The Evolution of Line Surge Arrester Technology

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Abstract

Protection for overhead lines against lightning has been a concern for utility engineers dating to the early rise of the telegraph. Line protection technology has evolved to better meet the demands of each era. Early devices such as lightning rods and simple current limiting gaps evolved into early surge arresters. Arresters have progressed from silicon carbide (SiC) to metal-oxide varistor (MOV) technology and later incorporated lightweight polymer housings. The latest progress was achieved by re-introducing external gaps to enhance the mechanical performance and longevity of line surge arresters (LSAs). Individual line arrester components in the assembly also benefited from user demands for increased durability. The continuing advancement of LSA technology can be attributed to both the public and commercial demand for a continuous and uninterrupted supply of electrical service.

This paper reviews the historical progress made to date and attempts to analyze where further enhancements are required.

Introduction

The damaging effects of lightning are an age-old problem. Before the rise of the industrial and electrical revolutions, lightning was known to have a paramount impact on the safety of people and towns. Early protection of telegraph lines became important, based on frequent damage from lightning strikes. Soon after the first telegraph message was sent in 1844, there was a need to protect from lightning. At the time the solution was simple lightning rods. This product had limited protection capability but did help divert the damaging high current to ground. This would dissipate the energy and current, while preventing further damage to the system. It did nothing however to limit the voltage magnitude which could overload equipment on the system.

The modern term "arrester" was introduced in 1847. However, expanded protection of overhead distribution and transmission lines was not commonplace. Surge protection was largely limited to transformers and other critical equipment where the internal insulation could fail due to significant overvoltages. Protecting distribution and transmission line insulation was simply not considered at the time.

Early Protection Devices

Fast forward to the 1950s. The latest line protection technology was expulsion arresters. They were applied on 34.5 kV and 138 kV lines. The devices were relatively lightweight and utilized fiber material for the housing. Like silicon carbide (SiC) arresters of that era they relied on a gap to isolate the active elements. Their poor longevity and maintenance costs quickly led to these devices being phased out. The protection of overhead lines was again largely avoided until the 1980s when the next design iteration appeared.

General Electric introduced a lightweight "strut arrester" in the early 1980s. Arresters of this period were manufactured using porcelain housings, while the strut design utilized a fiberglass wound tube with slip-on polymer sheds. The assembly incorporated an external air gap to ensure the MO resistor elements were not continuously energized. A select quantity were installed as a pilot project for an American Electric Power (AEP) 138kV line. The concept was cutting edge at the time, but the limitations in design flexibility and manufacturability limited its application. It did, however, give a peek at the next generation of line protection.

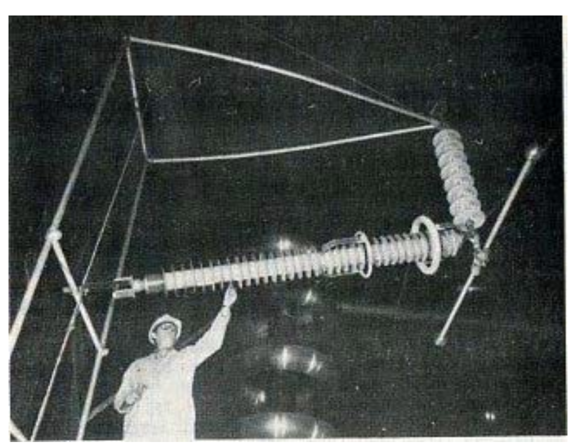

Figure 1: Strut arrester in laboratory – 1985

Non-gapped Line Arresters (NGLA)

A paradigm shift occurred when the first polymer distribution arresters entered the market a few years later. The rapid acceptance of this new technology led to the next generation of line protection. This evolution quickly led to the design and implementation of lightweight polymer-housed line arresters. These designs were direct connected, known now as non-gapped line arresters, without the use of a series gap. The product benefited from both the commercialization of metal-oxide varistor (MOV) blocks and the ability to remove both internal and external gap assemblies. These enhancements allowed customizing unique designs for a variety of mounting configurations and line voltages. The first commercially available design was introduced in 1988 by Hubbell (formerly the Ohio Brass Company) under the Protecta*Lite ® brand.

Figure 2: Installation of polymer housed NGLAs on 138kV circuit in late 1980s

Within 20 years over a million-polymer housed NGLA designs had been installed at various system voltages from 15-550kV. Implementing these products was aided by their ability to be configured for virtually all line applications. Designs may vary from simple to complex based on the unique nature of each application and the requirements of line designers. Note that design requirements are being increasingly influenced by the public perception of transmission lines. The seemingly endless configurations can be grouped in three variations: 1) arrester supported from line conductor, 2) arrester supported from structure, and 3) arrester mounted directly on phase insulator. Each configuration has a unique advantage that makes it more suitable for each application. An overview of each variation is provided to highlight best practice for each configuration:

Conductor-mounted

In this configuration, the arrester is mounted from the phase conductor with a ground lead connecting the arrester to ground. Attachment to the conductor is typically achieved using a hot line clamp or inverted suspension clamp. Necessary pivoting joints and mounting hardware are included to allow for a free range of motion as required for the application. A ground lead disconnector (GLD) is primarily installed at the bottom of the arrester in this configuration.

Figure 3: Conductor-mounted NGLA

Tower-mounted

In this configuration, the arrester is mounted from the phase conductor with a ground lead connecting the arrester to ground. Attachment to the conductor is typically achieved using a hot line clamp or inverted suspension clamp. Necessary pivoting joints and mounting hardware are included to allow for a free range of motion as required for the application. A ground lead disconnector (GLD) is primarily installed at the bottom of the arrester in this configuration.

Figure 4: Tower-mounted NGLA

Insulator-mounted

In select applications, the arrester can be mounted directly on the phase insulator. This arrangement is not always a viable option, based on the structure arrangement. The construction is primarily useful for dead-end arrangements or when post insulators are installed. The most common configuration includes mounting brackets or clamps which attach the arrester to insulator fittings on the line and ground side of the assembly. Necessary mounting hardware is generally included with the arrester to ensure the arrester can properly mount on the exact insulator installed. It's critical to ensure the arrester can safely disconnect from phase voltage in the unlikely event of failure. This free range of motion will prevent lockout of the line.

Figure 5: Insulator-mounted NGLA

The flexibility and ease of installing NGLAs made them a huge success in the global protection of overhead lines against lightning. Properly designed and installed NGLAs have proven to be highly reliable and the preferred choice for many utilities. That said, lessons have been learned since the early designs were introduced.

Recent publications have highlighted the need for robust, quality components in an NGLA solution. This includes not just the arrester, but the in-house design, testing, application engineering, and manufacture of high-quality insulators, connectors, and line hardware. This provides select manufacturers the competence to preassemble and kit many of the arrester components. The added step is key to benefit line crews during the installation process. It also ensures that non-standard LSA products can be properly configured and installed.

NGLA designs continue to evolve, making the product more robust and further enhance line protection. Enhancements include strengthened disconnectors to stand up to the mechanical requirements of the application, components with more corrosion resistance (such as high-quality stainless steel) and alignment with common connectors/hardware. It's important to consider parts that have been tested to industry recognized standards and have years of field experience.

Externally Gapped Line Arresters (EGLA)

A new line arrester concept entered the market in the 1990s. Although "new," externally gapped arrester designs have been used in some form for over 100 years. The reimagined EGLA capitalizes on maturing MOV elements, polymer housings and gap technology, which has led to a unique solu-tion for virtually all transmission applications.

The EGLA design principle is based on the combination of a series varistor unit (SVU) and an exter-nal series air gap. The gap functions to flashover at a precise point in the presence of lightning overvoltages. After the gap flashes over, surge current is directed through the MOV elements, which in turn limits the voltage from the initial spike. Internal MOVs conduct for the duration of the lightning surge and reseal to stop the flow of current. The gap functions to isolate the SVU from the circuit and prevent unintended ignition of the air gap. The EGLA remains idle until the next surge event.

Properly sizing the gap is critical to ensure the design can withstand but not flash over during other system events, such as switching, TOV, ferroresonance, etc. Select applications may require developing unique designs which mitigate switching surges. This is considered a rare application, as most switching events are adequately handled by arresters installed in the substation. If an EGLA is in-tended to handle switching duty, additional testing is required.

Initial EGLA designs were introduced in the late 1980s and early 1990s in Asia based on early product offerings from local manufacturers. These products have gained traction recently in other re-gions, including Europe, North America, and South America. Applications in the U.S. and Canada are still relatively low compared to the widespread and longstanding use of NGLA designs. The trend appears to be changing. This is based on a renewed focus on increasing transmission line reliability, especially for existing lines.

Hubbell realized the potential of the EGLA concept and introduced their design in 2022. The development of line arresters, generally, is quite unique because these are not off-the-shelf-type products. An externally gapped arrester is quite distinctive because it requires an exact under-standing of each application, down to the structure layout, geographic location, altitude, and climate of each installation. This is challenging for retrofit applications, common in the North American market, because details for tower geometry, phase insulators, and conductors are not always available.

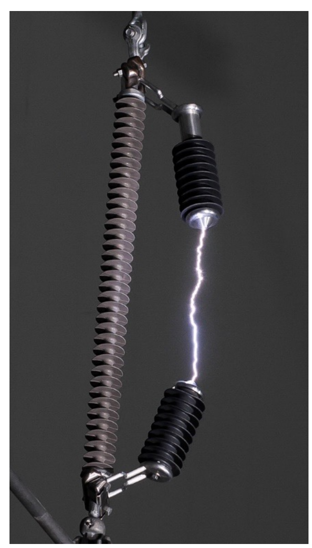

Figure 6: EGLA during sparkover testing

EGLA configurations can include one or two SVUs based on the utility and application needs. This is particularly advantageous to reduce the weight of the arrester and facilitate installation. Another benefit is mounting directly across the phase insulators. This is sometimes required when the con-ductor or insulator swing exceeds the series gap tolerance. It can also be helpful in areas that ex-perience high wind speeds, conductor loading due to ice, or other extreme environmental effects.

EGLA designs are governed by their own standard, IEC 60099-8. This international standard was re-leased in 2011 and subsequently revised in 2017. Revisions align with the latest version of IEC 60099-4. Unique tests are incorporated in the IEC 60099-8 standard to ensure robustness of the design and consistent performance of the external series gap. These tests include the follow cur-rent interrupting test and vibration test.

The EGLA design has been shown to be advantageous because it eliminates some of the common NGLA drawbacks. For instance, large fluctuations in the power frequency voltage will not risk over-loading the MOV blocks. Instead, the series gap isolates the SVU from any continuous flow of leak-age current. In the case of an NGLA, the MCOV is typically oversized to mitigate these power fre-quency concerns. TOV-type failures can be troublesome as system load continues to increase based on heightened demand.

Control of the series gap spacing is a critical requirement for the design of an EGLA. This requires a well-published tolerance on appropriate gap spacing from the manufacturer. This ensures the de-sign operates as intended during mechanical conditions such as conductor movement due to con-ductor galloping or high wind, icing of the line, avian interference, or other extreme conditions. Additional considerations are required to ensure proper electrical performance of the EGLA to sur-vive both power frequency and switching events without igniting the gap (unless a specialized product is designed to accommodate switching activity).

Since an EGLA does not physically disconnect from phase or ground voltage, the assembly also needs to maintain its mechanical integrity. In the unlikely event of SVU overload, the gap elec-trodes have to maintain both mechanical and electrical longevity by withstanding termination of an external power arc. This is a common requirement for line insulators, but a new consideration for arresters. It is key to choose a material for the electrodes with the appropriate strength and re-sistance to oxidation after arc termination. Acceptable materials include stainless steel, galvanized steel, or aluminum. Other materials may be used, but their resistance to corrosive environments after arc termination may be insufficient.

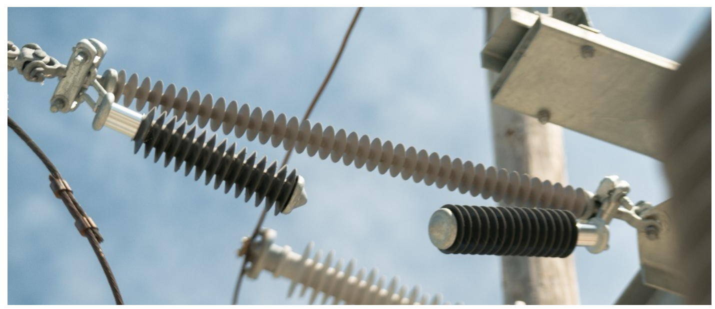

Figure 7: EGLA line arrester – 69kV

It is important to note that a NGLA is typically equipped with a disconnector to activate in the event of arrester overload. EGLA products include no such device. Select EGLA offerings have in-cluded a fault indicator to reveal the status of an EGLA in the event it reaches a failed state. This simple device reveals the operational condition of an EGLA from a sufficient distance (typically with a ribbon or bright lead that is revealed). Note, no such tests have been developed to cover fault indicators; however, this will be covered by future standards.

Standards Development

As the implementation and use of line surge arresters spread across the globe, success stories and lessons learned followed. The industry and select manufacturers have over 35 years of design and application experience to study. While the exact number has not been confirmed, it's estimated more than 5 million line arresters have been installed in this time. However, the development of industry standards for LSAs has otherwise been slow to catch up. NGLA designs are largely un-addressed by current IEEE and IEC standards. Instead, existing test procedures defined in IEEE C62.11 and IEC 60099-4 were largely utilized based on industry-wide adoption. The uniqueness of EGLA designs ultimately led to the introduction of a IEC 60099-8 test standard in 2011. Revisions introduced in 2017 align with recent changes to the main surge arrester standard, IEC 60099-4 which was revised in 2014.

It became apparent in recent years that additional work was needed to govern the unique applica-tion and design of LSAs. Arrester experts began the daunting task of writing a new standard to cover all LSAs. This ambitious effort includes provisions to cover both NGLA and EGLA designs for both AC lines and potential future DC applications. The task force pushed the limit further by defining this as a dual logo IEEE-IEC standard. This is the first joint logo standard covering surge arresters. The new joint IEEE-IEC standard will be identified as IEC 60099-11.

Work began on developing the new standard in 2017. Experts from around the world have been diligently identifying shortcomings which need to be addressed in the new standard. This includes revising existing arrester tests to cover the unique application of line arresters. Examples include operating duty, disconnector operation and repetitive charge transfer rating. New tests were also identified to cover the unique nature of line applications and the wide variety of designs on the market. Example tests under development include torsion, tension, lead maintenance and others.

Because industry standards have not previously identified the unique nature of line arresters, existing distribution and station arrester products have been adapted for these applications. The ongo-ing standard development for IEC 60099-11 has the potential to change this concept. Establishing new line surge arrester classes is an important aspect of the ongoing standard development. This includes LSA specific waveshapes, energy ratings, and charge transfer ratings for the new LSA classes. Note, these classes are still under development, but should be finalized later in 2024.

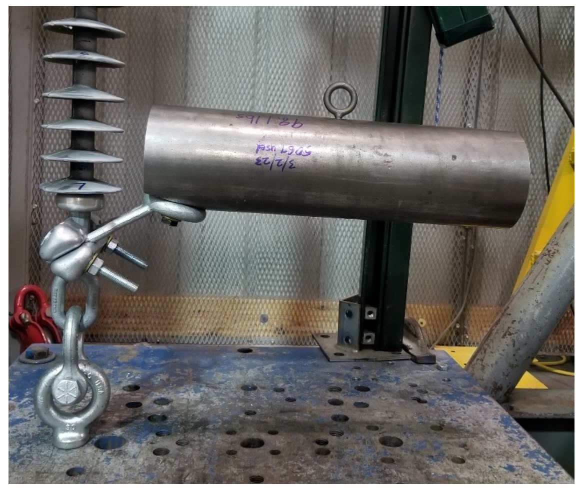

Figure 8: EGLA support hardware under mechanical testing

New requirements and application considerations can push for the future of specific line surge ar-rester designs. As change can sometimes be slow in the utility industry, the next step will be to finalize the new LSA standard and educate line designers and utility standard engineers. Each manu-facturer will similarly be tasked with certifying existing products and developing new arresters for the line-specific arrester classes. This time-consuming task will ultimately lead to the development, certification, and installation of improved LSA designs, including base arresters and hardware.

Future Enhancements

If history is any indicator, the future will continue to push the boundaries with the introduction of enhanced surge protection products. This could be achieved by a paradigm shift, like the launch of polymer housed line arresters. In the short term, it's likely that more robust products will be in-troduced. The implementation of new line surge arresters will only be possible through continued education and appreciation for the unique nature of LSAs. Such designs should not be considered an off-the-shelf or commoditized product. This will prompt manufacturers and users alike to de-mand a high-quality product suitable for the unique requirements of each application.

The relative few drawbacks of NGLAs will focus enhancements on creating more robust mechanical connections. This may include strengthened cables capable of withstanding higher levels of wind loading, icing, vibration, and conductor swing. Disconnectors may be reinforced to withstand simi-lar conditions. Unique test programs are currently being developed to quantify the durability of various line arrester components and the arresters themselves. Examples include lead manage-ment, which will both quantify and qualify ground and line cables. Other tests are considered for the tensile, torsion, and compression ratings for line arrester hardware and fittings.

All LSA hardware components should be capable of withstanding harsh conditions from the ex-tremes of desert heat to coastal salt spray. Continued enhancements are critical as extreme weather conditions appear to become the norm worldwide. Recent field performance has indicat-ed that prior industry-accepted products may not be suitable for all environments.

One improvement to enhance corrosion resistance is the transition from specifying traditional hot dip galvanized (HDG) components to thermal diffusion galvanizing (TDG). TDG is a method of apply-ing a uniform, sacrificial, zinc iron alloy coating using a metallurgical vapor diffusion process. Testing has proven that TDG exhibits a superior resistance to corrosion when compared to traditional HDG.

Performance can be considered equivalent to stainless steel components at a fraction of the cost. Industry standards (reference ASTM A1059) are evolving to incorporate TDG as a suitable or even superior alternative to HDG. An additional and possibly game changing benefit is the green nature of the TDG application process. The EPA ruled the TDG manufacturing process approaches zero dis-charge. This can eliminate the caustic cleaning solution and pickling acid required for traditional HDG treatments.

Figure 9: HDG test samples (left), TDG samples (right) after 2850 hours salt fog

Both user and manufacturer experience are a key factor to ensure a properly designed, tested, and configured line arrester solution for every application. This experience can sometimes be forgotten with mature product lines. Further industry adoption of LSAs is sure to drive field performance improvements and prompt major leaps that will benefit from new and emerging technologies. Short term impacts will improve the robustness and field performance of all line arresters. While the next major paradigm shift does not seem imminent, it's certain that the development of new standards will push the envelope and open the door.

Conclusion

The future is unknown; however, one thing is clear—the demand for clean, uninterrupted, and reliable electricity will be supported by the evolution of line surge arresters. Technological improvements will inevitably lead to LSAs being the first solution to improve line performance rather than an afterthought. The continued evolution of LSA technology will undoubtably justify the increased usage of this protection method.

It is safe to say the future is bright for the continued evolution of line surge arrester technology. Enhanced designs have gradually been introduced over the last 35 years. The establishment of a singular international standard will accelerate the introduction and development of the next generation of products. This step will not just prompt, but rather demand the introduction of more reliable and innovative designs. Further justification will be supported by continuing feedback, acceptance, and education on the advantages of using LSAs. The adoption of new technology will be an interesting development to follow and review in the future.

Hubbell is proud to have been involved since the beginning with line surge arresters. Our organization is keen to participate in the development of new and improved standards for surge arresters, with an acute focus on the unique nature of LSAs. We take great pride in our history and expertise, which support a board line arrester portfolio. Now with a complete offering of both NGLA and EGLA designs, you can count on the breadth, experience, and quality of Hubbell Protecta*Lite® solutions.

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About the author

Mr. Freeman graduated from the University of South Carolina in 2011 with a Bachelor of Science in Mechanical Engineering. He joined Hubbell Power Systems, Inc. as a Design Engineer responsible for high voltage surge arresters. His responsibilities included maintaining design and testing for various arrester products, including line surge arresters. He later transitioned to the Application Engineering team in 2015, with roles of increasing responsibility, including Sr. Application Engineer and Product Manager. Currently, he works as Sr. Product Manager responsible for all Hubbell surge arresters. A member of IEEE since 2012, he currently serves as Vice-Chair for IEEE SPDC WG 3.3.11. He is also a member of IEC TC37, IEEE 693 and involved with CIGRE.

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