LINE SURGE ARRESTERS: APPLICATIONS, DESIGNS, TRENDS, MONITORING AND RECOMMENDATIONS

Florent Giraudet, Siemens Surge Arresters, Germany

Abstract: The use of Transmission Line Arresters is a well-known application.
This cost-effective way has clearly shown the performance improvement for the electricity supply industry. However, there is often resistance to make it a common use.
The reduction of outages due to lightning activity and poor grounding makes their application vital.
Meanwhile some users apply this technology also for security of population, switching surge control, line upgrading and compaction, double circuit outage reduction or live line working.
Despite the fact that the use of Externally Gapped Line Arresters can achieve outstanding results by minimizing the investment, this smart protection device shows a mild growth excepting in some specific countries.
Monitoring and proactivity are two major items for the maintenance of transmission lines. Therefore, it is important to assess continuously the condition of Line Surge Arresters and to prevent them against mechanical failures and improper use.
This paper pretends to enlarge our global understanding of this high potential concept…

Key words: Line surge arresters, transmission and distribution lines, externally gapped line arresters (EGLA), non-gapped line arrester (NGLA), lightning and switching performance, transient overvoltages, MO-surge arresters, polymeric housing, silicone, cage design, ground flash density, flashover rate, footing resistance, insulators, basic insulation level, monitoring, third harmonic, thermal imaging, ground lead, disconnector, innovation.

1. INTRODUCTION

Transmission Line Arresters or Line Surge Arresters are mainly known to improve lightning flashover rate.
Lightning flashovers are a major problem for many utilities. Lightning is actually the main cause of unforeseen outages on transmission lines (e.g. U.S.: 57%; Brazil: 50-70%; Japan: 70-80%; Denmark: 57%; Colombia: 47-69%). A lightning flashover on a transmission line requires breakers operation to eliminate the resulting short-circuit resulting in a voltage interruption.
A brief power failure can cause important financial damages to the users and utilities.

Consumers are becoming more demanding since their processes are dependent on a reliable power system. Around the world, the growing demand for power has resulted in the need for increasing line availability and power supply quality. Users and manufacturers are fully aware of the issues and are looking for cost-effective solutions to improve the situation.

Line Arrester application is today a reliable solution thanks to advanced design of the polymer-housed arresters and the performance of the metal oxide technology. Significant improvements have been done since Metal Oxide Technology appeared on the market in the early 1970s. More than a million of units have been installed on utilities transmission lines worldwide for the last 15 years. Surge arresters are relatively low-priced while providing various benefits; it makes their use very cost-efficient.

The installation of Line Surge Arrester has been done on all different voltage levels mainly from 72kV to 765kV. There are different requirements and arrangements depending on the countries, the users and the expected benefits. It is not only their location but also their purpose that is decisive in this application. Various motivations as switching surge control or line upgrading/compacting are becoming more popular. Externally Gapped Line Arrester (EGLA) and Non-Gapped Line Arrester (NGLA) are two different technologies having advantages and inconvenience. The overall performance has given satisfaction while we might see some mechanical failures in some regions. Today, the return on operating experience is very complete. It becomes necessary to enlarge our knowledge and actively share it with our business partners.

2. MAIN USE OF LINE SURGE ARRESTERS FOR LIGHTNING PERFORMANCE

In addition to the common ways of improving the lightning performance of certain overhead power lines, properly applied line surge arresters can effectively and economically help reduce line system failure rates.

Method of lightning protection	Feasibility check	Economic viability
Add or extend shielding wire(s)	-Lines are generally unshielded due to sensitive reasons -Strongly depends on tower design -Not effective for high footing resistance	-High material & labor costs -Power interruption is required **-Non-economical solution**

Increase BIL (insulator replacement)	-Strongly depends on tower design and system clearances -Leads to travelling / propagating waves on the line for high footing resistances!	-High material & labor costs -Power interruption might be required **-Non-economical solution**
Improved tower footing resistances	-Additional copper counterpoise might be completely unefficient with high soil resistance -Only efficient for shielded lines -Eliminates only backflashovers and doesn't influence shielding failures.	-Moderate installation costs -Improvement & **cost-efficiency is not guaranteed**
Install Line Surge Arresters	-Versatile & Large fesability -Highest protective effectiveness even for high footing resistances in all terrains -Eliminate all types of lightning failures.	-Low material & labor costs -Live installation possible. **-Cost-efficient solution.**

Table 1: Comparison of mitigation methods

Line Surge Arresters are commonly used to address lightning phenomena with the goal of improving the overall reliability of transmission lines. LSAs eliminate uncontrolled flashovers of transmission line insulators in order to prevent earth faults and short circuits "inside" the system component "transmission line". We identify two main scnearios in case of lightning strokes: Back-flashover and Direct Flashover (also known as shielding failure).

Back-flashover at nearest insulators - Lightning strokes on shielding wire or on tower top
Insulator back flashover rates can be efficiently reduced in case of shielded overhead lines located either
in high lightning activity areas or having poor footing resistance. These types of outages could be reduced by placing arresters in all phases or only on the phase(s) with lowest coupling factor to the shield wires which normally is the bottom phase in high footing resistance areas. For applications in high footing resistance areas, it is important to apply the arresters not only on structures in the areas of high footing resistances, but as well also one or two structures away from the high footing resistance areas. This will prevent flashovers at the low resistance structures caused by the arrester operations at the high footing resistance structures. The higher the footing resistance, the more energy is absorbed by the individual line arresters.

Direct flashover at nearest insulators - Direct lightning strokes on phase conductor
Insulator flashovers result from so-called shielding failures mostly observed on unshielded transmission lines and very infrequently in shielded lines that may experience lightning strokes direct to the high voltage conductor. For unshielded transmission/distribution lines, those direct lightning strokes to the phase conductors will be much more frequent than for properly shielded lines, since these lines are simply not protected (shielded) against lightning at all. In such cases, line arresters can also be used to address shielding failure flashovers by applying the arresters on the exposed phases.

Line arresters installed instead of shielding wires in new or unshielded line systems, especially when grounding conditions are bad. Some specific tower designs with "triangular" phase conductors might not be equipped with overhead shield wires; therefore line arresters can be used to "protect" the topmost phase from flashover and effectively acting similar to a shield wire when the topmost phase intercepts a lightning stroke.

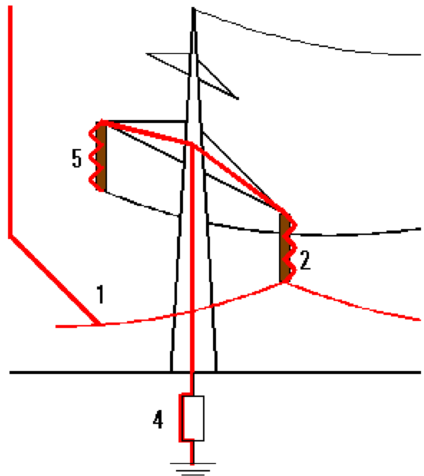

Figure 1 : Direct Flashover – Shielding failure

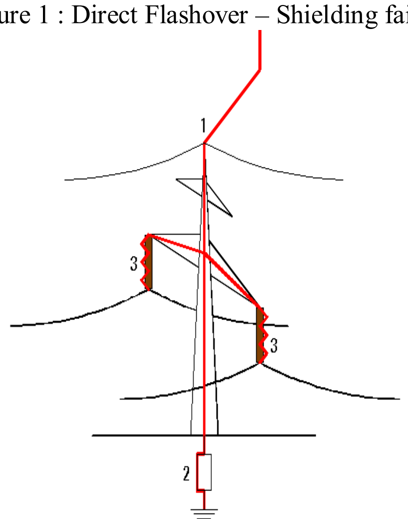

Figure 2 : Backflashover

These are the two basic scenarios to understand the principle of flashovers due to lightning activities. Other problems may occur. Underbuilt distribution lines or double-circuit towers may be severely impacted by lightning strokes. Lightning strokes nearby lines might also impact the performance.

3. LINE ARRESTER PROTECTION EFFECTIVENESS

The effectiveness of line arresters strongly depends on the protection configuration selected.
An intuitive and experiential approach might be enough in some specific cases but it cannot replace a scientific approach. It is highly recommended to perform a study to evaluate the expected benefits.

Although the installation of line surge arresters on every tower along the entire line as well as on every single phase ensures complete lightning protection, an optimal selection of line surge arresters, especially in terms of their quantity and installation locations, can have a significant impact on a system's long-term benefits. With this approach, the user only needs to equip particular phases or individual line segments with line surge arresters, and can still ensure sufficient lightning protection of the overhead line and reduce network failures. One particular benefit of this approach is that outstanding results can be achieved while investing only a fraction of the amount that would otherwise be required to install the maximum amount of equipment.

Manufacturers, utilities and consultants are using software analysis to examine and conduct preliminary tests of existing applications as a way of determining the optimal and cost-effective solution. There are different commercial lightning softwares available having their own assets [12].
Main programs are Sigma SLP, IEEE Flash, EPRI Tflash and STRI Line Performance Estimator.
There are differences in algorithms and simulation tools that can result in varying line performance.
Sigma SLP was specifically developed to enable the design of transmission/distribution lines including the application of line surge arresters.

The simulation takes the following factors into consideration:

<u>Line parameters</u>: operating voltage, number of three-phase circuits, ground wire data, length, span length and sag of the line, conductor type, diameter, and clearances
<u>Tower data</u>: tower surge impedances and footing resistance, tower geometry (position and distances of the individual phases and any existing ground wires), as well as soil impedance
<u>Insulator data</u>: arcing distance, connection length, rated lightning impulse withstand voltage
<u>Lightning activity</u>: ground flash density (lightning strokes per year and km²) or keraunic level (thunderstorm days per year)
<u>Operator's priorities</u>: fewer short interruptions, prevention of phase and multisystem short circuits, elimination of ground wires

SLP software individually simulates different installation cases regarding positions of the line surge arresters in the phases to be protected in order to determine the most effective configuration. In addition, the software divides the line into segments (depending on the line topology or distribution of the tower footing resistances along the line) and varies the installation of the line surge arresters depending on the number of towers to be equipped. After the simulation runs, a second phase of the analysis evaluates all the data. In a third phase, proposals are developed for an optimal solution.

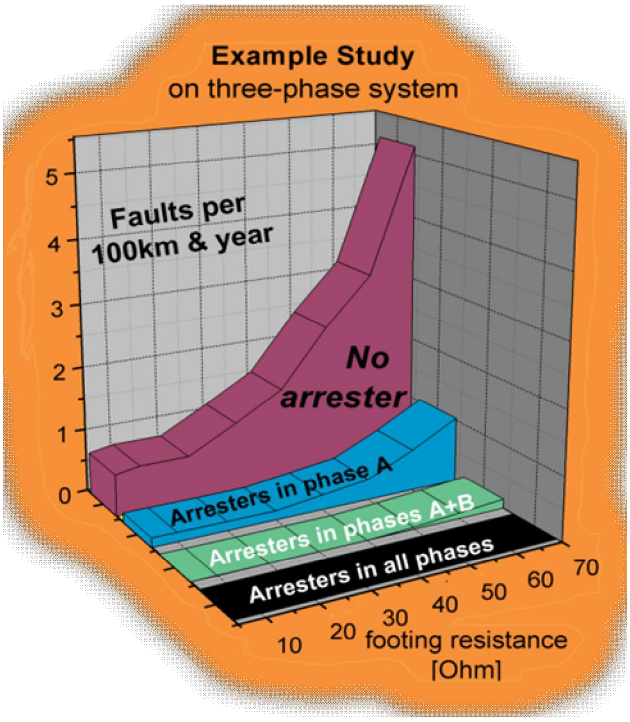

Figure 3 : Outcome from Sigma SLP

4. COMPARISON OF 2 DIFFERENT APPLICATIONS: EGLA VS. NGLA

Externally Gapped Line Arresters (EGLA) have an external spark gap placed in series that galvanically isolates the active part (SVU – Series Varistor Unit) of the line surge arrester from the line voltage under normal conditions. In case of lightning, the spark gap is ignited and the overvoltage is safely discharged through the resulting arc.
The active component limits the subsequent current to ensure that the arc is extinguished within the first half-cycle of the operating power-frequency voltage. After this, the line surge arrester immediately returns to standby condition. In this manner, the EGLA prevents all

insulator flashovers that would otherwise lead to short interruptions and failures in the power network. .
An additional benefit of EGLA line surge arresters is that there is no leakage current, because the series gap disconnects the MO blocks, which are the active part of the EGLA, from the system voltage in normal operating conditions. Depending on the line profile, an EGLA can either be attached directly in parallel on the suspension/tension insulators, on the insulator string, or on the tower cross-arm. It might be possible to suspend the SVU on the conductor for distribution lines. The active component can have either one or two SVUs (on each side) depending on the system voltage level and user's requirements. The compact design of the EGLA allows installation and lightning protection even on existing towers with very small clearances, as it is mostly the case in multi-circuit towers [4].
Relevant standards: IEC 60099-8

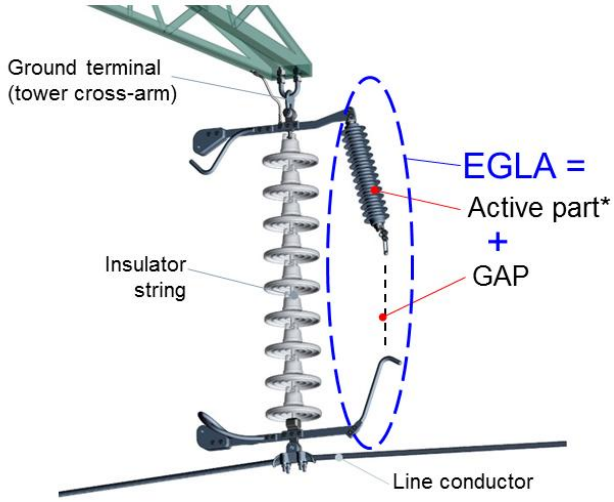

Figure 4 : **EGLA** - Disconnected from power line through series GAP

Non-Gapped Line Arresters (NGLA) offer a high degree of mounting flexibility and operational reliability. Depending on the tower design and the arrangement of insulators and lines, these arresters can either be installed directly on the insulator or on the tower. Thanks to their high energy absorption capability, today's non-gapped line arresters offer a very high level of protection against overvoltages caused by lightning and network-generated switching impulse current overvoltages.
To galvanically isolate the line surge arrester from the line voltage in the unlikely event of a fault or thermal overload, a disconnector is installed in series. It automatically and immediately disconnects the line surge arrester from the line voltage. This allows the affected overhead line to be renergized and operated until convenient replacement can be scheduled [4].
Relevant standards: IEC 60099-4 / IEEE C62.11. Application Guide IEC 60099-5 / IEEE C62.22, IEEE 1243 (lightning performance improvement)

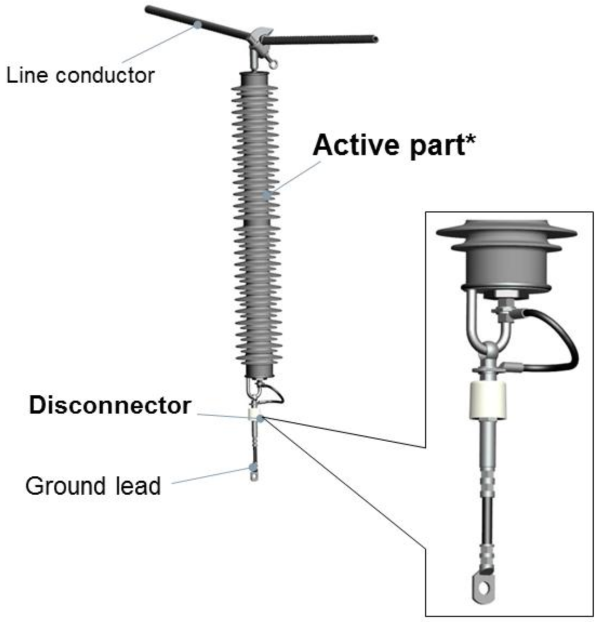

Figure 5 : **NGLA** - Directly connected to power line

Both technologies present advantages and inconveniences. The needs and the expectations from the users and operators must be clearly identified and described in order to take the right decision.

	EGLA (Externally Gapped Line Arrester)	**NGLA (Non-Gapped Line Arrester).**
F U N C T I O N	Operates only in case of lightning overvoltages since the gap is designed to withstand switching impulses (IEC). Does not share energy evenly as well as NGLA.	Can handle power-frequency, switching and lightning overvoltages. Directly connected between phase and ground as in substations. Shared energy can be calculated.
M A T E R I A L	Less material since energy handling requirements are lower than NGLA and no need to configure MCOV phase-to-ground. Additional hardware might be required depending on tower design.	More material since metal oxide volume and Housing size are similar to Station Class Arresters. Less hardware in some cases.
S T A N D A R D S	Used only in few countries since higher technical knowledge (IEC 60099-8) is required. New investment for type tests is in general necessary.	Largely used since their design and application is known and simple (IEC 60099-4) without type test repetition. Manufacturer shave already performed all the relevant type tests.

DURABLE	No leakage current, no electrical stress. Better ageing, we might expect a longer life.	Leakage current ~1mA and permanent electrical stress. Corona ring (from 500kV) + grading ring (from ~220kV) are required.
LEAD	No disconnector required, the gap is sufficient. No ground or HV lead, therefore less mechanical issues.	Improper installation might reach to mechanical failures. Disconnector, flexible lead or arrester arrangement might be a weak point due to vibration, galloping, conductor restraint, corrosion or other stress.
INSTALL	More options for installation in live conditions.	When hung on the conductor, installation becomes easy with minimum hardware.
FAULT	Cannot fail due to line fault.	Can fail due to line fault.
FAILURE	Arrester failures can be detected with the help of a fault indicator.	Arrester failures can be detected when the disconnect link falls away for the arrester.

Table 2: EGLA vs. NGLA

The use of EGLA is economically justified for a large scale project of lightning outages reduction.
NGLA becomes the adequate solution for a smaller scale project with specific purposes as switching surge control or lightning performance improvement in a special environment [8]. The system voltage, the design of the tower and the line parameters are often an important factor for the decision.

5. DIFFERENT PURPOSES FOR LINE SURGE ARRESTERS APPLICATION

Switching surge control - Lowering Clearances
Switching overvoltages are typically associated with high speed reclosing on EHV transmission lines. Strategically placed, surge arresters have been used instead of closing resistors and/or controlled switching schemes to control switching over-voltages along EHV transmission lines. Unlike lightning related applications, where arresters may be installed on consecutive structures, arresters to control switching surges are only needed at specific location along the line. At each location, arresters are usually installed in all phases. Line arresters along the line may typically require one energy class lower than what is needed for arresters installed at the line ends in the substations. Transient simulations should be performed in order to determine the amount of energy absorbed by the arresters. Line arresters for this application are typically used for system voltages of 245 kV and above. However, with the increasing use of compact or upgraded line designs, this application is no longer reserved just for EHV levels [9].

In North America, the NESC (National Electrical Safety Code) allows the acceptance of lower minimum clearances by reducing the switching surge factor. A minor investment in Line Arresters will provide significant benefits instead of using classic remedies for maintaining required clearances (fencing areas, structures modifications, re-tensioning conductors, etc..). Siemens executed such a project in Arizona (SRP) in 2012. The Switching Surge Factor (Maximum crest switching surge / Maximum operating crest voltage) were reduced from 2.2 pu down to 1.8 pu by installing Line Arresters in only three locations along 180 miles line. Live condition work allows a minimal capital invest and low installation costs.

It is more common to use NGLA application to control switching overvoltages since EGLA are generally not designed to handle switching impulses. For the IEC standard 60099-8, the external gap of EGLA is selected to withstand these transients. Furthermore for switching control, only few arresters at selected location are required, therefore the easiest way is obviously to use NGLA.
In North America, the switching surge control by using EGLA seems to be seriously considered.

Line upgrading and compaction
Line upgrading involves increasing the system voltage by keeping the existing structure. In general for such a modification, several issues must be considered as phase clearances or insulator length. Line Surge Arresters become extremely helpful and economically justified to convert the existing lines or substations to higher voltages without changing the clearances and insulator strings.
Due to the necessity for the utilities to build discrete and aesthetic line structures and the development of the composite line post insulators, compact line designs are a realistic alternative to the standard line designs [9]. Line arresters are controlling overvoltage stresses on the line insulation. With proper selection and insulation coordination, both lightning and switching surge flashover rates can be reduced substantially by the use of Line Arresters. NGLA application might a better option to control switching overvoltages [3].

Double circuit outage reduction
Line arresters may also be used on all three-phases on one of two circuits to prevent reliably simultaneous double-system faults. This approach can be effectively used for all system voltages, including EHV systems [4].

Underbuilt distribution lines

If a distribution line shares a tower or a pole with a shielded transmission circuit, the underbuilt distribution conductors are not likely to be struck directly. However, the distribution line is vulnerable to back flashovers, because the coupling between distribution conductors and shield wires is weak.

The insulation strength on the distribution line is also weaker. Once a distribution conductor flashes over, coupling to the transmission conductors will increase and make a back flashover less likely on the transmission circuit. The transmission circuit's lightning performance may improve at the expense of the distribution circuit's lightning performance. The situation can be remedied with line arresters on the distribution circuit. Usually arresters are needed at every tower or pole, on at least one phase.

Security of population - Touch and Step Voltage Reduction

Line arresters may be used in urban areas in order to significantly reduce the risk of having dangerous touch or step voltages due to power frequency earth potential rise following the insulation flashover. This application have been adopted and experienced for example by RTE France. Issues of touch potential coordination become especially important when surge arresters are used to substitute shield wires as the only form of lightning protection on MV and HV lines [9].

Live line working - Temporarily Reduce Minimum Approach Distance

It becomes more and more common to execute maintenance tasks when the system is energized, especially in North America. Most of the American utilities are at the experimental stage but they are probably taking the lead for this specific dangerous work in live conditions. For such live-line working, Line Arresters can be used to reduce the minimum approach distance. A practical way must be found to ensure the arrester integrity prior the execution of the maintenance tasks. The light weight of line arrester is an advantage. The application is similar to protective gap. The crest value of the overvoltages which might exist at the work site is determined by the arrester rating. The arrester offers the advantage of protecting the workers from power-arc radiation compared to a protective air gap. The installation of arresters on all phases on structures adjacent to the work (work site structure not being equipped with LSA) site may be sufficient to protect workers, depending on surrounding grounding conditions. As a switching surge is a slow front surge with low dV/dt, the overvoltage present at work site structure will be higher but just slightly over the protective level of the arresters with little dependence on the separation distance between the work site and the LSA installation. When the protective level of arresters, corrected for separation distance, is lower than the slow front impulse flashover voltage of line insulators and live line tools, flashover at work site has a negligible probability of occurrence. Line Arrester should be used without a disconnection device in this application to ensure better worker protection [9] [3].

Lowering costs and losses in your system

A promising study conducted by arresterworks.com has demonstrated the possibility to lower losses on Transmission Lines by installing EGLA on each tower and each phase instead of using an Overhead Ground Wire (OHGW). For instance, the analysis shows that costs savings can reach up to ~4.5M USD in 30 years for a double circuit 230kV lattice tower equipped with 2 shield wires. New constructions make the use of EGLA much easier and efficient in comparison to an upgrade of older lines.

Significant costs savings for the line construction are also a decisive factor. Integrating the application of EGLA instead of OHGW for the initial design of the transmission lines can reduce sots up to ~6% as evaluated by New York State Energy Research and Development Authority (NYSERDA)

We might expect in a near future a new generation of transmission lines fully equipped with Externally Gapped Line Arresters [1].

Extending Life of Breakers at Substations

Since a lightning flashover on a transmission line requires breaker operation, the Application of Line Arresters along a transmission line reduces stress on breakers at substations and extends their service life.

Furthermore, during a multi-reclosing operation, switching impulses can enter the station while the circuit breaker is still open to clear the fault. Such an event has a low probability but the risk of long-term damage is pretty high for the line side bushing of the circuit breaker [3].

Extended protection of substations

By locating arresters on towers in the vicinity of a substation, it is possible to eliminate the risk of flashover near or in the substation. This leads to a reduction of the stress on substation equipment due to incoming travelling waves. In some cases the need for additional expensive metal enclosed arresters can be reduced. However the protective performance of line arresters such as residual voltage needs to be evaluated properly, as it may not be equivalent to substation arrester ratings. Detailed modelling of incoming surges suggests that Line Arresters tend to reduce the steepness of incoming waves [3].

6. FOCUS ON EGLA

EGLA application is actually not a new development although it might be called new application since the outstanding features are not well-know.

In **Japan** and **South Korea**, hundreds of thousands of such components for all system voltage levels from distribution to 550 kV are in service for over 25 years and 10 years respectively. In **Malaysia**, EGLA has been used in TNB transmission system since 1995 and it was proven that their installation has improved the overhead lines performance [14]. **Hong Kong** applies EGLA for 132kV and 400kV system voltages for over 10 years in severe environment. EGAT in **Thailand** also applies EGLA on their 115kV transmission lines. **France** has experienced EGLA for more than 10 years from 63/90kV to 230kV system voltage. In the **USA**, the demand of NGLA is trending higher while the EGLA option is seriously considered. In 2013, **China** Southern Grid has installed more than 90 EGLAs on a ±500kV HVDC line 940km long with successful operation. This new development is really promising since the proper operation of the EGLA with DC current has not been experienced before …

Spotlight on KEPCO, South Korea

Figure 6 : EGLA KEPCO – Dead-end insulator string

Figure 7 : EGLA KEPCO – Suspension insulator string

In South Korea, the studies have shown that 80% of transmission faults are caused by lightning.
KEPCO is facing several issues resulting to an high failure rate due to high Ground Flash Density and high soil resitance. Since 2006, KEPCO has installed more than 50.000 EGLA sets on their transmission lines for 154kv and 345kV system voltages. The Korea utility is still investing to equipped selected transmission lines.Today, the performance improvement is pretty impressive since KEPCO managed to reduce in some specific areas the double-cirucit failures to 100% and the overall back-flashover failures to 90% [13].
KEPCO is still massively investing in EGLA application to completely equip some of the transmission lines.

For KEPCO, EGLA is THE cost-effective solution easy to install and use. The equipement is light and compact. It can be mounted directly on insulator strings. There is still a continous operation when the active part is damaged. There is no need of disconnecting device, the external gap is enough.
Arrester manufacturers just supply the SVU (Arrester body) and the arcing horns. The hardware of the insulator string to fix the SVU has been standardized and is supplied separately.

Item	EGLA	NGLA
Lightning overvoltage	Required	Required
Switching overvoltage	Not Required	Required
Power frequency overvoltage	Not Required	Required
Long duration current impulse withstand	Not Required	Required
Thermal stability	Not Required	Required
Power Frequency v-t characteristics	Not Required	Required
Anti-aging due to continious energizing	Not Required	Required
Pressure relief	Required	Required
Disconnection operation	Not Required	Required

Table 3: EGLA vs. NGLA made by KEPCO

For the reasons mentionned above and the fact that KEPCO was clearly influenced by Japanese companies in the study phase, the choice of the EGLA type became obvious.

Spotlight on RTE, France

RTE (French Utility) has defined specific requirements for the Externally Gapped Line Arresters that will be installed on their transmission lines. The design and the type tests execution are a challenging innovation [6].
The EGLA solution was designed and developed for lightning protection of a double suspension insulator string suitable for 225kV transmission lines considering an option for live work installation. This concept avoids the restriction of power interruptions.

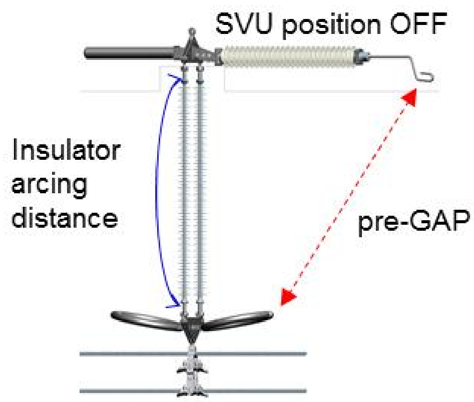

Figure 8 : EGLA installation (live-line work)

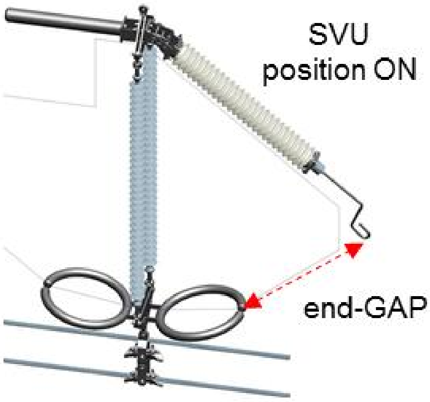

Figure 9 : EGLA in service

In order to ensure the proper operating principle of the EGLA, there are three main general electrical requirements to be verified. The IEC standard 60099-8 defines the procedure and the pass criteria for the tests [5].

1/ EGLA shall not operate at any switching surge due to re-closing operations

For switching impulse wet withstand voltage test, the EGLA must be tested under wet conditions and modeling a failed SVU simulated by shorting the SVU with a copper wire. The test must demonstrated that EGLA does not operate under switching surge overvoltage with peak value equal to the switching withstand voltage of the insulator to be protected.

2/ EGLA shall operate at any lightning surge overvoltage above the BIL level of the insulators

This test must be performed on an EGLA with intact SVU and under dry test condition.

The gap distance must be increased until sparkovers ceased to occur. Afterwards, 15 lightning impulses of each polarity must be applied to the EGLA in order to verify that no flashover will take place in the insulator assembly. All these 15 lightning impulses (90% flashover probability) shall not lead to a gap sparkover and no insulator flashovers shall be observed.

3/ EGLA shall interrupt the follow current within a half cycle of the power-frequency voltage after external series gap sparks over due to lightning surge overvoltage.

This test also clarifies the performance of the EGLA under polluted conditions by taking into account the current that would flow over the surface of the SVU housing due to the presence of a wetted pollution layer. So this test covers also the question regarding the creepage distance of the housing, where the conventional definition, as normally applied to equipment under permanent voltage stress, is not applicable.

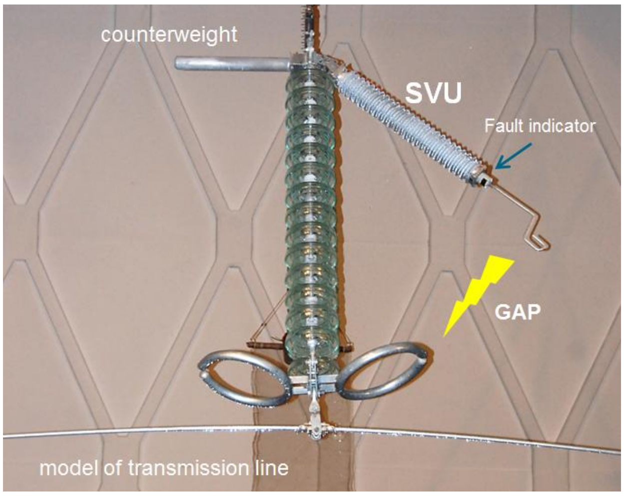

Figure 10 : Complete assembly for switching impulse wet withstand voltage test

In France, Externally Gapped Line Arresters must be equipped with a **fault indicator** in order to provide a clear visual indication. This device has to go through a series of specific tests to guarantee its stability and performance. An important one is the short-circuit test carried out on complete arrangement (EGLA and insulator string) fully in accordance with RTE specification. The EGLA was tested with four different currents and for three different current durations, as shown in the next Table 4.

	High current			Low current
Current /kA	31.5	20	10	1
Time duration /s	0,5	0,9	1	1

Table 4: Short-circuit current ratings

The acceptance criteria of this short-circuit test for 225kV EGLA, as specified by Rte, are:

-No test sample parts larger than 60 g shall fall down to the ground.

-Neither the insulator string nor the counterweight of EGLA shall be damaged during testing.

-The nameplate of EGLA is legible.

-The gap distance after the test is equal to or greater than the distance set up before the test.

-The fault indicator must operate properly and must be visible from 30 meters.

Figure 11 : Fault indicator before short circuit test

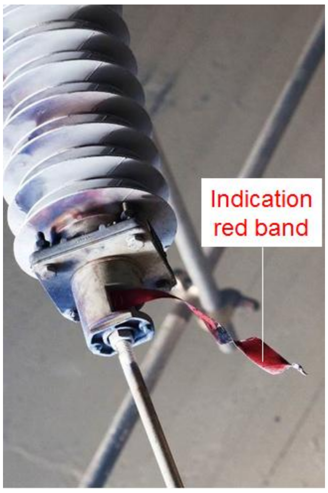

Figure 12 : Fault indicator after short circuit test. Red band must be seen properly

7. MONITORING, CONDITION ASSESSMENT AND RECOMMENDATION

The failure rate of the surge arresters is estimated to be far lower than 0.1% / year. It is actually very difficult to provide sufficient accuracy and perform statistic calculations since the majority of the failures are not reported and the cause is not identified. Surge Arresters are among the most reliable components on the grid and there are currently no major developments in arrester monitoring devices. Line Surge Arresters are generally installed in remote area and are difficult to access without helicopter, cranes or specialized industrial climbers.
A systematic monitoring for NGLA is not always necessary because they might not provide meaningful information and complex monitoring devices might not be economically justified. For EGLA, monitoring devices are generally not applicable. Instead, Fault Indicators are used to detect the failure of the active part.

However, it becomes a necessity for the users to increase reliability and being proactive in maintenance.

The line operators often want to record the amplitude and the frequency of overvoltages that occur on the transmission line. Different solutions are available in the market. Basic devices like surge counters are often used for Station Class arresters to get statistical analysis of the overvoltages but they will not provide any information of the arrester condition. The Metal Oxide Varistors can withstand an unlimited numbers of overvoltages without being damaged. If required, Surge Counters can be equipped with a leakage current meter to measure the total leakage current flowing through the surge arrester.
The total leakage current, mainly capacitive, can be easily influenced by the pollution layer on the arrester housing for instance. Therefore, it cannot be used to monitor the health status of Metal Oxide Varistors.

Third harmonic method (resistive current)
In order to go further, the line operators are generally more interested to monitor the condition of the arrester's active part. A new generation of monitoring solution (digital devices including wireless communication) can be mounted on the Line Surge Arresters. These monitors will assist the users in the early detection of relevant changes. The monitoring device performs two basic functions. The first is measuring total leakage current and determining the resistive leakage current component by analyzing the leakage current's 3rd harmonic. The second function is registering surge current impulses, as well as detecting and registering the overall number, level, and duration of impulses. Those information can then be used to perform a precise analysis of arrester activity. This advanced solution is additionally equipped with wireless communication for evaluating long-term measurements, counter history, and energy summation. It might be interesting for some specific cases, especially for system voltages from 245kV and above.
In general, below 245kV, the complete monitoring solution might be more expensive than the arrester itself. Therefore, it might be installed only at specific locations but not on each arrester.

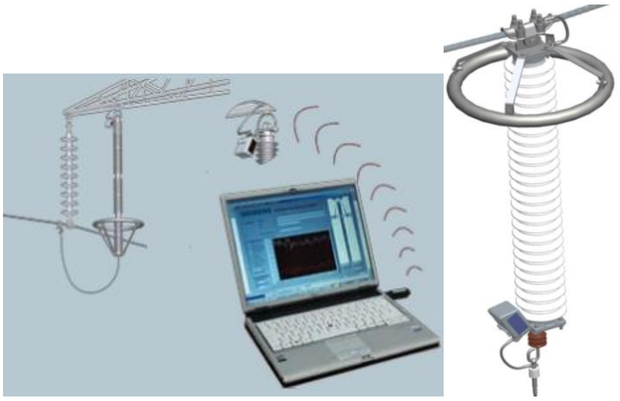

Figure 13 : Wireless monitoring system

Thermal imaging
The permanent leakage current through the Metal Oxide Varistors dissipates energy. Under normal operation, the temperature is close to the ambient value. If the surge arrester shows an abnormal behavior, the leakage current will increase and then a significant temperature gradient will be easy to identify. It is recommended to perform analysis without sunlight and during the night to make sure the overall temperature cools down and to increase the accuracy of the measurement.
Some maintenance processes must be defined by the users to select and follow-up the arresters showing abnormal behaviors. There is no existing guidance for this purpose but expertise can be provided by consultants, users and specialized infrared thermographers. The data can be collected quickly from relatively long distances depending on the infrared camera. We might imagine soon some specific drones collecting thermal profiles instead of going physically in each substation to collect the data [2].

Figure 14 : Abnormal temperature on MV Arresters

There is no official guideline to monitor line surge arresters. The guidance in IEC 60099-5 and the experience from the operators and the manufacturers can provide an overview of the different methods.
Thermal imaging and third harmonic method (resistive current) remain the best ways to assess the health of the surge arresters. Anyhow, it is not economically viable to equip line surge arrester with monitoring devices in order to systematically assess health condition [11].
Thermal Imaging might be the most cost-efficient solution to monitor health condition of the surge arresters. Looking at the innovation and tendencies, it is easy to imagine in a near future a new generation of “smart” arresters integrating electronic components to monitor health condition. The data transfer will be done using a drone and directly with wireless mobile telecommunications.

Recommendations
Based on service experience, there are important factors to be considered in order to maintain the life expectancy of the line arresters. In most of the cases that have been reported, the arrester failure would be due to inherent manufacturing defect, improper selection or configuration, mishandling or improper installation.

Design
The user should pay a special attention to the design of the surge arrester. The most ”advanced” design is the cage design where the MOV stack is surrounded by FRP rods forming a stable cage. HTV silicone rubber is molded directly onto the varistors, the FRP rods and the end fittings. It is very important to use an appropriate primer to ensure a sufficient bonding of the silicone to the inner parts which will **prevent moisture ingress**. The performance and reliability of directly molded cage design with high quality silicone have been demonstrated for the last 15 years. They have reached a high degree of maturity. The cage design is a must for NGLA and EGLA where the failure mode of the surge arrester is essential for safety reasons. **Fragmenting overload is not acceptable.**

Energy
Energy handling capability of the line surge arresters is an important part of the selection procedure. Transmission lines equipped with overhead ground wires would definitely require lower energy ratings. The consideration of switching surge will require higher energy ratings. A proper selection and configuration of the surge arresters must be done closely between the user and the manufacturer. Modern approaches and new possibilities of power system analysis provide improved information about energy handling requirements in arrester applications. Users perform more often system studies and have detailed knowledge about the appearing energy or charge transfer stress on arresters.

Mounting consideration


Figure 15 : Installation of 420kV NGLA in Columbia

The mounting consideration is an essential step while designing line surge arresters. LSAs are installed and used under harsher service conditions than other surge arresters. They are installed in such a way that they may move due to wind and/or line swinging and vibration. They can be treated in rough way on site and during installation. Line Surge Arresters are also more exposed to extreme weather than arresters at substations. The complete assembly is permanently stressed over its life.
However, we should clearly distinguish EGLA and NGLA while discussing the mounting considerations.
NGLA are a very common application since they are less complex and very similar to station class arresters. Their use involves the need of leads and disconnectors in order to isolate the arrester from the line in case of failure. EGLA application does not require any disconnector and ground/HV lead. This is an advantage compared to NGLA where the leads and disconnectors might be subject to permanent stress.

There is no standard available yet to address the requirements for the mounting arrangement. In general the main problems are the connections between the arrester and energized conductor or grounded structure which are subjected to static and dynamic loads. It can lead to fatigue or overloading, resulting in broken connections or damage to the arrester.

We can identify three different arrangements to install Non-Gapped Line Arresters (NGLA):

1/ A popular method in North America [10] is to hang the line arrester **on the tower arm or on the support structure** with a lead connecting the live side. Several mechanical failures have been reported with this installation type. It is important to avoid improper mounting/connections.

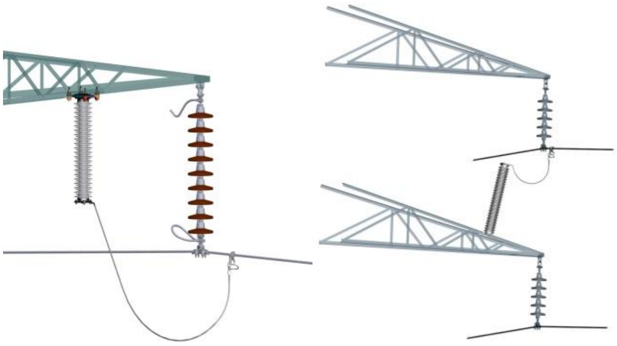

Figure 16 : Examples of line arrester hung on tower arms

Reported issues:
- Too close installation. In case of disconnection, the arrester is considered as a conductive path, therefore the phase-earth clearances might be not respected. A direct contact is also a risk since the conductor and the arrester can swing
- Disconnector on the wrong side. The disconnected lead should not hang from the conductor; it is a source of corona and interference.
- Tense/Rigid lead. It might lead to premature ageing because of mechanical stress and bending moment. Under wind condition, the stress is increased.

2/ A very classic method worldwide is to hang the line arrester with a clamping system **on the conductor** and connect it to the tower/structure with a ground lead. This installation type has given high satisfaction as long as the stress on the lead and disconnector is minimized.

Figure 17 : Examples of line arresters hung on conductors

Following recommendations must be respected:
- The installation distance of the clamping system from the insulator must be properly defined to avoid issues with clearances and BIL restoration.
- The ground lead must be flexible and long enough to allow a natural deflection of the line arrester without important tensile force on each side. A tense lead is not acceptable. The appropriate sag must be defined.
- Consequently, the disconnecting device should be design in a way to allow such a movement. These devices can withstand tensile forces but are sensitive to bending forces. Bending-free systems are available in the market.

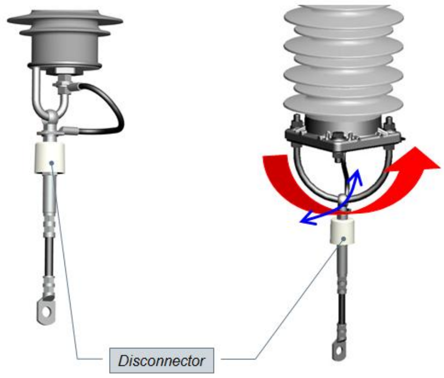

Figure 16 : Diconnetor able to swing freely in all directions

3/ Installing the line arresters in **parallel to the insulator** is also a standard method in North America [10]. It is appropriate for underbuilt distribution lines and compact lines. This installation type requires pre-engineering because of the vicinity with the insulator.

Figure 18 : Examples of line arresters hung on conductors

The attachment method and connections need to be optimized for each insulator assembly. In case of disconnection, the failure mode must be properly verified to make sure the full system BIL is restored. The mechanical strength of the arrester design must be properly selected to avoid any bending/bowing.

If possible, the “preferred” solution is to hang the arrester on the conductor with the adequate lead length.
Each tower design is specific for each project; therefore the recommendation for the mounting arrangement must be properly defined between the user and the manufacturer.

8. CONCLUSION

The electricity supply industry is a conservative sector. New technologies and innovative solutions are in general experienced progressively. Currently, the majority of the activities are related to lightning outages reduction. The application of Line Surge Arresters does not only improve the performance and the operation of the power systems but also improve the design and lower the costs of the construction and the maintenance. The financial benefits are easily demonstrated. This device is still misunderstood and not systematically used when applicable. The communication might be an important way of enhancement to widely share the knowledge and experience. It would be very welcome from the main grid operators and utilities to better communicate the outstanding achievements that have been reached through a mid-term assessment.

For line upgrading and compaction, the opportunities and the advantages are significant for the industry. Unfortunately, the applications are underutilized because the engineers have the responsibility to redefine the ratings that have applied for the last century [2].

Each revolution passes through three stages. First, it is ridiculed as replacing the OHGW by EGLA for instance [1]. Second, there will be a clear opposition from the major players in the sector. Third, it will be accepted as being self-evident.

LSAs application will certainly become a standard component for the distribution and transmission lines in a near future. A promising Working Group has been founded in order to define a "global" standard for the application of Line Surge Arresters.

Figure 19 : Cover of an IEC/IEEE Dual Logo International Standard

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10. BIOGRAPHY

Florent Giraudet was born in Aix-en-Provence, France on June 20, 1987. He received the Dipl.-Ing. degree in 2010 in industrial engineering from the CESI Lyon, France. He joined Siemens AG, Energy Sector, Berlin in the same year, where he began as an area sales manager and project manager for Surge Arrester technology in North America, Europe and Africa.