

# Evaluating SAS vs. MOSA technologies for enhanced lightning protection on distribution lines

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## 1. Introduction

The field of surge protection in power systems has undergone substantial technological evolution over the years. Various innovations have emerged to address market needs and overcome limitations of earlier systems. An examination of this progression, particularly the shift from gapped to non-gapped technologies and back again, yields valuable insights.

In an era of increasing dependence on stable and secure electrical supply, the importance of Line Surge Arresters (LSAs) in overhead power lines has become paramount. While Metal Oxide Varistor (MOV) technology dominates high-voltage LSA applications, the medium-voltage sector presents a more diverse landscape. This paper investigates the performance characteristics of Surge Arc Suppressor (SAS) devices as an alternative to conventional MOV-based solutions, with a focus on their efficacy and reliability under diverse operational conditions.

SAS technology, often misunderstood and sometimes criticized by proponents of MOV systems, warrants a comprehensive and objective analysis. This paper aims to provide such an assessment, serving as a definitive resource for industry professionals, manufacturers, and power utilities in making informed decisions regarding surge protection strategies.

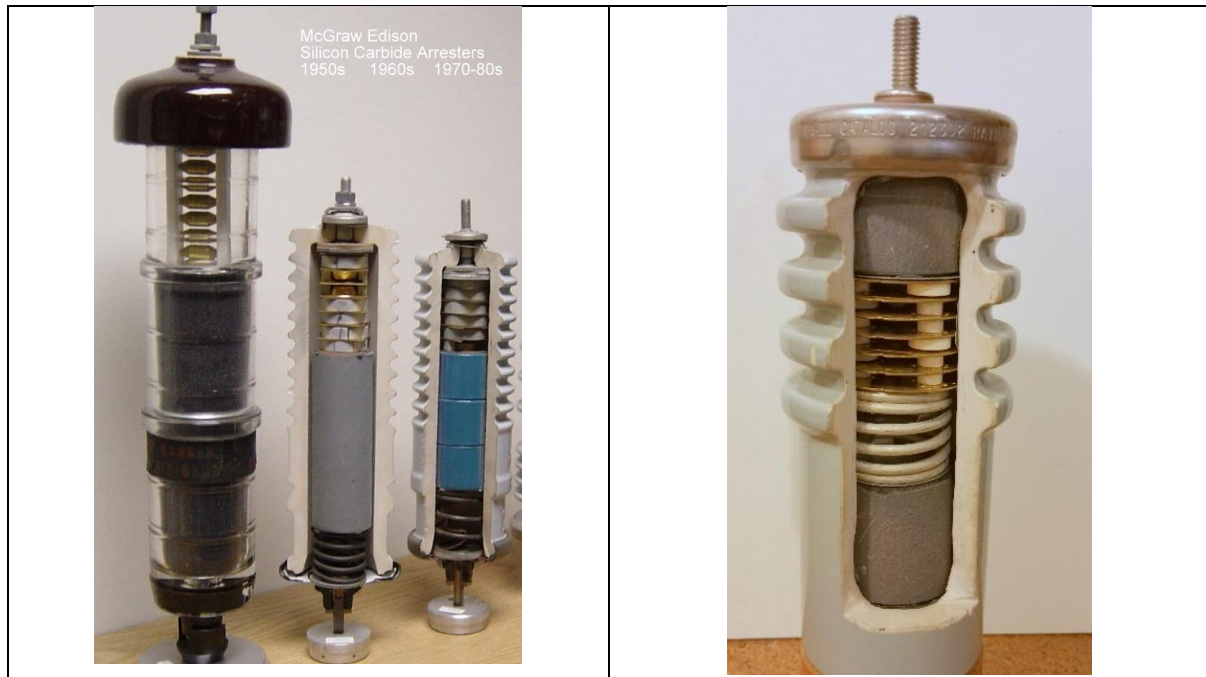
By synthesizing empirical data, real-world case studies, and a thorough review of existing literature, this paper offers actionable insights directly applicable to the selection and implementation of Surge Arc Suppressor devices. Through a critical examination of historical developments, we can better anticipate and address future challenges and opportunities in the field of surge protection.

## 2. Historical Perspective: Understanding Current Mindsets through the Evolution of Surge Arrester Technology

### a) Evolution from Silicon Carbide (SiC) Arresters to Metal-Oxide Surge Arresters (MOSA) - fear of past demons

In 1990, arrester manufacturers largely dismissed silicon carbide gapped arresters (SiC gapped) due to their technical limitations, particularly in light of

the introduction of Metal-Oxide Varistor (MOV) technology. SiC gapped arresters (Figure 1) were criticized for their instability and degradation over time, which negatively impacted their sparkover characteristics. This skepticism extended to MOV gapped arresters, as the presence of a gap was generally associated with inferior performance.



*Figure 1 Internally Gapped Silicone Carbide. Credit Arresterworks*

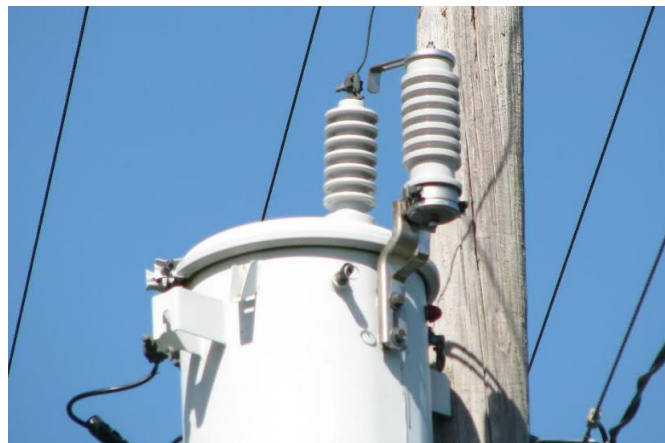
However, following the widespread adoption of gapless MOV surge arresters, the industry observed significant improvements in the residual voltage (protection level) of MOV gapped arresters. This advancement faced opposition primarily from manufacturers focused on non-gapped MOV products, which had become the dominant design. Utilities seeking lower residual voltages often opted for gapped arresters, which offered advantages such as higher Temporary Overvoltage (TOV) capabilities in delta circuit applications.

The introduction of gapped MOV technology by a U.S. manufacturer met considerable resistance from competitors promoting non-gapped MOV technology. Experts involved in international committees and working groups initially viewed this "gapped" technology with skepticism, suspecting it was an attempt to mask inferior blocks. They later acknowledged that this perception was unfounded, as high-quality MOV blocks were consistently used in the technology.

The proposed IEC 60099-6 standard, intended to regulate gapped MOV arrester technology, faced years of delays due to opposition from certain experts. Currently, IEC 60099-6 accommodates gapped MOV products, while IEEE C62.11 covers both gapped and non-gapped MOV products.

In the contemporary U.S. market, gapped MOV arresters have gained significant traction, particularly for riser pole applications. Market share estimates suggest they account for approximately 5-10% of distribution arrester sales in the United States.

Some examples in the U.S. (Figure 2) demonstrate the adoption of Externally Gapped Line Arrester (EGLA) technology on pole-mounted transformers in distribution networks. This relatively new approach has met resistance from industry professionals concerned about potential damage to transformer windings from very fast front transients. Despite these concerns, further rigorous research is warranted in this area.



*Figure 2. EGLA used of pole mounted distribution transformer. Source : Arresterworks.*

Recent trends indicate a renewed interest in gapped arresters within the medium voltage (MV) industry. Some companies emphasize their enhanced reliability on distribution systems, while others highlight their superior protective performance in Resistor-Capacitor (RC) snubbers, as illustrated in Figure 2.

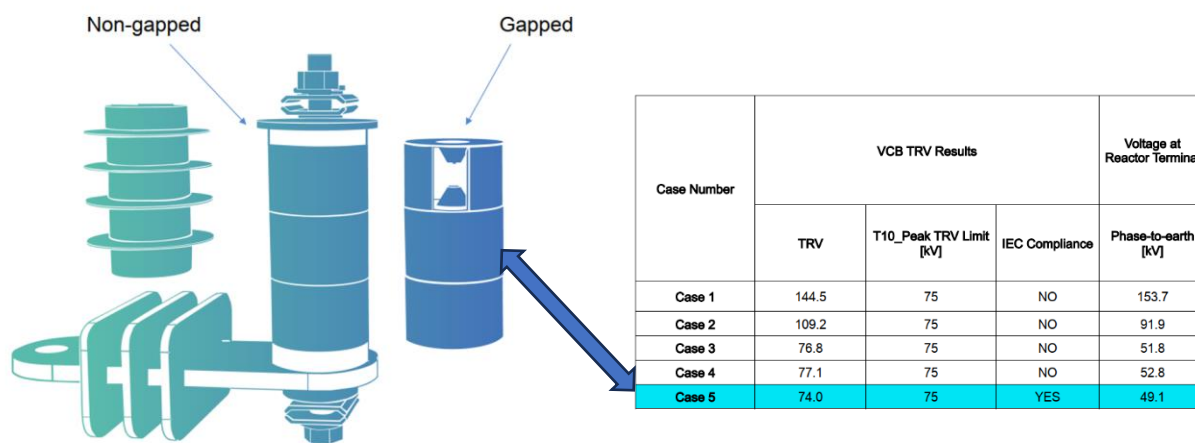


Figure 3. Source: *Optimizing Application of MV Surge Arresters in Resistor-Capacitor (RC) Snubbers* – Tim Rastall & Kerim Ozer – INMR Congress Berlin 2022

### b) Adoption of Series-Gap Technologies: EGLA and Gapped MV Types – The Evolution of Series Gaps

An examination of the history of LSA and the introduction of EGLA, initially developed in Japan, reveals that technology adoption is not solely based on rational performance assessment.

EGLAs have gained prominence in Japan since the 1980s. By 1988, Japan had deployed nearly 4,500 EGLA units and discontinued the use of Non-Gapped Line Arresters (NGLAs) due to evident technical advantages. However, it took decades for other countries to comprehend and implement this technology.

The first IEC standard 60099-8, specifically addressing EGLA applications, was only published in 2012. Limited manufacturer and user experience initially impeded effective, widespread adoption. Many manufacturers were hesitant to invest, given the uneven market distribution.

Currently, EGLAs dominate numerous markets and have become the exclusive authorized technology for overhead line protection in some countries. Several manufacturers, previously opposed to EGLAs, have now introduced their inaugural EGLA portfolios. Others have been compelled to comply with user requirements to meet technical specifications.

The industry has experienced two significant technological shifts: the adoption of EGLA (IEC 60099-8) and Gapped MV types (IEC 60099-6). Both

technologies incorporate series gaps and have encountered resistance from the traditionally conservative "Antigap" sector.

These developments corroborate a universal principle applicable to both human sciences and technology: Any innovation, invention, change, or revolution typically progresses through three stages in collective consciousness:

1. Perceived as ridiculous
2. Considered dangerous
3. Recognized as obvious; eventually leading to widespread adoption

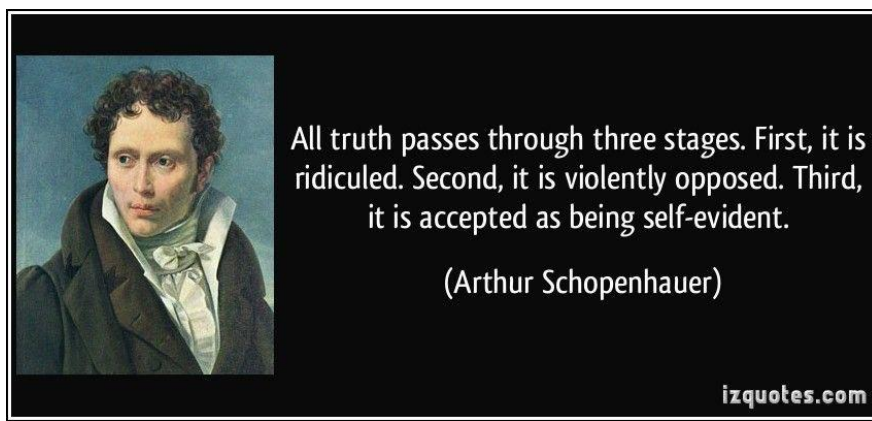


Figure 4. Quote from Schopenhauer – izquotes.com

### 3. Industry Challenges and Limitations of Conventional MOSA Technology

#### a) Market Overview with Focus on Medium-Voltage (MV) LSA

Surge arresters are critical components in electricity distribution networks, significantly enhancing system reliability and operational stability. MV Surge Arresters encompass a wide range of applications, each requiring specialized designs to meet specific requirements. These applications include:

- Pole-mounted transformers and transition points (riser-pole)
- Line surge arresters (EGLA & NGLA)
- MV transformers and switchgears
- Industrial applications (motors, generators, furnaces)
- Capacitor banks (high energy)
- Battery storage systems
- Cable sheaths (SVL)
- Coil and line traps

- Renewable energy installations (solar, wind turbines)
- Separable arresters (plug-in types)

Of particular importance are riser-pole arresters, utilized where overhead distribution lines transition to underground systems. Another significant market segment involves distribution-class surge arresters designed to mitigate lightning-induced outages on MV lines, offering both gapped and non-gapped solutions.

These devices adhere to international standards such as IEEE C62.11 and IEC 60099-4, and are engineered to withstand extreme conditions. However, when deployed outdoors on a large scale and exposed to severe weather and atmospheric conditions, conventional MOSA faces certain limitations. This article aims to explore these challenges and their implications for the industry.

#### b) Critique and Limitations of Current Standards: Focusing on Medium-Voltage Surge Arresters

MOSA have been a staple in the electricity supply industry for over four decades. Contemporary designs and applications offer enhanced reliability when engineered, manufactured, and tested in compliance with international standards. This analysis does not aim to critique the technology itself; rather, it seeks to highlight specific areas for improvement that could augment reliability in particular applications and voltage ranges. Globally, numerous MOSAs have demonstrated reliable operation for more than 40 years.

This discussion will not address criticisms of manufacturers who fail to adhere to international standards, nor will it explore the issue of substandard equipment frequently installed in electrical grids, often due to budgetary constraints and short-term planning.

Reports of Surge Arrester failures are infrequent. The CIGRE Working Group A3.39 [1] encounters difficulties in identifying users willing to share information on this subject. Consequently, we must rely on failure statistics from independent testing laboratories, which have provided valuable insights.

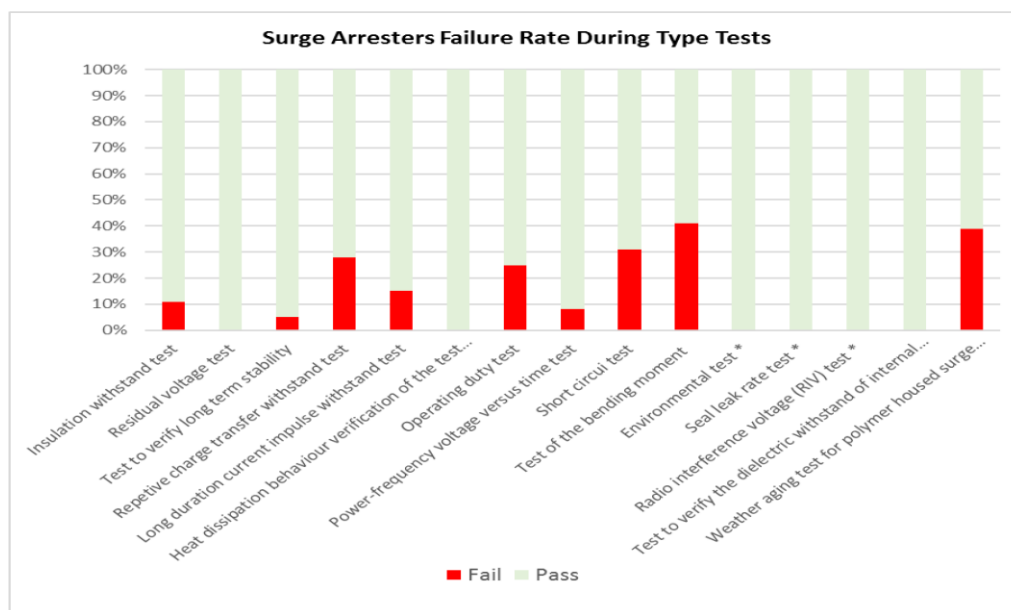


Figure 5. Surge Arresters Failure Rate during Type Tests – Statistics CESI test lab [1]

From the results presented in Figure 5, we can derive specific inferences. The analysis herein is theoretical and establishes a correlation between the most prevalent types of distribution arrester failures and their primary causes, as indicated by the aforementioned results. It is important to note that this analysis is subject to scrutiny, given that the statistics do not differentiate between MV and HV applications.

- **Moisture ingress** ranks as the foremost cause of failure across all types of surge arresters. This is predominantly verified through bending moment tests that incorporate thermal conditioning and water immersion.
- Distribution Class Arresters are particularly susceptible due to the utilization of less expensive polymer materials, a compromise made to remain competitive in an aggressive market. When subjected to constant electrical stress, these low-cost polymers often fail to pass the **Weather Aging Test**, making this the second leading cause of failure.
- The market offers a variety of Distribution Arrester designs, each presenting unique challenges regarding short-circuit performance. Whether employing cage design, wrap design, cast resin, or winding filament, manufacturers face the complex task of balancing lightweight construction with robustness.

The two other recurring causes of failure are charge transfer (Qrs) and thermal charge (Qth). These issues are predominantly associated with MOV block manufacturers. As with surge arresters, various quality levels of MOV blocks are available in the market.

Nevertheless, it is possible to access sporadic reports and statistics from field applications through published papers and individual sources, as illustrated in Figure 6 [2].

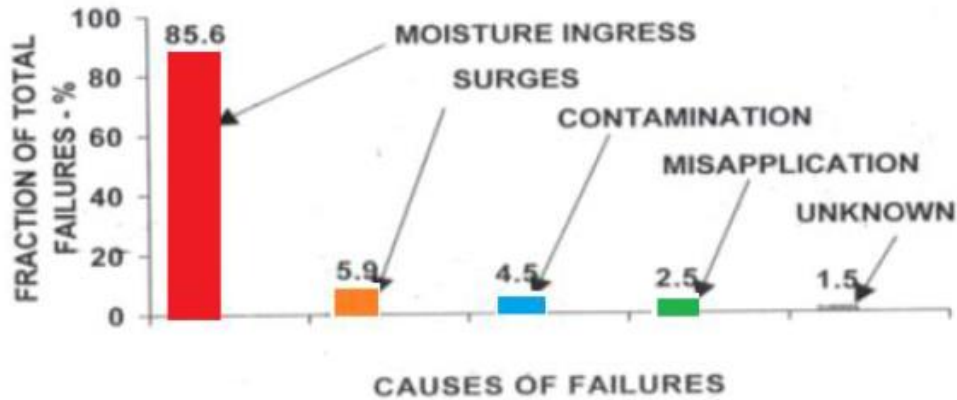


Figure 6. Statistics of Failures in South Africa on Distribution Class Arresters [2]

Most surge arresters that adhere to industry standards and incorporate state-of-the-art methods and technologies typically exhibit excellent performance. However, these reports and feedback from practical experience indicate a recurrent issue with distribution surge arresters. Furthermore, industry professionals frequently encounter feedback that falls short of expectations. In many instances, the information provided remains confidential and is not intended for public dissemination.

Besides designs issues, manufacturing flaws and defect, the IEEE Guide (Std 1410-2010) for Improving the Lightning Performance of Electric Power Overhead Distribution Lines provides average failure rate data for Heavy Duty Arresters (Standard Distribution Class DH as per IEC) with a 40mm MOV diameter. According to this guide, the failure rate per Direct Stroke on an unshielded line ranges from 12% to 33%. While these figures warrant further interpretation and verification, it is evident that conventional distribution surge arresters (either HD or DH) are susceptible to lightning strikes on unshielded lines. This statistic represents a universal truth related to lightning exposure and does not account for failures attributable to design or manufacturing processes.

**Table 3—Classification of Arresters for Distribution System**

Arrester Class	Block Diameter (mm)	Energy Rating (kV/kJ MCOV)	Energy Rating (J/cm <sup>3</sup> )	Failure Rate per Direct Stroke in Unshielded Line
Light Duty	25	3.0	170–200	33%–100%
Normal Duty	32	4.8	170–200	17%–50%
Heavy Duty	40	6.7	170–200	12%–33%

Figure 7. IEEE 1410 Guide . 7.3.2 Arrester energy absorption capability

As per the IEEE guide, the failure rate estimates presented in Figure 7 apply to three-phase plus neutral lines without overhead ground wires, assuming arresters are installed on all poles and for each phase.

### c) Identified Limitations of MO LSAs on MV lines

While MO LSAs have been successfully implemented on transmission lines for an extended period, their adoption on distribution networks has been comparatively limited. This disparity can be attributed to several factors:

#### **1. Economic Considerations:**

- Distribution line outages typically incur lower financial penalties compared to transmission line failures, reducing the economic incentive for MO LSA deployment.
- The substantial initial capital expenditure required for MO LSAs often presents a barrier to implementation, particularly when manufacturers fail to articulate a compelling return on investment.

#### **2. Technical Constraints:**

- **Lightning Stress:** Distribution lines frequently lack shielding, potentially resulting in higher lightning charge transfer that may exceed the standard Qrs ratings of MO LSAs.
- **Overvoltage Tolerance:** Certain distribution systems are susceptible to temporary overvoltage (TOV) levels that surpass the operating thresholds of MO LSAs.

#### **3. Reliability Concerns:**

- Field reports have indicated instances of MO LSA failures due to compromised sealing integrity, particularly moisture ingress, raising questions about their long-term reliability in distribution environments.

Given these limitations, alternative technologies such as Surge Arc Suppressors (SAS) or Current-Limiting Gaps (CLGs) have emerged as viable solutions, addressing some of the shortcomings associated with MO LSAs in distribution network applications.

## 4. Working Principles of Surge Arc Suppressors (SAS)

### a) Overview of SAS Technology

SASs and MO LSAs are both designed to mitigate lightning impacts on electrical power systems. Typically installed alongside insulation on overhead towers, these technologies serve similar purposes but possess distinct characteristics that influence their application.

SAS devices, also known as Current Limiting Gaps (CLGs), are employed to mitigate lightning-induced interruptions in distribution networks, although their recognition is not universal [8]. Notably, Japanese electrical infrastructure incorporates SAS technology in transmission lines up to 154kV systems. The CIGRE Technical Brochure 855, released in 2021, formally categorizes SAS devices as a subtype of Line Surge Arresters. However, their technological framework diverges significantly from conventional MO LSAs predominantly deployed in transmission systems.

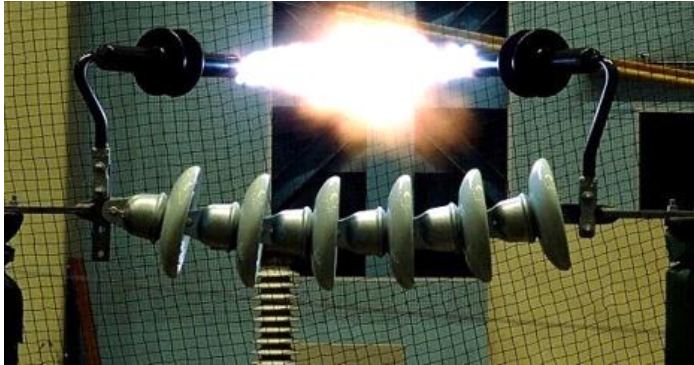
Unlike resistor valve type arresters composed of SiC elements and series gaps, SAS are not intended to safeguard high-value substation equipment such as power transformers. Instead, they employ an innovative design incorporating one or more arc quenching chambers, providing follow current quenching capabilities. This feature has been rigorously assessed and corroborated, similar to EGLA.

Originating in the 1990s, SAS have progressively gained global recognition, largely due to their favorable lifecycle expenditures and resilience against high charge transfer ratings in unshielded overhead lines. Presently, SAS have emerged as a compelling alternative for distribution grids worldwide, offering an efficacious strategy for reducing lightning-associated disruptions on medium and high-voltage lines.

To understand SAS functionality, it is essential to explore their key features. Central to the SAS is the arc quenching chamber, which extinguishes the electrical arc formed between two contact points. This chamber allows electric current to flow through it, reducing the arc's energy until extinction. Unlike active arc-quenching components in circuit breakers that utilize materials such as SF<sub>6</sub> gas or vacuum, these chambers passively extinguish arcs through their design.

SAS devices are available in various configurations, including:

1. **Multi-Chamber Models:** These designs split the electrical arc into smaller segments, facilitating extinction (Figure 9).
2. **Single-Chamber Models:** In this configuration, the single chamber utilizes two orifices to direct the arc onto specific points on an insulator, where it is subsequently extinguished (Figure 8).



*Figure 8. Single-Chamber Model (2 bodies)  
Source: CRIEPI Report Japan [3]*



*Figure 9.. Multi-Chamber Model  
Source: Sreamer Electric AG [5]*

## b) Technical limitations

SAS devices are effective at mitigating power failures caused by lightning strikes. However, it is crucial to understand their limitations, particularly regarding fault currents. Careful analysis of system parameters is necessary before implementing SAS on any transmission line.

SAS devices are designed to interrupt follow currents within a very short time frame (less than half a cycle), thus avoiding the need for circuit breaker operations and subsequent outages due to lightning. Typical SAS designs can handle currents up to 10 kA, depending on their specifications. However, they have constraints in terms of operational capacity and maximum interruptible follow current. Consequently, SAS devices are most effective in applications where expected fault currents fall within these operational parameters.

The magnitude of the maximum possible fault current is inversely proportional to the distance between the SAS device and the power transformer. Proximity to the transformer results in higher fault currents. Therefore, maintaining a minimum separation between the SAS and the transformer is essential to ensure the device operates within its design limits.

### c) Advantages of SAS Over MO LSA

SAS offers several advantages compared to MO LSA:

- **Favorable Life-Cycle Costs:** SAS presents more attractive life-cycle costs compared to Distribution High (DH) Class surge arresters. It should be noted that cost considerations are complex and subject to market and economic fluctuations.
- **Superior Charge Transfer Capability:** SAS exhibits a charge transfer capability significantly higher than all other surge arrester classes. This characteristic provides SAS with a distinct advantage in applications involving unshielded systems or those with challenging grounding conditions and high soil resistivity.
- **Robustness & Weather Resistance:** SAS offers greater robustness and resistance to environmental stress compared to MO LSA. All surge arrester types made of MO resistors require a specific sealing system to prevent moisture ingress on the MO resistors surface. In contrast, SAS often features an open structure with highly resilient active components. Additionally, pollution and contamination can be critical issues for MO LSA, whereas SAS can operate in harsh environments without compromising interrupting performance.
- **Lightweight & Easy Installation:** MO resistors material is comparable to ceramic material and can be relatively heavy compared to SAS devices, which can be optimized to facilitate easier installation and handling. This is a particularly convenient feature for typical linework on distribution systems.

### Disadvantages of SAS Over MO LSA

Despite its advantages, SAS has certain limitations when compared to MO LSA:

- **Absence of Non-Linear Voltage-Current Characteristics:** The non-linear voltage-current characteristics of MO resistors are unique. When directly connected between phase and ground, MO resistors provide isolation for the system. During transient overvoltages, MO resistors clamp the voltage

produced by lightning, divert the surge to the ground, and protect the connected equipment. Because of these characteristics, MO LSAs can be particularly effective in protecting sensitive components, such as transformer windings. Although SAS devices do not possess these non-linear voltage-current characteristics, their protection level characteristics are sufficient to prevent lightning-induced outages on overhead lines.

- **Limited Operational Lifespan:** The service life of SAS is determined by the number of operations. The performance of follow current interruption degrades over time due to the cumulative effect of current density from each operation.

## 5. A Life-Cycle Costs Approach Incorporating Failure Rate Analysis

Some MO LSA manufacturers criticize SAS for deviating from established technology and perceived unreliability. To address this criticism, we propose conducting an analysis based on empirical data related to lightning stroke distribution. This analysis employs simulation software (Sigma SLP) to compare the Failure Rates of MO LSA and SAS, considering factors such as charge transfer stress from lightning strokes and sparkover frequency for SAS. While comments and suggestions are provided in the conclusion, failures resulting from design issues, manufacturing defects, or quality-related factors are excluded from this analysis due to limited available information.

### a) Failure rate for MO LSA

The concept of "Failure Rate" for MO LSA originates from Reliability Studies, which involve statistical analyses of failures based on a specific Lightning Performance model. Factors such as stroke distribution and Ground Flash Density (GFD) significantly influence the results. From a system perspective, notable differences exist between shielded and unshielded lines. To define the failure rate, we establish a correlation between the tested MOV "Qrs Repetitive Charge Transfer Ratings" (200 $\mu$ s) and the Statistical Lightning Charge Transfers computed by SIGMA SLP for MO LSA. It is assumed that any charge in coulombs exceeding the nominal Qrs rating of the MO LSA will result in a failure. IEC test protocols already incorporate a 10% safety factor, and the

impact of operations below the nominal Qrs on the life expectancy of MO LSA has not been extensively studied.

### b) Failure rate for SAS

The concept of "Failure Rate" for SAS devices differs from that of MO LSAs. SAS devices are highly resistant to critical lightning discharges, with smaller SAS devices often exceeding 2.4C Qrs ratings, compared to MO LSAs for distribution, which typically do not exceed 0.4C Qrs ratings. While high-amplitude lightning strokes do not damage SAS devices, certain events can compromise their interrupting performance. Ultimately, the failure criterion for an SAS device is the occurrence of an interrupting operation, which may be associated with cumulative charge transfer.

### c) System Parameters and Assumptions for the Case Study

- 100 km, 36 kV unshielded distribution single-circuit line
- Pole footing resistance: 20  $\Omega$ ; average soil resistivity: 800  $\Omega \cdot \text{m}$ . Soil ionization model is used in regards to the ground electrode impulse response.
- 1,714 protective devices (SAS or MO LSA) installed on every pole and phase across the 100 km line. It results in a average span between poles of 175 meters.
- EGLA employed to simulate spark-over operation (approximation of NGLA behavior)
- EGLA Series Varistor Unit (SVU): Distribution Class surge arrester (DH/HD) with repetitive charge transfer (Qrs) of 0.4 C (200  $\mu\text{s}$  duration), equivalent to  $\sim 36$  mm MOV blocks
- Qrs test includes a 10% safety margin; charge transfer exceeding 0.4 C considered as EGLA failure
- Lightning stroke distribution based on 5 years of Lightning Location System (LLS) data from Southwest Turkey, favoring MO LSA compared to conventional CIGRE two-line distribution.
- Ground Flash Density (GFD): 4 flashes/ $\text{km}^2/\text{year}$
- Computed charges in Sigma SLP considered with 200  $\mu\text{s}$  duration
- SAS devices assumed failure-free up to 5 operations for analysis purposes
- Study period: 35 years, computing 1,000 samples (realistic timeframe for electrical device life expectancy)

- A constant rate of 5 SAS failures per year is assumed, accounting for potential external factors such as physical damage and wind-induced stress, as well as a more critical lightning stroke distribution with a higher frequency of high-amplitude strokes.
- A non-homogeneous lightning stroke distribution with 75% coverage is considered for SAS devices as a worst-case scenario.
- Further research recommended to analyze SAS device failure rates beyond 35 years
- Induced Overvoltages are not considered in this study due to the high Critical Flashovers (CFO) ratings on the 36kV line.

Note: SIGMA SLP is an object-oriented software package designed to calculate transmission and distribution line lightning performance, estimating expected outages based on configurable system parameters and lightning activity.

### d) Results of the case study

all operation	241	145	343	303	186	472	334	195	549	339	202	541	301	185	452	243	141	337
above 0.4C	30	13	19	48	29	43	44	23	35	52	25	44	56	28	44	32	12	26
samples sorted by max. charge	Tower 2			Tower 3			Tower 4			Tower 5			Tower 6			Tower 7		
	T 2-A 1	T 2-A 2	T 2-A 3	T 3-A 1	T 3-A 2	T 3-A 3	T 4-A 1	T 4-A 2	T 4-A 3	T 5-A 1	T 5-A 2	T 5-A 3	T 6-A 1	T 6-A 2	T 6-A 3	T 7-A 1	T 7-A 2	T 7-A 3
1	2.47	2.11	2.39	2.32	1.90	2.23	1.34	1.26	1.46	2.20	1.95	2.14	2.90	2.54	2.79	1.46	1.30	1.47
2	1.70	1.36	1.63	2.04	1.90	2.06	1.14	0.92	1.34	1.99	1.83	1.98	1.83	1.73	1.73	0.92	0.84	1.07
3	1.31	0.82	0.89	1.60	1.54	1.62	1.03	0.89	0.99	1.45	1.30	1.37	1.72	1.62	1.70	0.70	0.67	0.97
4	1.12	0.74	0.88	1.38	1.30	1.37	1.00	0.88	0.99	1.17	1.01	1.34	1.63	1.46	1.65	0.68	0.67	0.90
5	0.89	0.70	0.81	1.33	1.25	1.32	0.99	0.77	0.95	1.13	0.99	1.10	1.63	1.45	1.54	0.58	0.54	0.86
6	0.79	0.69	0.76	1.21	0.97	1.16	0.93	0.76	0.94	0.89	0.71	1.08	1.56	1.40	1.46	0.58	0.54	0.80
7	0.78	0.65	0.75	1.13	0.94	1.09	0.93	0.73	0.80	0.83	0.60	1.07	1.28	1.21	1.22	0.56	0.52	0.79
8	0.76	0.57	0.70	1.09	0.94	0.91	0.90	0.72	0.78	0.78	0.60	0.77	1.18	1.00	1.10	0.56	0.49	0.75
9	0.72	0.55	0.69	1.03	0.86	0.90	0.84	0.67	0.73	0.74	0.59	0.67	1.04	0.84	0.99	0.55	0.49	0.62
10	0.70	0.54	0.63	1.02	0.83	0.89	0.84	0.66	0.72	0.68	0.57	0.65	1.03	0.81	0.97	0.53	0.49	0.59
11	0.70	0.50	0.61	0.98	0.83	0.88	0.80	0.66	0.69	0.65	0.56	0.62	1.00	0.81	0.96	0.53	0.48	0.58
12	0.68	0.48	0.55	0.95	0.78	0.88	0.80	0.62	0.68	0.62	0.52	0.61	0.94	0.80	0.95	0.52	0.47	0.56
13	0.65	0.45	0.54	0.94	0.78	0.79	0.79	0.62	0.67	0.59	0.50	0.59	0.85	0.78	0.88	0.52	0.40	0.56
14	0.65	0.40	0.50	0.92	0.70	0.79	0.78	0.56	0.65	0.59	0.48	0.54	0.81	0.71	0.88	0.52	0.37	0.56
15	0.64	0.39	0.49	0.89	0.66	0.75	0.76	0.49	0.62	0.59	0.48	0.54	0.77	0.69	0.87	0.51	0.34	0.55
16	0.62	0.39	0.49	0.87	0.66	0.74	0.76	0.48	0.60	0.59	0.48	0.53	0.75	0.65	0.85	0.51	0.31	0.53
17	0.59	0.37	0.47	0.86	0.65	0.71	0.75	0.48	0.57	0.58	0.48	0.52	0.75	0.61	0.82	0.51	0.30	0.50
18	0.55	0.37	0.42	0.80	0.56	0.68	0.74	0.47	0.56	0.58	0.47	0.52	0.73	0.57	0.81	0.50	0.30	0.50
19	0.53	0.35	0.41	0.80	0.55	0.66	0.73	0.46	0.55	0.56	0.46	0.52	0.72	0.57	0.80	0.50	0.30	0.50
20	0.53	0.35	0.40	0.78	0.54	0.61	0.71	0.42	0.55	0.56	0.44	0.51	0.65	0.55	0.78	0.49	0.29	0.46
21	0.51	0.34	0.38	0.78	0.52	0.60	0.71	0.42	0.54	0.56	0.43	0.49	0.64	0.55	0.78	0.47	0.29	0.46
22	0.51	0.33	0.38	0.73	0.51	0.59	0.63	0.41	0.52	0.55	0.43	0.48	0.61	0.50	0.74	0.47	0.29	0.44
23	0.51	0.31	0.38	0.71	0.49	0.59	0.61	0.40	0.52	0.55	0.43	0.48	0.59	0.47	0.70	0.46	0.27	0.43
24	0.50	0.29	0.38	0.70	0.47	0.58	0.56	0.38	0.48	0.55	0.42	0.48	0.57	0.47	0.65	0.45	0.26	0.43
25	0.48	0.28	0.37	0.68	0.44	0.58	0.56	0.33	0.46	0.54	0.41	0.47	0.57	0.44	0.61	0.45	0.26	0.42
26	0.48	0.27	0.36	0.67	0.44	0.56	0.55	0.33	0.45	0.53	0.38	0.47	0.57	0.43	0.60	0.44	0.26	0.40
27	0.46	0.26	0.36	0.65	0.43	0.53	0.54	0.31	0.45	0.52	0.37	0.46	0.56	0.42	0.57	0.43	0.24	0.39
28	0.44	0.26	0.35	0.62	0.43	0.51	0.54	0.31	0.44	0.52	0.35	0.46	0.55	0.41	0.55	0.43	0.24	0.38
29	0.41	0.24	0.35	0.60	0.41	0.49	0.52	0.30	0.42	0.52	0.35	0.46	0.55	0.40	0.52	0.43	0.24	0.36
30	0.40	0.23	0.35	0.59	0.40	0.48	0.49	0.29	0.42	0.50	0.34	0.45	0.55	0.38	0.51	0.42	0.24	0.36
31	0.39	0.22	0.35	0.58	0.39	0.48	0.48	0.28	0.41	0.50	0.32	0.45	0.52	0.35	0.50	0.41	0.23	0.35
32	0.39	0.21	0.35	0.57	0.38	0.47	0.46	0.28	0.41	0.50	0.30	0.45	0.52	0.34	0.49	0.40	0.23	0.35
33	0.38	0.21	0.35	0.57	0.36	0.47	0.46	0.26	0.40	0.50	0.29	0.45	0.51	0.34	0.48	0.38	0.23	0.35
34	0.38	0.20	0.34	0.56	0.36	0.46	0.45	0.26	0.40	0.49	0.28	0.44	0.51	0.33	0.48	0.38	0.22	0.35
35	0.38	0.20	0.34	0.55	0.35	0.46	0.44	0.25	0.40	0.47	0.28	0.44	0.51	0.33	0.47	0.38	0.22	0.34
36	0.38	0.20	0.34	0.53	0.34	0.45	0.43	0.25	0.39	0.47	0.27	0.44	0.50	0.32	0.47	0.37	0.22	0.34
37	0.38	0.20	0.34	0.47	0.34	0.45	0.43	0.24	0.39	0.47	0.27	0.43	0.49	0.32	0.47	0.36	0.21	0.34
38	0.38	0.20	0.33	0.47	0.33	0.44	0.43	0.24	0.39	0.46	0.25	0.43	0.48	0.32	0.45	0.36	0.21	0.33
39	0.37	0.19	0.33	0.47	0.32	0.44	0.42	0.23	0.39	0.46	0.25	0.42	0.47	0.31	0.44	0.36	0.21	0.33
40	0.37	0.19	0.32	0.47	0.32	0.43	0.42	0.23	0.38	0.45	0.25	0.42	0.47	0.31	0.44	0.35	0.21	0.33
41	0.37	0.18	0.32	0.46	0.30	0.42	0.42	0.23	0.38	0.45	0.25	0.41	0.47	0.30	0.42	0.35	0.21	0.33
42	0.36	0.18	0.32	0.45	0.29	0.41	0.41	0.23	0.38	0.45	0.24	0.41	0.47	0.28	0.42	0.35	0.21	0.33
43	0.36	0.18	0.32	0.44	0.29	0.40	0.41	0.23	0.37	0.45	0.24	0.41	0.47	0.25	0.41	0.34	0.21	0.33
44	0.36	0.18	0.32	0.44	0.27	0.38	0.40	0.23	0.37	0.44	0.24	0.40	0.46	0.25	0.40	0.34	0.21	0.33
45	0.36	0.17	0.32	0.44	0.27	0.37	0.40	0.22	0.36	0.44	0.23	0.39	0.46	0.25	0.40	0.34	0.20	0.32
46	0.35	0.16	0.31	0.42	0.26	0.37	0.39	0.22	0.36	0.44	0.22	0.37	0.46	0.24	0.39	0.34	0.20	0.32
47	0.35	0.16	0.31	0.41	0.26	0.36	0.38	0.22	0.36	0.43	0.22	0.36	0.45	0.24	0.39	0.34	0.20	0.32
48	0.35	0.16	0.30	0.41	0.25	0.36	0.38	0.21	0.35	0.43	0.21	0.36	0.45	0.23	0.37	0.34	0.20	0.32
49	0.35	0.16	0.29	0.40	0.25	0.35	0.38	0.21	0.35	0.43	0.21	0.35	0.45	0.23	0.37	0.34	0.19	0.31
50	0.35	0.15	0.29	0.39	0.24	0.35	0.37	0.21	0.35	0.43	0.21	0.35	0.45	0.22	0.36	0.33	0.19	0.31
51	0.34	0.15	0.28	0.38	0.23	0.35	0.37	0.20	0.35	0.41	0.20	0.35	0.44	0.22	0.36	0.33	0.18	0.30
52	0.34	0.15	0.28	0.38	0.22	0.35	0.37	0.20	0.35	0.41	0.20	0.35	0.43	0.22	0.36	0.32	0.18	0.30
53	0.34	0.15	0.28	0.38	0.21	0.34	0.36	0.20	0.34	0.39	0.20	0.34	0.43	0.22	0.35	0.32	0.18	0.30
54	0.34	0.15	0.28	0.38	0.21	0.34	0.36	0.20	0.34	0.39	0.20	0.34	0.42	0.22	0.35	0.31	0.18	0.30
55	0.34	0.15	0.27	0.38	0.20	0.34	0.36	0.20	0.33	0.39	0.20	0.33	0.41	0.21	0.35	0.31	0.17	0.30
56	0.33	0.15	0.27	0.38	0.20	0.34	0.35	0.19	0.33	0.39	0.19	0.33	0.40	0.21	0.35	0.31	0.16	0.30

Figure 10. Charge transfer through MO LSA resulting from 1000 lightning strokes samples following a tailored stroke distribution

Category	Parameter	Value	Unit	Notes
<u>General Simulation Parameters</u>	Total Samples	1000	-	Monte Carlo Statistical Method
	Total Operations	5509	-	Gap sparkover
	GFD (flash/km <sup>2</sup> /y)	4	flash/km <sup>2</sup> /y	Ground Flash Density
	WE (m)	72.97	m	Line Shadow Width (attraction corridor)
	NL (Expected strokes on line)	29.1	stroke per year	Hitting the Line Shadow Width
	1000 samples represent	34.36	years	-
<u>Line Parameters</u>	Line Length	100	km	-
	Average span	0.175	km	-
	Number of Poles	571	-	Assuming installation on every pole and every phase
<u>EGLA (MO LSA) Analysis</u>	Failure condition	-	-	Damageable by lightning when charge exceeds 0.4C
	Number of EGLA on the line	1714	-	Assuming installation on every pole and every phase
	Qrs charge transfer ratings	0.4	C (Coulombs)	200µs waveshape, typical distribution class surge arresters
	One EGLA failure every	0.057	years	-
	One EGLA failure every	20.8	days	-
	Expected failures in 34.36 years	603	-	Numbers of failures if >0.4C
<u>SAS Analysis</u>	Failure condition	-	-	Cannot be damaged by lightning, but can be damaged by exceeding a certain number of operations
	Number of SAS on the line	1714	-	Assuming installation on every pole and every phase
	Guaranteed numbers of operations	5	-	Incl. safety factor (test reports show higher numbers)
	Expected operations per SAS after 34.36 years	3.21	-	Considering homogeneous distribution of lightning strikes along the line
	Expected operations per SAS after 34.36 years incl Aggravating factors (worst case)	4.28	-	lightning strikes only 75% of the line, not homogeneous

Table 1. Detailed results of the lightning simulations

### e) Preliminary Conclusion

As illustrated in Figure 10 and Table 1, the following results can be observed:

1. Over a 35-year period, approximately 600 MO LSA units are projected to fail due to excessive charge transfer from high-amplitude lightning strokes, representing 35% of the total installed units.
2. SAS theoretically exhibit zero lightning-induced failures with an expected average number of operation per device of 4.28 over . However, an estimated 175 SAS failures could occur, assuming a constant failure rate of 5 units per year. This worst-case scenario accounts for potential external factors such as physical damage and wind-induced stress, as well as a more critical lightning stroke distribution with a higher frequency of high-amplitude strokes.
3. The comparative lifetime performance of MO LSA and SAS integrations extends beyond lightning statistics, encompassing a more complex set of variables.
4. While utilizing larger MOV diameter (Station Level type, approximately 48mm or larger) can significantly reduce MO LSA failures, this approach necessitates a higher initial capital investment compared to distribution class units. It is noteworthy that MO LSA manufacturers have not optimized their product portfolios for applications requiring high charge transfer ratings.
5. Given the absence of comprehensive performance data over a 35-year period for current MO LSA or SAS designs used in distribution networks, several additional factors warrant consideration:
  - a) Gapped vs. Non-Gapped Arresters: This remains a contentious issue within the industry. The continuous voltage stress on Non-Gapped Lightning Arresters (NGLA) impacts life expectancy, a factor insufficiently addressed by international standards for large-scale, mass-produced projects.

- b) **Comprehensive Studies:** Further research is essential to align Qrs (Repetitive Charge Transfer Rating) with lightning parameters, particularly for applications on unshielded lines.
- c) **Future Standards for SAS:** Manufacturers must reliably guarantee a minimum number of operations to facilitate accurate life-cycle cost assessments.

## 6. Global Market Overview

### a) Current Market Landscape

The market for SAS technology, a specialized application for distribution overhead lines and higher voltages, is discrete yet well-established. Global estimates indicate approximately 3 million SAS units in operation, predominantly deployed on networks up to 154kV, with some applications extending beyond this range. SAS devices have gained increasing significance in distribution networks, particularly as MO LSA manufacturers have been unable to fully meet all market demands.

SAS technology has been globally deployed for over 25 years to enhance lightning performance on overloaded lines:

- **Japan:** More than 120,000 units have been installed on networks up to 77kV since 1994, with notable applications on 154kV networks as well.
- **CIS countries, including Russia and Kazakhstan:** Approximately 2.5 million units have been in operation on networks up to 35kV since 1999. It is noteworthy that SASs have seen increased traction on high-voltage networks up to 110kV since 2009.
- **China:** The technology has gained traction since 2012, with over 200,000 units installed on networks up to 35kV.
- **Other regions, such as Vietnam and Indonesia:** An estimated 100,000 SAS units have been installed since 2012.

In total, current estimates suggest nearly 3 million SAS units are operational worldwide.

## b) National Standard and Existing Specifications

Despite its growing adoption, SAS technology has remained relatively isolated geographically. A key challenge impeding its international adoption is the absence of standardization according to IEC or IEEE international standards.

China has taken steps toward standardization, notably with the creation of the Chinese Society for Electrical Engineering (CSEE) standard T/CSEE 0082-2018, known as a group standard, and the DL/T 2110—2020, known as an industry standard. These standards outline general technical requirements for multi-chamber gap (MCG) lightning protection devices used in medium-voltage distribution lines, as well as other devices used in high-voltage applications. The implementation of these standards demonstrates China's commitment to ensuring the quality and safety of SAS technology while promoting its widespread adoption across the nation's power distribution infrastructure.

In 2021, the Russian national grid organization, PJSC ROSSETI, adopted the standard STO 34.01-2.2-037-2021, titled “Line Lightning Protection Devices for 6-110 kV AC overhead power lines”. While this standard specifically applies to LLPDs, it is significant that LLPDs represent 99.9% of the SAS market in Russia. This demonstrates that aligning SAS with common regulatory requirements is feasible.

In Japan, SAS technology primarily adheres to national specifications. The technical literature refers to FCIAH devices for “Fault Current Interrupting Arcing Horns”.

As will be discussed in the conclusion, concerted efforts toward standardization are crucial for establishing an international standard that engages all stakeholders in the field.

## c) Case Studies in Malaysia

Malaysia provides an insightful case study for the integration of SAS technology into power distribution networks [6]. Initially, MO LSAs were deployed on distribution lines in accordance with the IEEE 1410 Guide. However, multiple failures were reported, attributed to various factors such as grounding conditions, soil resistivity, and specific surge arrester requirements.

These challenges prompted the Malaysian Distribution System Operator to explore alternative solutions, leading to the adoption of SASs.

The implementation of SAS technology in Malaysia has proven both reliable and effective, successfully addressing the unique challenges inherent in the country's power distribution infrastructure. This experience underscores the versatility and value of SASs, highlighting their capability to meet diverse market needs and enhance the resilience of power distribution systems.

Malaysia's experience serves as a crucial case study for other nations considering the inclusion of SASs in their power distribution strategies. It warrants significant attention from MO LSA manufacturers and emphasizes the need to assess certain technical characteristics of MO LSAs used in the network, including but not limited to technical specifications, design, and product quality (root cause analysis).

Month	Count	Negative Count	Positive Count	Minimum Peak Current (kA)	Maximum Peak Current (kA)	Average Peak Current (kA)
June	22	21	1	3.20	52.50	14.45
July	451	443	8	3.35	97.40	20.24
August	207	205	2	5.18	86.95	18.43
September	52	51	1	6.09	75.52	19.49
October	39	37	2	6.05	54.83	16.29
November	716	686	30	4.13	178.21	20.96
December	318	315	3	3.83	91.21	20.40
Total	1805	1758	47			18.61

Figure 11. Report Lightning near line of interest for case study in Malaysia



Figure 12. Installation of SAS by Malaysian DSO

## 7. Conclusions

In the domain of lightning protection for power systems, both MO LSA and SAS technologies present distinct advantages and challenges over an estimated 35-year lifespan, as examined in this study. While comprehensive research incorporating additional aging factors and system constraints would be valuable, resource limitations constrain such extensive analysis. MO LSAs exhibit vulnerability to high-amplitude lightning strokes, with failure rates approaching 35% of installed units under conducive conditions. Conversely, SAS technology demonstrates negligible failures attributable to excessive lightning charge transfer. A 2009 CRIEPI report documented 9 failures among 115,900 SAS units in Japan over approximately 20 years, further supporting this observation.

It is imperative to approach this comparison with scientific rigor and methodological precision, acknowledging that the issue transcends mere lightning statistics. While MO LSA failures can be mitigated through the implementation of larger MOVs, this solution necessitates increased capital investment. SAS units, however, offer superior charge transfer ratings and an ergonomic design that facilitates integration, potentially yielding lifecycle cost advantages. Nonetheless, both technologies are subject to multifaceted complexities not fully elucidated in this paper, warranting further investigation to provide a comprehensive evaluation of their respective merits and limitations in power system protection.

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