

Externally-Gapped Line Arrester Technology: Background, Development & Future Directions

Florent Giraudet – METARRESTERS Consultant – florent.giraudet@metarreesters.com

INMR Berlin 2022

Introduction

This paper deals with the Externally-Gapped Line Arrester (EGLA) technology as the most effective and suitable Line Surge Arrester (LSA) design to meet the requirements of overhead lines. While the use of EGLAs is not yet fully understood and adopted by the electricity supply industry, we strive to provide experience feedback on the long term. Indeed, the example of Japan is very relevant and deserves to be communicated more widely.

Although the technical superiority of EGLA is emphasized in this paper, the operating principles and differences between EGLA and Non-Gapped Line Arrester (NGLA) are not compared here, this has been covered in various other technical papers. The facts about adoption in the precursor countries are sufficiently striking to call into question certain practices today.

We consider that the basic principles of lightning outages mitigation are understood by the reader. Multiple publications exist to demonstrate the technical-economic advantages of LSAs in reducing lightning induced outages.

The idea of this document is to have a retrospective vision, to analyze the EGLA technology and the use of today and specially to project ourselves in the years to come to understand how the EGLA can influence the power transmission industry and facilitate the energy transition. We have noticed a lack of communication in the last 30 years about this kind of application, so we want to make it possible for everyone to understand.

1. A historical introduction to the ZnO technology

Until the 1930's, surge protections were simple spark-gap type arresters made of aluminum cells with additional oxide film. After the 2nd World War, resistor valve types arresters made of Silicon Carbide (SiC) elements and series gaps was largely used.

With the rapid development of power grids and the increase in voltage levels during the 20th century, protection against switching surges has become a more critical issue than lightning surges. A magnetic blowout feature was developed to effectively reduce the AC follow current but it was impossible to eliminate completely the follow current as long as SiC elements were used (1). Moreover, the performance of SiC Arresters was affected by multiple lightning strikes and the existence of series gap had an effect in regards to stable discharge characteristics.

In the 1970's, the energy supply industry has undergone an important technological development with the GIS switchgears and UHV 1,100kV systems. Those complex SiC devices were not able to satisfy the requirements and therefore ZnO gapless surge arresters had the inherent properties to enable the next evolution.

A certain Misao Kobayashi who worked at Meidensha Corporation in Japan was the pioneer engineer in the development of the ZnO technology. For these reasons, Meidensha is known to have discovered and developed the technology around the world. The diagram below (Figure 1) shows the different evolutions and major steps that were necessary before arriving at the ZnO technology used today in all surge arrester industries.

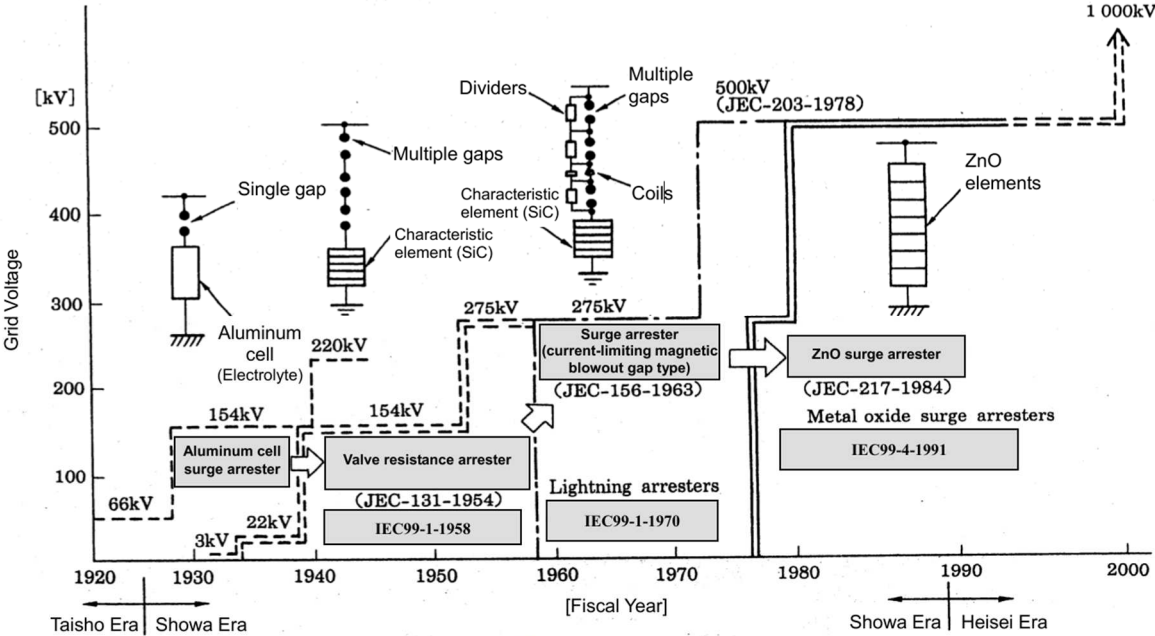


Figure 1. Historical Diagram of Surge Arresters technologies (1)

The first prototypes of ZnO blocks were facing technical difficulties in regards to life expectancy, withstand capability of the continuous operating voltage and its power losses. First ZnO blocks were showing degrading performance with increase power losses over time. Meidensha Corporation rapidly tackled the ZnO composition and manufacturing process to make the ZnO blocks resilient to a permanent voltage which shows decreasing power losses with time.

These installations below (Figures 2 and 3) highlight the ability of the 2nd generation of ZnO blocks to meet the lifetime requirements.

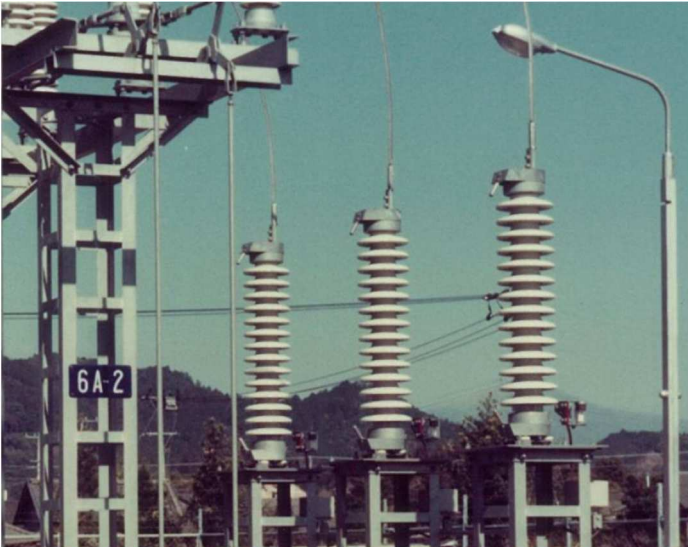


Figure 2. The first ZnO surge arrester in the world: Hayato Substation of Kyushu Power Co: 66 kV heavy pollution type, Japan 1975 (1)



Figure 3. 500kV MOSAs at Manitoba Hydro AC-DC converter stations still in operation (installation 1979). Courtesy of Manitoba Hydro

2. LSA development: a Japanese story but also American

Japan starts ...

As Japan has developed the technology of ZnO arresters and the country is particularly concerned by the instability of the power grid due to lightning strikes, it is in Japan that the first application of LSA was born. The Japanese electric utility, Shikoku Electric Power Co. pursue efforts from 1972 to 1975 to develop LSA with the Silicon Carbide (SiC) Technology. The results of the conducted field tests were not satisfactorily (2). We assume here that the challenge was to achieve the required protection level with SiC which is much higher than ZnO. Also, the frequency of lightning discharges had a direct impact on the performance and the life expectancy.

As described in the historical introduction, the ZnO technology was developed and introduced in the latter half of 1970's. It was initially used for substations but rapidly adapted on power transmission lines. According to available historical sources, the first use of Line Surge Arresters was in 1980/1981 on a 77kV line in Japan with gapless types (NGLA) (2)

EGLA was first applied to 6.6 kV distribution lines in Japan in the early 1980s (no accurate source).

Directly afterwards, the first EGLA for 66/77kV transmission lines was applied in 1985. The Figure 4 below shows the installed numbers of LSA's in the 1980's, we can see the rapid trend for EGLAs and the subsequent abandonment of NGLAs. In 1988, nearly 4500 EGLA units were in operation in Japan.

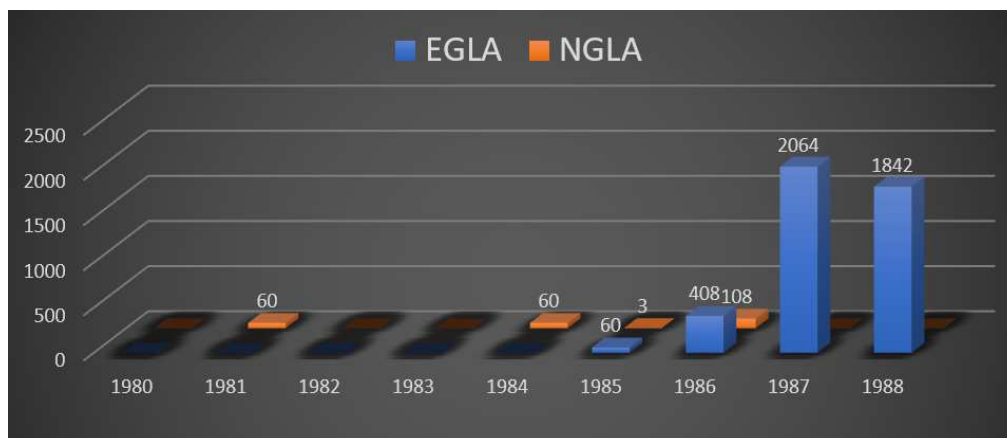


Figure 4. LSA installations in Japan in the 1980's (3)

The reason for choosing the EGLA over the NGLA is supported by various technical reasons which made it the right application for overhead lines. Some key elements are described in the paragraph 4.

One of the difficulties that Japanese manufacturers and utilities faced was on how the external series gap could be designed with existing insulator assembly to be protected effectively. For that reason, the EGLA development in Japan is marked by **two major generations**. The first generation with SVU (Series Varistors Unit) generally installed on the cross-arm known as conventional and the second generation known as compact to facilitate integration on insulators string which replace arcing horns.

In the 1990's, new compact EGLA designs have been developed due to technical and market requirements but also thanks to the latest improvement in surge arresters manufacturing that allowed lower costs and material. Those developments were strongly supported by the important growth of the country and the rapid development of the economy and social needs for higher quality electric power supply.

This compact version has been released from 1999 by reexamining the discharge capability and therefore by reducing the diameter of ZnO blocks. Indeed, since most of the transmission are

effectively shielded, the lightning current goes mainly to the ground in comparison to a shielding failure where the lightning current goes mainly through the EGLA. By reconsidering the shielding effect, the reliability and the performance of overhead ground wires (OHGW), an ultimate reduction of the ZnO blocks was possible without affecting the failure rate. Of course, this achievement is also possible because the EGLA is not continuously under voltage in comparison to NGLA, which allow smaller ZnO stacking without TOV and switching constraints.



Figure 5. Conventional EGLA type (1st generation) (2)

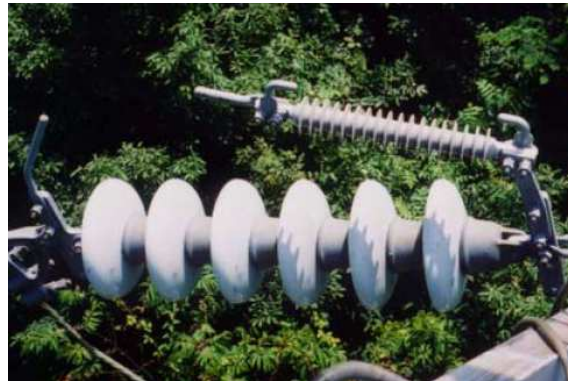


Figure 6. Compact type since 1999 (2nd generation) (2)

The other key point in the evolution of the compact version is the method of installation and integration that replaces the arcing horns of the insulator strings. This development is actually very important and should be highlighted. Many users worldwide over the past 20 years who have attempted to use EGLAs on pilot projects have been discouraged because of the need to ensure a stable air gap. Since most lines never anticipated an EGLA installation, integration initiatives were quickly curtailed due to the difficulty of integrating SVU and air gap into the insulator string. The Japanese have understood this from the beginning. The interaction between the line designers and the surge arrester specialists allowed for an adaptation and thus an intelligent integration. When the SVU is rigidly fixed on the strings, the gap remains stable and is not affected by the wind swing on the phase conductors. Since the compact version, we could say that EGLAs have become a standard component for overhead lines in Japan.

The same is true today for South Korea, which has more than 150,000 EGLA units on its network. The tenders are issued only for the SVUs. The rest of the hardware and integration is the responsibility of the power utility who turn this application into standard components for overhead lines.

[USA innovate in the same time ...](#)

The story in the United States is quite different. As curious as it may seem, the first ZnO Line Surge Arrester installation in the USA is in fact an EGLA. A rather strange fact because following this pilot project in 1985, all American manufacturers have developed and used NGLA across the country.

The arrester was designed by General Electric and a limited number of them were installed on an experimental basis on 138-kV lines of American Electric Power. The design was quite good and performed well, but was very expensive to manufacturer and was not continued as a commercial offering. We can see on the picture below that this “rigid” design includes an insulator for the gap.

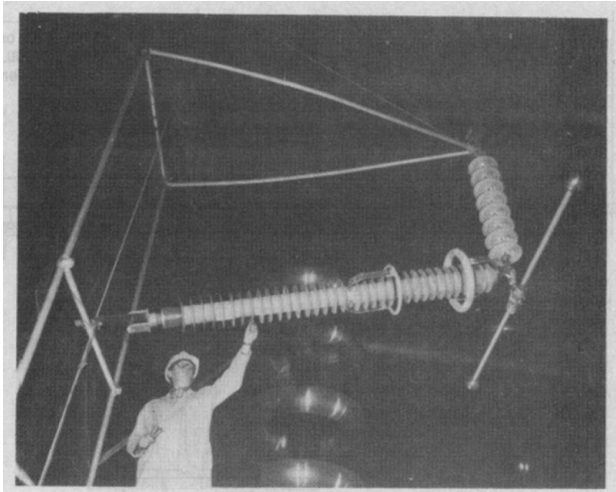


Figure 7. First EGLA 138kV mounted on a simulated tower for HV tests – USA 1985 (4)

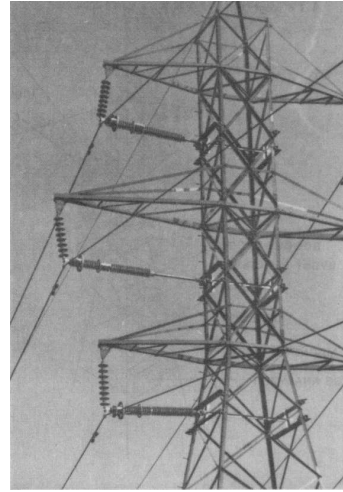


Figure 8. First EGLA in USA mounted on a suspension tower in 1985 - APCo grid (4)

3. Service experience from Japanese utilities

As per 2009 data (2), almost 365,900 units are installed in Japan. 120,000 units are not EGLA types but simply Current Limiting Gaps (CLG*) specifically used for low voltages (77kV and below). Therefore, we can estimate about **250,000 EGLA units in operation in Japan since the 1980's**.

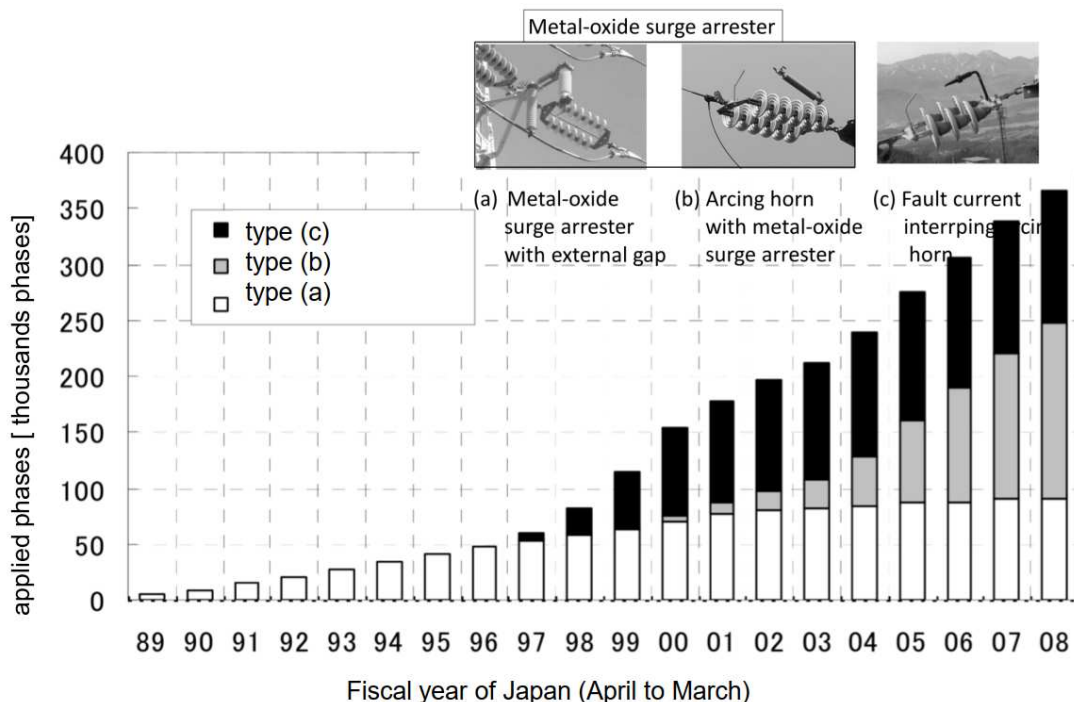


Figure 9. 20-year history of EGLA installation in Japan. Source: CIGRE SC B2 XWG3 / CRIEPI report 2009

Dedicated monitoring of EGLA units does not apply in Japan. Regular inspections are performed on transmission towers, insulators and therefore on EGLA in the meantime.

Japanese utilities and grid operators are also able to localize a fault when a lightning induced outage is detected. Lightning Location Systems can provide accurate information about the impact of strokes and its amplitude. When detection systems provide suspicious information, a maintenance team can be sent on site to verify the condition of the EGLA units. Since the EGLA gap isolates the failed SVU from the system, a failure does not impact immediately the grid and can be replaced in the next few days without emergency.

Luckily, a lot of precious data from EGLA application and lightning induced outages are available in Japan and can be accessed through the CRIEPI report (last version from 2009). It shows that statistical information in Japan are pretty accurate and complete.

3 main types of failures have been reported within 20 years between 1989 and 2008:

- SVU Overload/Failure due to an excess of lightning discharge current above the nominal charge/current ratings (predictable failure rate)
- SVU Overload/Failure due to a fluctuation of the EGLA gap mainly caused by an inappropriate tightening process of bolts/nuts during assembly.
- SVU polymer housing has been eaten by birds which is not a proper failure but the SVU should be replaced since the follow current interruption is no longer guaranteed.

Over 20 years, the total number of overload/failures reported on a total of 365,900 units is 55 units!

This is an extraordinary figure that should make you think about the EGLA technology and its reliability in improving the lightning performance on transmission lines compared to NGLA.

These figures must be put into perspective because there are 3 types of designs:

	Type (a) EGLA 1st generation	Type (b) EGLA compact 2 nd generation	Type (c) Current Limiting Gaps (CLG)
Approx. Quantity	90,000	160,000	115,900
Overload/Failure	10	36	9
Bird deterioration	0	19	0

Table 1. Overview of EGLA failures in Japan over 20 years operation (2)

CLG are not discussed in this paper since there are not EGLA. Their active part is not made of ZnO blocks but of several small gaps in series. The function is similar but the performance cannot be compared.

If we look at the modern EGLA type (compact) made of light-weight polymer housings and optimized ZnO blocks sizes, only 36 failures have been found for 160,000 units installed across the country for a period of 10 years. It should be noted that installations were made progressively and time of failure occurrence has not been reported. Bird deterioration is not considered since it is inherent issue of polymer material not specific to EGLA application.

Failure rate EGLA Compact = 0.0225 failure / 1000 units / year

In view of the statistical information on failures, there are countermeasures to easily reach low failures rates close to zero by adapting the charge transfer capability of SVU and improve the tightening system of the EGLA sets (better design/ extensive vibration tests)

It is relatively rare to find statistical information on failure rates because problems are not often reported systematically, even more so at the level of an entire country. The CRIEPI report statistics are probably the most complete over a period of 20 years concerning LSA's.

In order to make a proper analysis, comparisons should be made with other countries using NGLA arresters. This is not the purpose of this paper, but it could be the subject of a separate study. We can just rely on field experience and intuition at this stage. **NGLA failures are much higher!**

4. Why is the EGLA often considered a more advanced superior design than the NGLA?

As described in the history of EGLA in Japan, its adoption and its development were mainly driven by a technical superiority. Other countries have integrated EGLA technology quite quickly in the early 2000s such as Mexico and France, which has provided high satisfaction and massive usage thanks to its reliability. There is no country that has changed its strategy by going back to NGLA technology while we regularly see countries that used NGLA now switching to EGLA technology.

The technical debate and argumentation are often biased for commercial reasons as not all surge arrester manufacturers have a complete EGLA portfolio. The 2 technologies are often put on an equal level in order not to be penalized, which is also understandable.

Today, NGLAs still suffer from a relatively bad reputation because of mechanical failures involving lead cables, disconnectors, or some of the accessories required for their installation. Although the new 60099-11 standard will address these problems, the failure rates of NGLAs are still much higher than those of EGLAs. It is therefore an obstacle to LSA's widespread adoption.

The EGLA design is much more suitable for use on overhead lines that are constantly solicited by vibration and difficult climatic conditions. During a thunderstorm or severe weather event, the probability of a temporary overvoltage (TOV) or switching surges stressing the LSA following lightning discharges is higher and could affect an NGLA which has a main function to address lightning overvoltages. An EGLA will eliminate the lightning fault but will remain insensitive to TOV and switching surges thanks to its air gap. Also the air gap isolation ensures a successful re-closing operation even if the arrester body has failed.

The air gap is a simple and robust feature that provides essential properties to the operation of the EGLA for long term reliability. The ZnO blocks are only used when necessary, the rest of the time the SVU is not subjected to any electrical stress.

It should also be noted that the current IEC 60099-8 standard for EGLA already covers testing for artificial pollution (follow-current interruption test) and vibration fatigue resistance while NGLA has not evolved yet.

The EGLA design provides an attractive advantage of no deterioration on arrester housing and ZnO blocks due to continuous energization, which enables the establishment of compact light-weight designs. In simple words, it means that TOV handling would require more ZnO blocks and switching handling would require larger ZnO blocks. Silicone rubber material can also be reduced due to the absence of tracking and erosion process (lower creepage distance).

Thus its isolation from the system also gives it the possibility to reduce the active part to its bare minimum. This allows different options to integrate the EGLA in a harmonious way onto the transmission line. We also see a wider range of possibilities for installation or maintenance in live conditions. The air gap provides a safety distance required for this special work. The pictures below of Figure 10 and 11 show a typical assembly process (trial) in France where EGLA ensure a proper installation according to national safety regulations for live line work.

The ultimate argument also remains its cost. Although some users may have seen higher prices than NGLA for market reasons, EGLA requires less material to be produced. Thus, these manufacturing costs remain more attractive than NGLA.



Figure 10. 225kV EGLA design for live line installation.
Courtesy of RTE.



Figure 11. 225kV EGLA design for live line installation.
Courtesy of RTE.

5. Major recent achievements and outstanding EGLA projects

Canada leads the way ...

East West Tie Project in Ontario Canada has paved the way for an elegant and smart EGLA integration of the line design stage to tackle the terrible rocky soil condition in northern Ontario in order to achieve low footing resistances on tower structures. This innovative project has made it possible to transmit stable energy over more than 450 km to indigenous communities in remote areas. The double circuit 230-kV line was energized in April 2022. This smart integration in the design phase of the line coupled with the use of the most advanced solutions allows to redefine the construction costs and even their environmental impact.

More than 3700 EGLA units have the primary function to eliminate completely double circuit outages and significantly reduced single circuit back-flashovers. It is also the first-of-its-kind EGLA application on large scale in North America that will open the door to a better understanding of the technology and hopefully a larger adoption across the USA and Canada.



Figure 12. 230kV EGLA one body design on V-string configuration. Courtesy of NextBridge.



Figure 13. 230kV EGLA two body design on I-string (jumper) configuration. Courtesy of NextBridge.

USA back on track with EGLA...

American Electric Power has initiated a pilot project in 2019 to equip a 765kV transmission line with first of its kind EGLA solutions. Manufacturers have had to become more ingenious in order to offer discreet and practical integration into the existing line. The EGLA 765kV are in operation since summer 2021.

The financial consequences of lightning induced outages on such critical transmission lines are enormous. AEP is looking carefully at those innovations solutions to ensure stable and interrupted power supply and prevent grid instability. Furthermore, the increased reliability allows an increased supply capacity of electricity, a key argument for such UHV transmission lines. Again, modern composite surge arrester designs allow for maximum charge transfer capability while minimizing weight and visual impact. EGLAs are also an attractive solution for live line installation, an increasingly common practice to reduce the impact of maintenance work.

US utilities were familiar with NGLA application, they are thousands of NGLA in operation across the country. Nevertheless, the advantages of EGLA technology have made its selection mandatory for an application on 765kV system. This also the first EGLA development worldwide at this voltage level. It should be noted that China already developed EGLA for 800kV HVDC system.

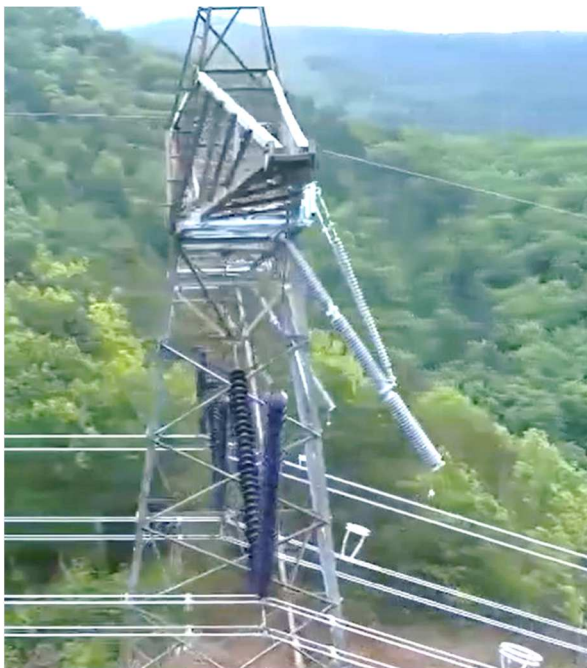


Figure 14. 765kV EGLA one body design on V-string configuration

Source: Siemens Energy LinkedIn Video



Figure 15. 765kV EGLA "rigid gap" hanging from the conductor of a dead-end insulator

Source: Hitachi Energy LinkedIn Video

Turkey embarks on LSA application and chooses the EGLA ...

In 2020, it was Turkey's turn to implement its first LSA pilot project, which involved the installation of a hundred 170kV EGLAs on a critical network node. This discreet integration is noticeable and also facilitates the installation on the existing line. Insulator/EGLA solutions are a convincing design to achieve cost optimization and above all to allow reliable stability of the EGLA spark gap which remains a critical point for insulation coordination.

The satisfaction of the pilot project will bring confidence to the grid operator and will allow to plan more important investments on the Turkish grid in a serene way.



Figure 16. 170kV EGLA two body design on I-string configuration (suspension)
Source: GROUND2020/21 & 9th LPE Brazil



Figure 17. 170kV EGLA two body design on a double tension configuration
Source: GROUND2020/21 & 9th LPE Brazil

After a few years of experience, Vietnam invests heavily...

The relatively massive adoption in recent years of EGLAs in Vietnam also shows the confidence given to the technology with gap. The Vietnamese power grid is particularly concerned by lightning-related outages. Between 2018 and 2020, the national grid operator has launched several tenders for the first time for the supply and installation of EGLA 220kV and 500kV. It is interesting to note that the quantities recently applied on the 500kV grids are almost 3 times higher than the total amount of 500kV EGLAs installed on the Japanese grid since 1990. This is due to the democratization of technology, design optimization, cost reduction, smart integration and a global strategic approach.

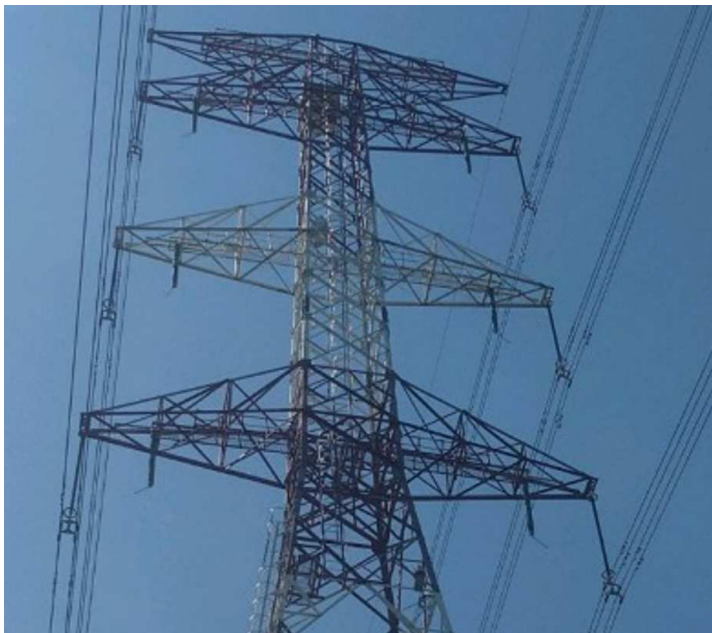


Figure 18. 500kV EGLA one body design on I-string configuration.
Courtesy of EVN Vietnam.

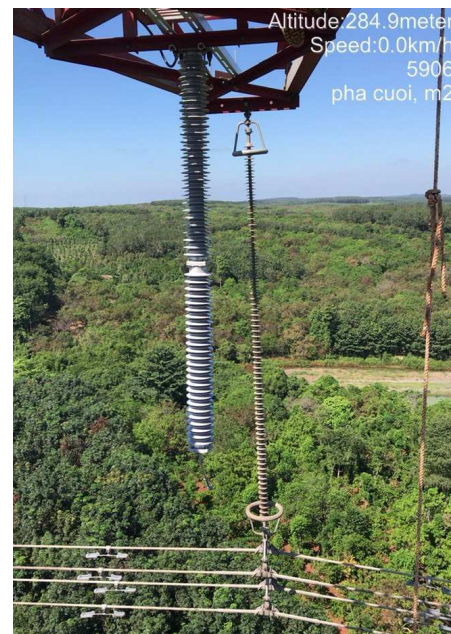


Figure 19. 500kV EGLA one body design on I-string configuration. Courtesy of EVN Vietnam.

6. Current improvement in TC 37/PT 60099-11

Besides the recent release (December 2021) of the CIGRE Technical Brochure 855 about LSA's application providing a global and complete picture in 170 pages, the working group TC 37/PT 60099-11 is currently preparing the future standard for LSA's covering both EGLA and NGLA application. This is a standardization that will be stamped with the dual IEC/IEEE logo, so we are getting closer to full harmonization.

Over the years, major claims have been issued by CIGRE working groups, user's experience feedbacks, local committees and diverse contributions through international congresses and conferences about the reliability and failure rate of NGLA, especially in regards to mechanical considerations. NGLA applications haven't their own standard. They must refer to IEC 60099-4 or IEEE 62.11 (Station / Distribution Classes), therefore mechanical considerations are not covered by suitable testing methods. Indeed, LSA's are installed and operated under harsher service conditions than other surge arresters. They are routinely exposed to high winds and motion due to line swinging and vibration. LSA's are typically exposed to more extreme weather than arresters in a substation. Hence, the complete arrester assembly is permanently stressed over its lifetime. Many utilities and grid operators have reported early defects on the leads (flexible cable often associated with the disconnecter) and the clamping systems. Vibrations induced movements and various conductors' motions are not considered in existing standards in regards to mechanical testing.



Figure 20. Broken ground lead disconnecter NGLA (5)

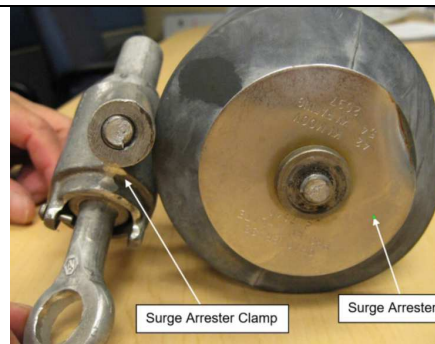


Figure 21. Broken clamp NGLA (5)

EGLA applications have their own standard with IEC 60099-8 which is satisfactory until today but still insufficient. The subject of LSA's must be treated as a whole and therefore requires a merge with the NGLA. Vibration tests already exist for EGLA but the "mechanical tests" section will be expanded to cover LSA specific failure modes.

Beyond the terms and definitions that must be adapted to allow international understanding (e.g. MCOV vs U_c), the future standard will propose a major harmonization to simplify the energy classification of the different types of LSA's.

It will be required to classify LSA's by using 2/20 μ s waveshape based on field experience and system studies on overhead lines applications. It is also used for decades in the Japanese standards and IEC 60099-8 (Y Class) for EGLA Applications. The latter is by definition directly designed to consider the lightning phenomena on the overhead lines, the EGLA not being used in the substations.

	Distribution & Transmission Lines Used for Lightning Performance Improvement – reduction of lightning induced outages					
New LSA Designation	L6	L5	L4	L3	L2	L1
Equivalence Station IEC	SH	SM	SL	DH	DM	DL
Equivalence Station IEEE	Station F/G	Station E	Station C	HD	ND	LD
Equivalence EGLA	(Y4)	(Y3)	(Y3)	(Y2)	(Y2)	(Y1)
Nominal Discharge Current 2/20 μ s	20 kA	15 kA	15 kA	10 kA	10 kA	5 kA
High Current Impulse 2/20 μ s	65 kA	40kA	40kA	25kA	25kA	10kA

Figure 22. New proposal of energy classification for Line Surge Arresters (EGLA & NGLA) in PT 60099-11

The global idea remains simple and logical since all LSA's currently in operation have been mainly designed from standard Distribution or Station Class applications. The concept consists in merging both Station & Distribution in one single unified table to cover all LSA types for lightning performance related applications.

2/20 μ s waveshape results from concrete lightning studies based on CIGRE lightning current parameters and observational results of lightning currents on transmission towers.

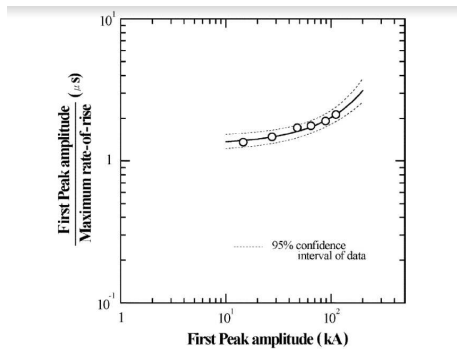


Fig. 18. Relationship between first peak current and front duration defined by "first peak amplitude/maximum rate of rise."

Figure 23. Measured lightning currents from observational towers.

TABLE IV PARAMETERS FOR EMTF CALCULATION		Table A.1 – Tabulated values of lightning current parameters taken from CIGRE (Electra No. 41 or No. 89) [5] [9]						
Item	Parameter	Parameter	Fixed values for LPL 1	Values	Type of stroke	Line in Figure A.3		
Lightning	Impedance of channel	400 Ω	50	4*	20*	5*	1st negative short*	
	Wave shape	2/70 μ s ramp wave	300	4.6	11.5	29.5	Subsequent negative short*	
Tower	Location of striking	① Tower top ② G.W. (mid span) ③ Conductor (at tower) ④ Conductor (mid span)	300	20	20	80	350	First positive short (congr.) Negative flash Positive flash
	Height	G.W. Upper phase Middle phase Bottom phase	40.0m 36.7m 33.9m 31.5m	1.1	4.5	20	First negative short	
	Surge propagation		210m/ μ s	0.22	0.96	4.1	Subsequent negative short	
	Surge impedance		270 Ω / 150 Ω	100	2	18	150	First positive short (congr.) First negative short
	Footing resistance		10 Ω	6	50	1000	First negative short	
	Span		300m	0.55	6	52	Subsequent negative short	
	G.W.	Nos. of wire	1	10 000	20	800	10 000	First positive short
		Resistance	1.27 Ω / km	8.1	24.3	65	175	First negative short*
		Surge propagation		8.9	39.9	181.5	Subsequent negative short*	
		Surge impedance		20	5.2	2.4	92	First positive short
Power Conductor	Resistance	0.089 Ω / km	200	4.1	20.1	98.5	Subsequent negative short*	
	Surge propagation		200				Long	
Line arrester	Nos. of bundle	1	0.5				Long	
	Series gap length	550mm	1.8	5.5	18	18	First negative short	
Line arrester	Nos. of circuit line	1 of 2 circuit lines	0.22	1.1	4.5	4.5	Subsequent negative short	
	Phase	All 3 phases	5.2	20	200	200	First positive short (congr.) First negative short	
Line arrester	Series gap length	550mm	0.5	32	140	140	Subsequent negative short	
	Phase	All 3 phases	25	250	2 000	2 000	First positive short (congr.) Multiple negative strokes	
Line arrester	Series gap length	550mm	7	33	150	150	Multiple negative strokes	
	Phase	All 3 phases	0.15	13	1 100	1 100	Negative flash (all)	
Line arrester	Series gap length	550mm	31	180	800	800	Negative flash (without angle)	
	Phase	All 3 phases	14	65	500	500	Positive flash	

Figure 24. Input of lightning current parameters from CIGRE

The Nominal discharge current with 2/20 μ s waveshape is usually the expected figure of lightning peak current magnitude through LSA in service. Typically, it refers to a discharge current magnitude due to lightning stroke on tower top or on the shield wires (back-flashover).

High Current Impulse with 2/20 μ s waveshape represents the maximum allowable lightning peak current magnitude through LSA in service. Typically, it refers to a discharge current magnitude due to a direct stroke on power conductors (shielding failure).

Another major evolution and improvement is the implementation of a proper testing protocol to cover effectively the LSA's charge transfer (Qrs) and thermal charge (Qth) resulting for lightning discharge currents.

Over 70% of lightning ground flashes have multiple strokes with few milliseconds intervals which is far smaller than the thermal time constant of the arresters in the order of minutes or even hours.

Utilities and engineering consultants generally perform specific system studies that can estimate the energy absorption and/or charge transfer ratings through LSAs. IEC/IEEE standards defines a series of type tests to provide confidence to the users that LSA's will not fail due to an energy/charge excess

of their ratings. Therefore, manufacturers have the duty to follow the standards and perform the appropriate tests to guarantee the expected performance.

The annex H in IEC 60099-4 includes already for a couple of years different testing requirements in regards to LSA's application. An impulse duration of 200µs has been considered as a suitable compromise to cover both the typical application and the effect of multiple strokes. Arresters intended for LSA applications shall be tested in accordance with the lightning impulse discharge capability test to verify the rated lightning impulse discharge capability of the arresters.

The test to verify the repetitive charge transfer rating (Qrs) with a 200µs impulse duration has been integrate into the EGLA standard IEC 60099-8. On the other hand, this same test for NGLA is found in Appendix H and is often overlooked by manufacturers but also by users. Typically, NGLA refers today to Station Class Arresters with 2...4ms impulse duration for the Qrs test which is rather a projection of switching surges instead of lightning surges. MOV Blocks can withstand lower charge ratings when tested with 200µs impulse duration. This requirement should become mandatory for line surge arresters' applications in order to control effectively failure rates and therefore the life expectancy of the equipment.

Another change that results from a clear understanding of Appendix H is the updating of the thermal energy test (Wth) which is still a reference for NGLA application. This test is representative of the switching surges and should no longer apply for lightning surges. The purpose is to verify the thermal stability of the arresters after injecting critical current impulses. It applies to NGLA only since they have a continuous operating voltage, unlike EGLA which is not affected. The purpose of this test is to verify the arrester's ability to thermally recover after transfer of the rated thermal charge, Qth instead of Wth, respectively, under applied temporary overvoltage and following continuous operating voltage conditions.

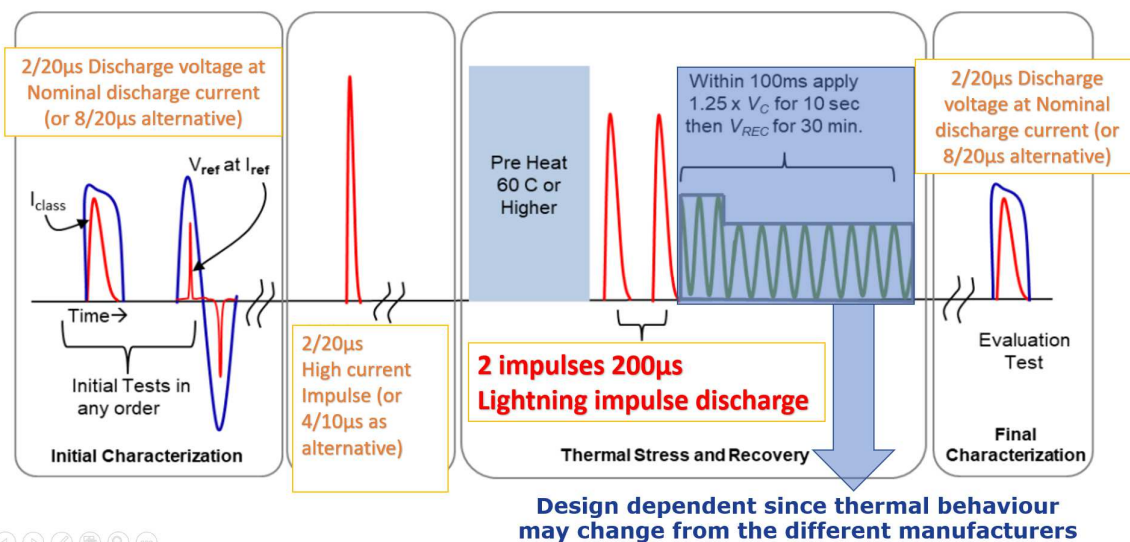


Figure 25. New test protocol proposal for Qth thermal charge of NGLA

The new 60099-11 standard will therefore evolve to cover these shortcomings and make it easier for users to understand the selection and testing process.

7. EGLA to become a standard component for the electricity supply industry

The title sounds quite ambitious but the EGLA technology make it possible to build more competitive, compact and efficient lines.

The ecological transition, the urge to decentralize production sources and the need to transport more power in the same section corridors are pushing the industry to constantly innovate in technologies that meet market requirements.

Insulated cross-arms have enabled the construction of compact lines by increasing the mechanical loads limits and reducing the wind swing. High Temperature Low Sag Conductors (HTLS) combined with advanced insulated cross-arm can unlock the potential for upgrading existing line to operate them at higher voltages and higher ampacity without increasing the right-of-way and keeping clearances within an acceptable range.



Figure 26. Example of Composite Insulated Cross-Arm (CICA) 500kV system voltage from SHEMAR

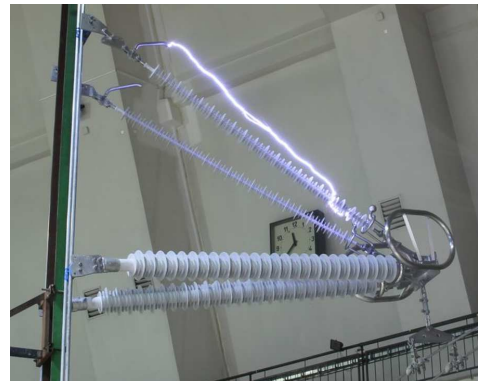


Figure 27. Lightning Impulse flashover on CICA 230kV. Courtesy of SHEMAR

Although these recent innovations have brought concrete solutions in the design and construction of transmission lines, there are still physical and technical limitations that can be overcome with Line Surge Arresters, and more specifically with the EGLA.

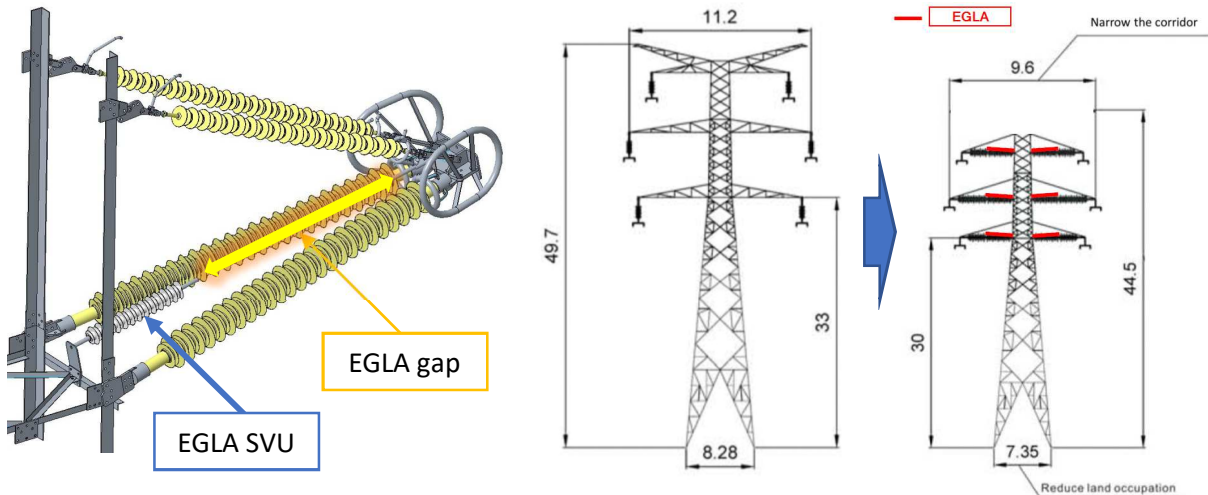
First of all, we have to admit that the line engineers do not work closely with the surge arrester engineers. We see two distinct worlds that evolve in their own directions with little communication. The surge arrester technology, the protection levels and the energy/charge ratings are still misunderstood and misinterpreted. Everyone is a specialist in their own field, it is rare today to see engineers with a global and technical vision on the whole system.

Secondly, it must be confessed that the LSAs operation has not necessarily had a very good press in recent years, particularly because of the NGLA failures. As per a survey in the CIGRE TB 855 from WG C4.39, **half of the NGLA users** experienced mechanical failures of the lead wire.

It is common to see utilities considering the installation of LSA only as a last resort when the grounding conditions could not be improved and no conventional method is realistic. Maintenance teams and asset managers do not look favorably on the use of additional equipment. Life expectancy and failure modes remain major questions that are often left unanswered.

We propose here to bring an innovative look at compact line construction using available technologies. EGLAs are very reliable when applied properly. EGLA can be used for an ultimate compaction of transmission lines that makes the line completely lightning-proof and also safer in case of ground fault.

In some cases where the grounding conditions makes the construction of the line challenging, the EGLA can also be seen as a mean to reduce the construction costs. Indeed, the implementation of extended grounding systems and counterpoises, the increase of the line insulation or the installation of additional shield wires might exceed a reasonable budget to achieve the construction in regards to lightning performance.



Theoretical Example of an integrated EGLA into a Composite Insulated Cross-Arm (CICA)

Traditional Lattice Tower

Ultimate Compaction using EGLA & CICA technologies

Figure 27. Innovative approach for ultimate compaction with CICA/EGLA embedding. Raw Data/Drawings from SHEMAR

There are many benefits when EGLA is placed at the heart of the line design and not as a last resort to mitigate lightning outages:

- Get rid of shield wires (OHGW) and reduce tower material
- Narrow the corridor and shorten clearances and insulation levels to the minimum
- Reduce land occupation, concrete foundations and thus constructions costs
- The line becomes 100% lightning-proof, no lightning induced outage possible
- Ampacity can be increased to its maximum with limited risk
- The line becomes safer in case of ground fault (reduce risk of step/touch voltages)
- CICA designs allow a great EGLA integration: it provides lower lightning sparkover voltages, makes the gap extremely stable and simplify maintenance in live conditions

Line Designers and Surge Arresters specialists must continue to work together in order to enable innovative technology to facilitate the construction of compact line and line uprating as a requirement for the grid decentralization and energy transition.

Some key requirements must be respected in order to bring confidence to the users. When properly designed and integrated, the EGLA should have the same life expectancy as the other components of the transmission line. Here are brief checklist to increase reliability:

1. Perform specific system studies to determine the required charge transfer & high current impulse through your EGLA in relation to the atmospheric conditions, soil conditions and system parameters. In our example, upper phase conductors will handle a higher lightning discharge current since they will be converted into “virtual shield wires”.

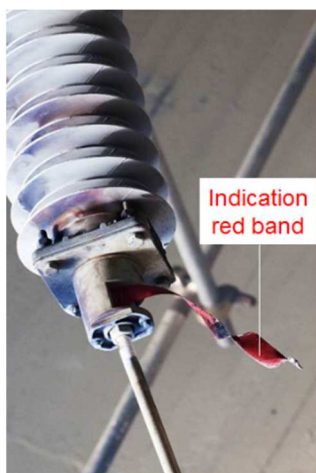
2. Use the resulting ratings of the studies to verify effectively the performance of the ZnO blocks (EGLA active part) following the latest standards for LSA application.
3. Review and update if necessary the integration of the EGLA into your system. Smart integration together with the insulator string is the key for a proper gap stability and life expectancy.
4. Be proactive to follow-up the quality and manufacturing processes. There are some discrepancies in the standards between composite insulators and composite surge arresters. Those standards take time to evolve. Not all designs are created equal.
5. Since reliability is high, conventional monitoring is not cost-effective. Explore modern techniques to localize lightning flashovers, estimate charge transfer and gather real world input data.

6. Monitoring and proactive maintenance

Monitoring is a “question” that often comes up but also a concern that is often expressed by utilities and grid operators. As explained above, the surge arrester is often seen as an asset that can fail and must be monitored. Preconceived opinions must change when feedback provides factual information. It is important to understand that EGLA failure rates are very low. But also, that a failure on one EGLA does not jeopardize the system because other EGLAs play their role along the line.

The industry has developed monitoring solutions to address those concerns and needs:

- 1) Basic monitoring solutions to inform that the surge arrester has failed: **disconnecter type or fault indicator**. Often used on LSA's or Distribution Class Arresters
- 2) Advanced monitoring to provide meaningful (or not) information about the surge arrester condition: **wireless sensors or modern digital devices**. They measure the leakage currents, temperatures and record current impulses. Often used on Station Class Arresters in Substations but also on LSA's.
- 3) **Temperature measurement** of the arrester's core using Infrared cameras. A relation is established between the leakage current and temperature when using thermal imaging.



EGLA Siemens Energy with Fault Indicator
Source: Earthing Africa 2017



NGLA Siemens Energy with Disconnecter
Source: INMR 2019 / Siemens website



NGLA Hitachi Energy with EXCOUNT II monitoring
Source: Hitachi Energy Catalogue



NGLA Tridelta Meidensha with smartCOUNT monitoring
Source: LinkedIn

Figure 28. Overview of different LSA monitoring solutions available on the market

All these devices meet needs but are far from perfect. With the exception of the NGLA disconnectors which has another isolation function, all these devices are not completely satisfactory to evaluate the health of the arrester (proactive maintenance), to signal a damaged arrester (curative maintenance) or to measure the lightning discharge currents (statistical information and confirmation of performance).

Here is a non-exhaustive list of the disadvantages of these devices:

- Can be expensive compared to the price of the surge arrester
- Information is not in real time, data must be collected on site. LSA's are often installed in remote areas and are difficult to access without helicopter, drones, or specialized climbers.
- Even solutions with long range wireless connectivity are not functional in remote areas
- Their use requires a power source that is often problematic in terms of maintenance and reliability.
- Their reliability and lifetime compared to surge arresters is questionable and is not covered by the standards.

NGLA would always require disconnectors anyway and are not a preferred choice in our opinion for LSA's applications unless the intention is to control switching surges.

The EGLAs present by their nature a higher reliability. Given the very low failure rate and that their failure is caused by an excess of charge transfer related to a lightning strike, it is now possible to provide reliable solutions that allow to have information in real time.

True Digitalization of the Monitoring

There are today proven technologies which can tackle the challenging process of monitoring (6). Lightning detection techniques have been developing and improving in performance in recent years. The integrated digital solutions have also come to answer the need for automation of processes but the possibility to be more proactive in maintenance thanks to the intelligent interpretation of the data.

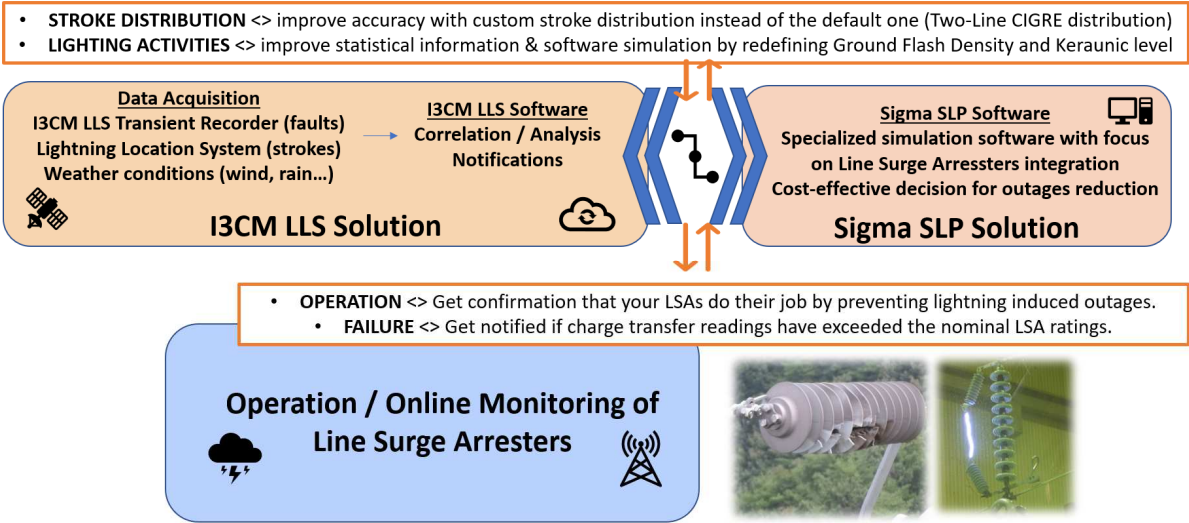


Figure 29. Innovative approach for monitoring LSAs with I3CM LSS solution

I3CM LLS is an unique solution that combined effectively transient recorders, Lightning Location System (LLS) and weather conditions data. This system, using a single software, can precisely detect lightning induced outages and geolocalize with high accuracy the tower and the phase conductor(s) that have been affected.

Besides the tremendous potential of that application for lightning performance improvement (which are not detailed here), this solution has the possibility to estimate the charge transfer through the surge arrester and therefore the probability of failure of all LSAs installed along a specific line.

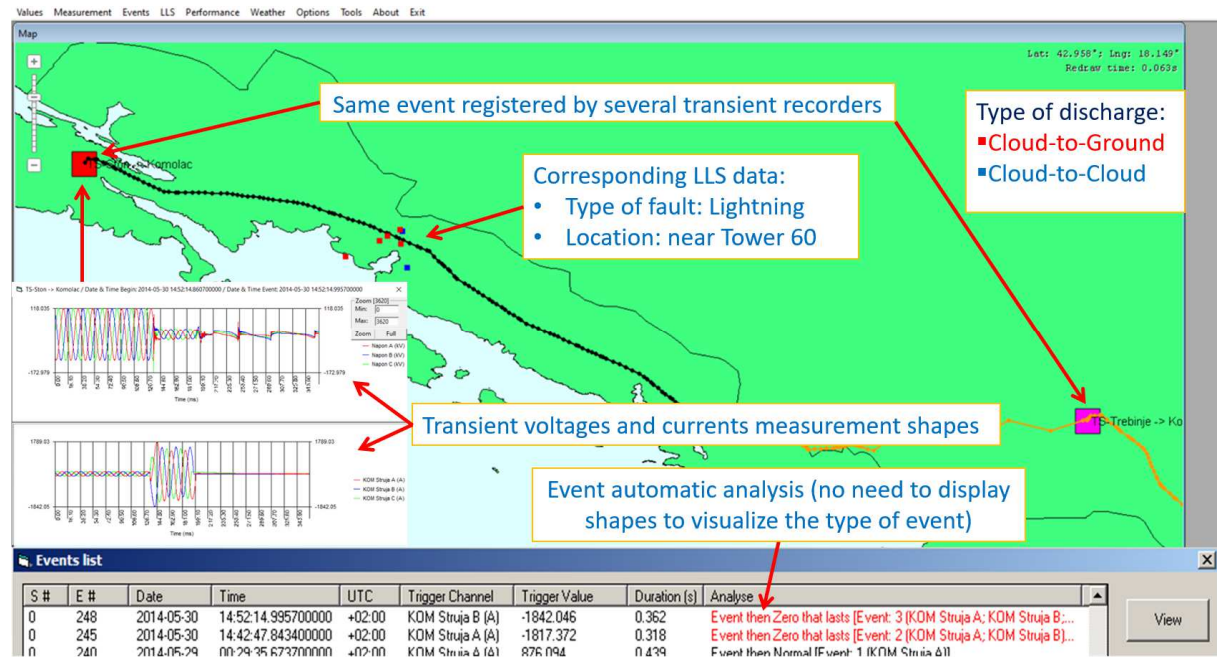


Figure 30. Example of a recorded fault: Display of event registered by I3CM transient recorder(s) and corresponding LLS data

I3CM LLS is a standalone add-on of a simulation software (Sigma SLP) for the computation of overhead lines lightning performance with special focus on the application of LSA's.

Continuous improvement of the Lightning Location System (LLS) data regarding location accuracy, detection efficiency and stroke amplitude estimation have led to a new era of possibilities for the users.

Measurements and data from I3CM LLS allow to provide accurate and real statistical information to the simulation software. Typically, Sigma SLP users are able to use custom stroke distribution which are more representative of their specific line/application.

Since LLS data provider can estimate the amplitude of lightning strokes which hit the overhead lines, it becomes possible to estimate charge transfer and probability of failures once a simulation has been performed on this specific line section.

The circle is complete. Satellites and transients recorders coupled with cloud computing and specialized software can unlock the potential for a state-of-the-art monitoring of LSA.

7. Conclusion

The development of ZnO technology is almost 50 years old.

The high-voltage network industry in Japan developed the first EGLA 40 years ago to meet the specific needs of overhead lines by combining the unique characteristics of ZnO varistors with the advantages of air gaps.

30 years ago, Japan already had more than 30,000 EGLA units installed on their network.

With more than 365,000 EGLA units now installed on the Japanese network, only 55 failures have been reported between 1989 and 2008. There is no comparable study today that demonstrates the reliability of EGLA over 10 years with such large volumes. With this experience feedback, we observe that this failure rate is acceptable and that it is relatively simple to adjust the design to reach a near zero rate, if required.

EGLA technology has been adopted significantly in many countries in recent years. The specifications and project's requirements for large-scale projects are forcing manufacturers and users to adopt EGLA more and more due its technical superiority.

Market and industry realities do not necessarily lead sometimes to rational decisions about technology adoption. The user experience must remain an important evaluation criterion.

The CIGRE Technical Brochure 855 about LSA application has been released in 2021 and provides a lot of experience feedback for the users. Hopefully next year, PT 60099-11 working group will release the new dual logo IEC/IEEE standard to define the design/type tests, routine test, acceptance tests and classifications for LSA's.

Once EGLA has regained the confidence of users in terms of service life and reliability, it will be possible to pave the way for new, more compact and safer overhead line constructions. Compact lines also bring their batch of innovations with the insulated cross-arms and HTLS conductors that require time for a wider adoption. The EGLA could bring a new impulse to meet the requirements of decentralization and efficiency. A better cooperation is required between line designers and surge arresters specialists.

Disruptive innovations like replacing shield wires by EGLA can only be achieved by the fulfillment of certain requirements that may be neglected today. Suitable system studies, adequate testing protocols, smart integration at design stage, strict manufacturing and quality processes and modern techniques for monitoring are some key requirements to be followed.

Several experience feedbacks have been shared on the ability to localize the lightning stroke on an overhead line by combining the Lightning Location System (LLS) and the transient fault analysis of a line. Modern solutions allow to evaluate the amplitude of the lightning stroke with accuracy levels of a hundred meters. But also, to know the type of lightning flashover and to identify the affected phase conductor in real-time. Some very specific solutions like I3CM LLS have even the potential to evaluate the charge transfer to detect failures, or even to have the confirmation that the EGLA has done its duty. We are entering a new era of digital monitoring.

References

- (1) Development of Gapless Surge Arresters and Application of Them to Power System Facilities
Misao Kobayashi - Surge Protect KK (Former Chief Engineer of Meidensha Corporation)
- (2) CRIEPI Report 2009 - Central Research Institute of Electric Power Industry
- (3) Application of Line Surge Arresters in Power Distribution and Transmission Systems – CIGRE COLLOQUIUM 2008 – Lightning Protection of Overhead Transmission Lines with Surge Arresters – Development of Line Arresters and the Technology in Japan
- (4) Design of Zinc Oxide Transmission Line Arresters for Application on 138kV Towers / Application of special arresters on 138kV lines of Appalachian Power Company - Koch, Timoshenko, Anderson, Shih, IEEE Trans PAS-104 No.10, October 1985
- (5) Interaction of vibration dampers with surge arresters - CIGRÉ B2 TF 007
- (6) Effectiveness of line surge arresters for lightning protection of overhead transmission lines
CIGRE TB 855