1. Introduction

The application of Line Surge Arresters (LSA’s) is well known for its cost-effective performance improvement in the electricity supply industry. Although their reduction of outages from lightning activity and poor grounding make their application vital, there is frequent resistance to make their usage commonplace. LSA’s are generally installed as a retrofit application, where conventional mitigation-measures have not shown significant improvement. Besides the lightning performance improvement, various benefits can be derived from the use of LSA’s. Some users apply this technology for safety concerns such as preventing population and injury damage, switching surge control to optimize structures, reducing clearances, line uprating and compaction, and live-line working. Even though the implementation of Externally Gapped Line Arresters (EGLA’s) can achieve outstanding results by minimizing investment, this smart protection device shows a mild growth, except for some specific countries. Users generally underestimate the advantages and benefits of the EGLA solution, while most of them face issues with Non-Gapped Line Arresters (NGLA’s). The EGLA application not only significantly improves the performance and operation of the power system, but also enhances the design and lowers the cost of construction and maintenance. The benefits and costs savings become even more important if properly considered and integrated in the design stage of the transmission lines. Unlike with substations, line designers and engineers do not consider the application of line arresters as systematic in optimizing their transmission line systems. Surge Arresters are among the most reliable components on the grid. When designed, dimensioned and installed properly on transmission lines they must be as reliable as the insulator and power line hardware. This paper intends to present Siemens knowledge, experience, feedback and latest innovations for compact and cost-efficient lightning-proof transmission lines.

2. Main use as retrofit application for lightning performance

Across the globe, most of the utilities and transmission system operators (TSOs) are considering LSA’s when conventional methods do not provide satisfying results. LSA’s are often considered as curative maintenance but not proactively in the design stage of the transmission lines. Table 1 tries to describe the different mitigations methods which are commonly used to improved

<table>
<thead>
<tr>
<th>Method of lightning protection</th>
<th>Feasibility check</th>
<th>Economic viability</th>
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| Add or extend shielding wire(s) | -Lines are generally unshielded for specific reasons (river crossings / clearances issues)  
-Strongly depends on line design / parameters  
-Not effective for high footing resistance and bad soil resistivity | -High material & labor costs  
-Power interruption is required  
-Non-economical solution |
| Increase BIL (insulator replacement or extension) | -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  
-Experience required for insulators replacement in live conditions |
| Improved tower footing resistances | -Additional copper counterpoises and grounding extension might be completely inefficient with high soil resistivity  
-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 feasability  
-Highest protective effectiveness even for high footing resistances in all terrains  
-Eliminate all types of lightning failures. | -Low material & labor costs  
-Several options for live-line installation.  
-Cost-efficient solution.  
-Possibility to replace insulators and EGLA as an integrated solution! |

Table 1: Comparison of mitigation methods

### 3. Various Benefits for Line Arrester Application

Besides the lightning performance improvement, various benefits can be derived from the use of LSA’s. Some users apply this technology for different purposes as:

- switching surge control to optimize structures and reducing clearances,
- line uprating and compaction,
- safety concerns such as preventing population and injury damage,
- and live line working to reduce the minimum approach distance

LSA’s, especially the EGLA’s, have an untapped potential to lower the costs of the line constructions and the operation.

#### a. Switching Surge Control

Reducing surge factors helps to lower clearances and therefore optimize transmission line designs. Switching over-voltages are typically associated with high speed reclosing on EHV transmission lines. Strategically placed, LSA’s 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 locations along the line. At each location, arresters are usually installed in all phases [9]. LSA’s 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. LSA’s for this application are typically used for system voltages of 245 kV and above. However, with the increasing use of compact or uprated line designs, this application is no longer reserved just for EHV levels [4] [5].

Even though EGLA’s are the most suitable design for overhead line application, NGLA application is dedicated to control switching over-voltages. For the IEC standard 60099-8, the external gap of EGLA is designed and tested to withstand switching transients. In addition, it is quite challenging to define an EGLA spark gap distance to withstand power-frequency wet and guarantee operation in case of switching impulse wet. The tolerances in the gap adjustment are very narrow. Furthermore, for switching control, only few arresters at selected location are required, therefore the easiest way is obviously to use NGLA because it might be not worthy of verification insulation coordination for only few units.

As an example of project, Figure 1a shows the reduced switching surge factor from 2.2 (red curve) to 1.8 (blue curve). It helped the utility to get their existing clearances acceptable. Figure 1b shows the installation of the NGLA in live conditions for the same project.
b. Line Uprating and Compaction

Compact and Uprated Lines are not a new topic for utilities and line designers. Significant improvements have been made in the last decades with insulators composite technology, but the concept has not reached yet its final stage since line arresters have not been considered to reduce clearances and substantially decrease the arcing distances. Due to the necessity for the utilities to build discrete and aesthetic line structures and the development of the composite line post and long rod insulators, compact line designs are a realistic alternative to the standard line designs [9]. Even though the LSA’s offer outstanding possibilities to optimize line compaction, most of the designers have not considered the technology due to a lack of experience and cooperation with arresters’ manufacturers.

Line uprating involves the increase of the operating voltage and the current carrying capacity by keeping the existing structure. Both conductors’ bundle and cross-arms/insulators strings must be redesigned. In general, for such a modification, several issues must be considered as phase clearances or insulator length. LSA’s become extremely helpful and economically justified to convert the existing lines to higher voltages without changing the clearances and insulator strings. It is certainly required that insulators strings and hardware components must be changed due to RIV/Corona stress depending on the existing components and performance.

For line uprating and compaction, the principle is the same. Line arresters are controlling overvoltage stresses on the line insulation. The conventional ratings, mainly lightning impulse withstand level, of the insulators can be reduced to the protection level of the EGLA. The lightning impulse sparkover voltage of the EGLA gap must be lower (or equal) than the lightning impulse withstand voltage of the insulator string. The protection level of the EGLA is the maximum residual voltage when the lightning overvoltage initiates a flashover on the EGLA. When the tests are performed to verify the insulation coordination between the EGLA spark gap and the insulator assembly, the flashover can only occur on the EGLA. The Series Varistors Unit (SVU) of the EGLA has the capability of extinguishing the arc without the necessity of a line breaker operation.

Up to a certain voltage level (330kV), switching surges become a critical factor for the dimensioning of the string. EGLA’s are not generally designed to be capable of protecting the line insulation from switching surges. Depending on the system parameters, several mitigation methods can be used to reduce the switching surge factors as improving station class arresters, installation closing resistors on circuit breaker or installation of shunt reactors (primarily used to stabilize the voltage during load variations).

But few NGLA’s along the line are definitely the most convenient and effective solution to reduce switching surge control, minimize the gap distance of EGLA on EHV systems and therefore maximize the compaction or the uprating of the line.
c. Safety concerns - Prevent population injury & equipment damages

In France, since the 60’s, growing urbans areas and extension of HV transmission systems has resulted in vicinity problems between suburban living areas and overhead lines. Externally Gaped Line Arresters have been used in those sensitive areas or “hot zones” as houses, factory, parking, etc [14]. The main purpose is to increase safety by significantly reducing the risk of having dangerous touch or step voltages due to power frequency earth potential rise following the insulation flashover. 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]. Such ground faults can result in several kilovolts for hundreds of milliseconds. During an EGLA operation, the follow current that must be extinguished by the SVU (Series Varistors Unit) is limited to few amperes in the range of 2-3A with durations of 5-10 milliseconds. As it is the case for lightning performance improvement, a due diligence process starts with the investigation of the grounding quality and the configuration of shield wires. Conventional methods are often costly and ineffective. French engineers have understood in the 90’s the advantages of EGLA application as its compact design and reliability. French utilities have adopted and experienced EGLA for safety concerns and lightning performance improvement for almost 20 years with very positive results with respect to long-term reliability, reduction of outages and of course safety improvement. Furthermore, there is a potential use of LSAs for mitigating the risk of gas pipeline failure from lightning strikes but also to prevent electro-magnetic dysfunction in IT buildings that can be caused insulators flashovers.
d. Live line working - Temporarily Reduce Minimum Approach Distance

Live working is an established part of maintenance activities for many utilities. A continued concern is, however, to ensure that work site will not be exposed to unacceptably high overvoltages during such work. Some Utilities use Portable Protective Air Gap (PPAG) to limit overvoltages at the worksite for energized maintenance work, but there are several disadvantages associated with it. As an alternative, EPRI in the USA is investigating the use of LSA’s for this purpose. LSA’s may provide an enhanced protection of workers, provided that practical ways be found to ensure the arrester integrity prior and during the execution of the maintenance tasks. Regular insulation tests on the active part are not relevant, as at least the MCOV should be applied to properly assess the condition. NGLA’s are preferable since the purpose during live line working is to protect linemen against switching overvoltages. Energy ratings requirements, specific for each line and work site, must be accurately defined to optimize the weight of the arrester which is an important feature for handling and installation on the line. The NGLA is connected from the phase conductor to the tower. The crest value of the overvoltages which might exist at the worksite is determined by the arrester rating, its residual voltage of protection level in relation with the protection distance. The arrester offers the advantage that its operation is not associated with a power arc as is the case for a PPAG, thereby minimizing the risk of exposing workers to power-arcs. The installation of arresters on all phases on structures adjacent to the work (work site structure not being equipped with LSA) may be sufficient to protect workers, depending on surrounding grounding conditions. Line Arrester should be used without a disconnection device in this application to ensure better worker protection [9] [3] [16].

![Figure 4: Installation of NGLA for live line working](image)

e. Lowering costs and losses in your system

Rocky soils and in general areas with very high soil resistivity can be a very difficult problem of achieving good lightning performance in the poor grounding conditions. EGLA’s can be used to replace costly and ineffective additional counterpoises and grounding extensions. Simulations can be performed to guarantee the EGLA performance below a certain measured footing resistance with reasonable safety margin. EGLA’s can be integrated to the insulators strings to simply mounting and work on site. Cost savings are generally underestimated.

A study conducted by Arresterworks has demonstrated the possibility to significantly reduce the capital costs of the construction and lower losses on transmission lines by installing EGLA on each tower and each phase instead of using an Overhead Ground Wires (OHGW’s) [1]. Most of the utilities and EPCs are reluctant at this stage because shield wires and OPGW are required in the project’s specification and the lightning strokes can physically damage the phase conductors. Anyhow, the costs savings are quite impressive and line designers have solutions to reinforce the conductors’ design and install optical fibres in different locations.
4. Comparison of 2 different applications: NGLA vs. EGLA

Non-Gapped Line Arresters (NGLA) is a basic adaptation of the substation’s arresters used to protect valuable equipment like power transformers. The active part is directly connected between the phase conductor and the grounded structure. The residual voltage of the MOV column will limit the overvoltages across the insulators and prevent flashover when BIL is exceeded. NGLA requires a clamping system to the conductor, a Ground Lead Disconnector (GLD) and in most cases a grading ring with a corona ring. The mechanical and mounting consideration is an essential step while designing NGLA. They are installed and used under harsher service conditions than other surge arresters at substations. The complete assembly is permanently stressed over its life. NGLA installation is made in such a way that they may move due to wind and/or line swinging and vibration. Users and manufactures must pay a special attention to avoid premature mechanical failures [15]. 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 reenergised 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

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 (SVU) 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. No breaker operation required [2]. The active component can have either one or two SVUs (on each side) depending on the system voltage level and user’s requirements. Relevant standards: IEC 60099-8

Figure 6 : EGLA (1 SVU) - Isolated from power line through a series gap
5. A smarter protection - Advantages of the EGLA application

a. Material
Less material is needed to design an EGLA. Metal Oxide Varistors (MOV’s) have a smaller diameter since the energy handling requirements are lower than NGLA. The EGLA must not handle TOVs and switching overvoltages which is not relevant for lightning performance. The rated voltage (Ur) of the EGLA has a different definition than a typical rated voltage for NGLA application. Ur of the EGLA represents the maximum phase-to-ground voltage to be extinguished safely during the follow current interruption test. Less MOVs are required in comparison to a NGLA design where Ur represent the temporary overvoltage (TOV) with prior duty. Figure 7 shows the Voltage- Current characteristics of 192kV rated NGLA and EGLA. EGLA’s protection level has always lower residual voltages. Additional hardware (support, counterweights) might be required for retrofit application if the existing strings do not allow differently. For new transmission lines, the “smart” integration of the EGLA makes the solution compact and cost-effective. The hardware can be eliminated. EGLA are specifically designed to improve lightning performance. NGLA’s are an easy coping of the station class arresters which is not optimized. NGLA’s require a clamping system to the conductor, a Ground Lead Disconnector (GLD) and a grading ring in most cases.

b. Costs
As described above, less material means lower costs. Not only material as MOV, FRP and silicone rubber but also hardware and accessories can be reduced and even suppressed. Significant cost savings must be considered depending on the final design of the mounting hardware. The higher the voltage, the more important are the costs reduction. Installation costs have been reported to be lower from different utilities. EGLA can be preassembled together with the insulator’s strings. Operation and maintenance costs are also lower due to the reliability and long-term stability of the design.

c. Electrical Performance and long-term stability
The protection level (residual voltage) of the EGLA is always better than NGLA since less MOV are required. The EGLA’s air gap isolates the SVU from the system under normal operation. Therefore, MOVs are not continuously under voltage and there is no leakage current and no electrical stress. A better ageing and a longer life are expected. Japanese utilities have EGLA installed on their network for more than 25 years which are still in good condition. EGLA is a smart solution which is specifically designed to improve lightning performance.
d. Installation
The weight of the complete EGLA solution should be lighter than NGLA. The SVU can be pre-assembled on the ground on the insulator strings (or directly on the tower structure) to ease the installation on site. The installation generally does not require the use of helicopters and cranes as it is for NGLA installation. Immediate vicinity to the insulator simplifies the final configuration and guarantees a proper installation. There are more options for installation in live conditions for existing lines. The pre-assembly of a complete set (EGLA + Insulators + Hardware) can be prepared by the supplier to optimize the mounting time and be lifted on the structure while reducing the risk of losing components.

e. Maintenance / Operation
Basically, no maintenance is required. The failure rate of the EGLA is extremely low. If properly designed and installed in the system, it should be considered as reliable as the standard components in the insulators strings. There is no specific monitoring required since regular overhead line inspection are performed by utilities. Failed SVU can be easily identified visually during line inspections. EGLA’s design must be rigid and stable. No moving parts are acceptable. The ground lead and the mechanical stress (vibration/galloping) of the NGLA reduce the reliability in comparison to an EGLA [15]. High resistance to vibration and mechanical stress as seismic activities can be demonstrated. SVUs failures do not influence continuous operation of the line due to the gap that isolates from the system. There is no need of immediate replacement.

EGLA cannot fail due to line fault. The gap is dimensioned to withstand power frequency and switching overvoltages.

6. EGLA usage across the globe
EGLA application is not a new development although it might be called new application since the outstanding features are not widely spread and communicated by the leading utilities and manufacturers. Most of those countries below in Table 2, with some exceptions, only accept EGLA application on their network. NGLA is prohibited due to reliability and long-term performance. The information below might be not all accurate, but they are representative of the global market.

<table>
<thead>
<tr>
<th>Country</th>
<th>System voltages</th>
<th>Experience</th>
<th>Installed based across the country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>from distribution to 500 kV</td>
<td>~25 years</td>
<td>Millions of units. Standard components. Only EGLA accepted.</td>
</tr>
<tr>
<td>China</td>
<td>from distribution to 500kV AC ±500kV and ±800kV DC</td>
<td>~15 years AC ~5 years DC</td>
<td>Millions of units. Market slowly dominated by EGLA only.</td>
</tr>
<tr>
<td>Mexico</td>
<td>from distribution to 400kV</td>
<td>20 years</td>
<td>~450.000 units. Only EGLA accepted [17].</td>
</tr>
<tr>
<td>South Korea</td>
<td>154kV and 345kV</td>
<td>13 years</td>
<td>~150.000 units. Standard component. Only EGLA accepted [13].</td>
</tr>
<tr>
<td>France</td>
<td>63/90kV and 225kV</td>
<td>~20 years</td>
<td>Initially used for safety concerns. Today used for lightning performance mainly in overseas islands. Only EGLA accepted [14]. More than 3000 units.</td>
</tr>
<tr>
<td>Vietnam</td>
<td>110kV, 220kV and 500kV</td>
<td>~10 years</td>
<td>More than 3000 units. Market slowly dominated by EGLA only. Massive investments.</td>
</tr>
<tr>
<td>Thailand</td>
<td>115kV and 230kV</td>
<td>~10 years</td>
<td>Market dominated by EGLA.</td>
</tr>
<tr>
<td>Canada</td>
<td>230kV</td>
<td>-</td>
<td>First EGLA project in 2019</td>
</tr>
<tr>
<td>Malaysia</td>
<td>132kV, 275kV and 500kV</td>
<td>25 years</td>
<td>~1200 units [18]. Market dominated by EGLA</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>for 132kV and 400kV</td>
<td>10 years</td>
<td>Less than 1000 units</td>
</tr>
<tr>
<td>Taiwan</td>
<td>69kV</td>
<td>~10 years</td>
<td>Less than 1000 units</td>
</tr>
<tr>
<td>Cambodia</td>
<td>115kV and 230kV</td>
<td>-</td>
<td>First project in 2019</td>
</tr>
<tr>
<td>Laos</td>
<td>115kV</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Complete overview of EGLA countries
7. Conclusion

The electricity supply industry is a conservative sector. New technologies and innovative solutions are in general experienced progressively. In the last decades, most of the activities were related to lightning outages reduction. LSA’s 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. A better synergy between line designers and arrester manufacturers might be an important way of enhancement to widely share the knowledge and experience. On the one hand, manufacturers should make the users more confident about long-term reliability since it is one of the main concerns for utilities and their customers. On the other hand, 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 uprating 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].

Currently, the IEC 60099-4 or IEEE C62.11 for NGLA application do not make a clear distinction between Line Surge Arresters and Station Class Arresters in term of energy handling requirements and mechanical considerations. There is not an IEEE Standard that addresses EGLA’s. The latest IEC 60099-8 EGLA Standard has two energy classifications, neither of which is sufficient to clearly define the energy performance. These issues should be resolved with the release of the new IEC 60099-11 that will cover both EGLA and NGLA applications.

Each revolution passes through three stages. First, it is ridiculed as installing EGLA’s systematically to optimize structures, quality and costs. Second, there will be some oppositions from the major players in the sector. Third, it will be accepted as being self-evident. LSA’s application will certainly become a standard component for the distribution and transmission lines in a near future.
1. REFERENCES

[16] Private discussion with EPRI.