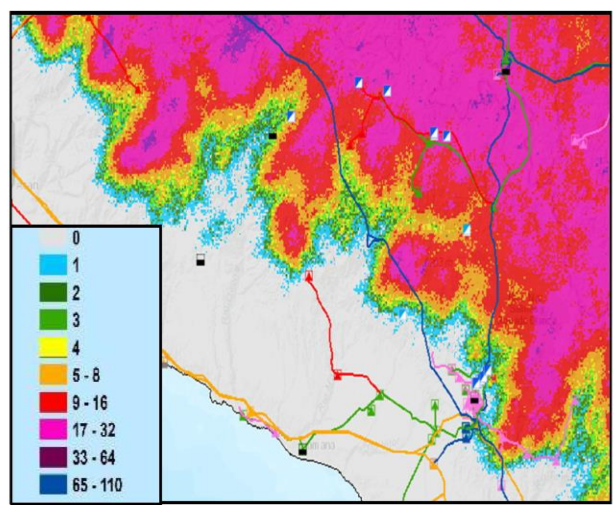


Fig. 1. Isokeraunic Map of Osinergmin

From the map, it can be observed that the lightning strikes per km² in the systems of the CHUQUIBAMBA substation, VALLE DEL COLCA substation, CHOCOCO substation, ORCOPAMPA substation, and HUANCARAMA substation range from 12 to 30 lightning strikes/km².

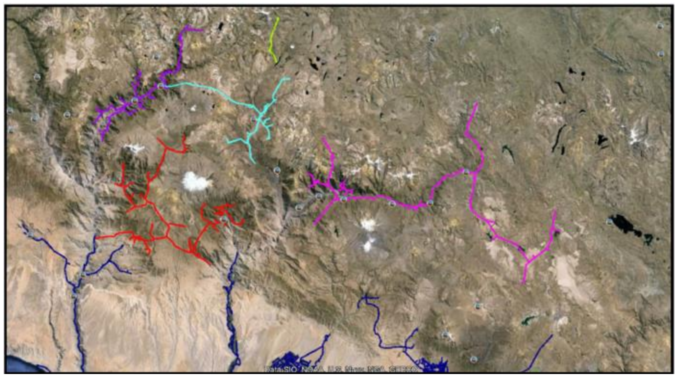

Fig. 2. Map of the MV networks of these substation

The total number of SEDs for each feeder of the substations involved in the project is presented below:

TABLE I. SEDS PER FEEDER

| TYPE AND POWER | SET | | | | | TOTAL |
|---|---|---|---|---|---|---|
| | CHOCOCO | CHUQUIBAMBA | HUANCARAMA | ORCOPAMPA | VALLE DEL COLCA | |
| **M** | **98** | **137** | | **28** | **77** | **340** |
| 5 | 18 | 53 | | 11 | 13 | 95 |
| 10 | 20 | 35 | | 8 | 18 | 81 |
| 15 | 7 | 26 | | 7 | 24 | 64 |
| 25 | 30 | 14 | | 2 | 17 | 63 |
| 37 | 10 | 2 | | | 3 | 15 |
| 40 | 12 | 6 | | | | 18 |
| 50 | 1 | | | | | 1 |
| 75 | | 1 | | | | 1 |
| 100 | | | | | | 2 |
| **T** | **27** | **37** | **4** | **20** | **67** | **155** |
| 5 | | 1 | | | | 1 |
| 10 | 1 | | | | 2 | 3 |
| 15 | 1 | 3 | 2 | | 2 | 8 |
| 25 | 11 | 8 | 1 | 2 | 17 | 39 |
| 30 | 2 | 1 | | 1 | | 4 |
| 37 | 1 | | | | 1 | 2 |
| 37.5 | 1 | | | | | 1 |
| 40 | 2 | 6 | | | | 9 |
| 45 | | | | 3 | 1 | 4 |
| 50 | 2 | 1 | 1 | 6 | 21 | 31 |
| 75 | 2 | 10 | | 3 | 3 | 18 |
| 100 | 2 | 5 | | 4 | 15 | 26 |
| 125 | | | | | 2 | 2 |
| 160 | | | | | 2 | 2 |
| 175 | | 1 | | | | 1 |
| 200 | | | | | | 1 |
| 250 | 1 | | | | | 1 |
| 400 | | 1 | | | | 1 |
| 630 | 1 | | | | | 1 |
| TOTAL | 125 | 174 | 4 | 48 | 144 | 495 |

Identify applicable funding agency here. If none, delete this text box.

### B. *Overvoltage Events*

Among overvoltage events, there are several types; however, for the purposes of this project, the focus is solely on controlling Electrical Spikes. These are composed of transient waves of current, voltage, or power that propagate along a line or circuit and are characterized by a rapid increase followed by a slower decrease.

### C. *Low-Voltage Surge Arresters*

Low-voltage surge arresters have been used in areas with higher isokeraunic levels in European countries, successfully reducing voltage fluctuations for customers. This technology yielded good results by decreasing damage to distribution transformers. In South America, this technology is already being used in Brazil.

The protection equipment for the Secondary Distribution Network is an electrical surge protection device – DPS (Transient Overvoltage Suppressor), single-pole, composed of a zinc oxide varistor (MOV) without a series discharger. It features non-explosive automatic disconnection with an indicator to signal its operational status.

The device includes terminals suitable for connection to electro-electronic equipment, electricity meters, and transformers (secondary coil). In the case of transformers, it connects directly to the secondary bushing via mounting hardware, with grounding through stainless steel screws. This device provides the following benefits:

- Preserves the safety of people and property.
- Ensures the normal operation of installations and prevents disturbances in other installations and services.

- Contributes to the technical reliability and economic efficiency of installations.

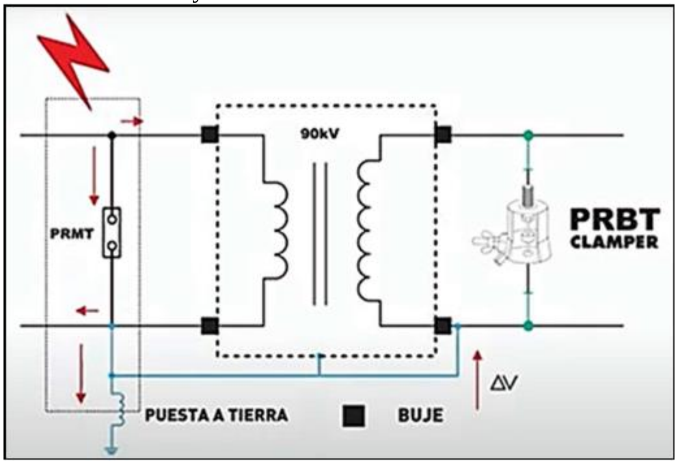


Fig. 3. Instalation F-N

This device must be installed on the secondary side of the transformer, between the phase and neutral, as shown in the following figure 3 It is noted that one LV surge arrester (PRBT) must be installed for each phase. In the case of three-phase LV networks, a total of 4 PRBTs are required, while for single-phase networks, 2 PRBTs are needed.

## III. Results

### A. Rentabilidad

The profitability of this project was calculated for the next 20 years of its useful life. The following table shows that the project's Internal Rate of Return (IRR) is 14.9%, while the Net Present Value (NPV), evaluated at 12%, is US$ 61,298.84. Lastly, it indicates that the investment will be recovered within the next 7 years.

TABLE II. PROFITABILITY

| Investment in equipment and others, without VAT (USD) | 28,119.00 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Total Investment (USD) | 28,119.00 | | | | | | | |
| Year | 0 | 1 | 2 | 3 | 4 | 5 | 10 | 20 |
| Operating and Maintenance Cost | 1,687.10 | 1,687.10 | 1,687.10 | 1,687.10 | 1,687.10 | 1,687.10 | 1,687.10 | 1,687.10 |
| Benefit from energy sales during maintenance hours (annual) | 6,158.00 | 6,158.00 | 6,158.00 | 6,158.00 | 6,158.00 | 6,158.00 | 6,158.00 | 6,158.00 |
| Net Profit | - | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 |
| Investment Cash Flow (USD) | -28,119.00 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 | 4,470.90 |
| IRR | 14.90% | | | | | | | |
| NPV | USD 61,298.84 | | | | | | | |
| Payback Period | 7 years | | | | | | | |

The project implementation enabled the protection of SEAL's secondary distribution networks through the installation of 1,300 DPS devices, distributed among three-phase networks (620 units) and single-phase networks (680 units). The devices proved effective in mitigating damage from surges, preserving transformers, and reducing failures in the electrical network. Installation costs were $89.22 per three-phase SED and $44.61 per single-phase SED, with a total investment cost of $28,119.00.

The financial analysis highlighted an Internal Rate of Return (IRR) of 14.9% and a Net Present Value (NPV) of $61,298.84, evaluated at 12%. The investment is expected to be recovered within an estimated period of seven years, with additional benefits arising from improved service quality and reduced outages. Using the Template.

## IV. Conclusion

The installation of low-voltage surge arresters in SEAL's distribution networks has proven to be a technically and economically viable solution. The results show a significant reduction in transformer failures, improved quality of electrical service, and greater protection for equipment and installations. The low implementation cost and the benefits obtained justify the expansion of this technology to other areas with similar conditions.

It is recommended to continue monitoring the performance of the DPS devices and to explore opportunities to further optimize installation and maintenance costs. This project reinforces SEAL's commitment to innovation and energy efficiency for the benefit of its customers and communities.

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