

# PERFORMANCE & REVENUE ENHANCEMENTS UTILIZING LINE SURGE ARRESTERS

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## ABSTRACT

Surge arresters are commonly applied across all system voltages to protect critical equipment insulation from failure due to high voltage surges. This paper presents the effectiveness of applying polymer housed line surge arresters to eliminate momentary interruptions caused by lightning. The appropriate selection and design of a line surge arrester is critical to ensure proper protection and performance are achieved. Utilizing line surge arresters can serve as an economical alternative to retrofitting lines with an overhead shield wire or completely rebuilding a line. Using this technology can improve performance, while also extending the useful life of valuable assets.

## INTRODUCTION

The Digital Age prompted a significant change in consumer demands for reliable electric power. In prior years a momentary interruption in electric power was considered tolerable for a residential consumer. However, with the advancement and prevalence of computers and other high-tech devices, momentary interruptions have become the major source of customer complaints. Consumer demands for reliable electric power continue to increase with technological advances.

The severity of a minor interruption can range from an inconvenience to a significant loss in productivity for consumers. The cost of momentary interruptions is known to significantly impact manufacturing facilities, by means of lost revenue. Interruptions can cause security and safety risks for hospitals, schools and government entities. Furthermore, momentary interruptions are now considered intolerable for the average residential consumer.

Methods to mitigate lightning induced interruptions, such as expulsion arresters, have been available for over 60 years. However, until the late 1980's, protective devices were not commonly applied on transmission lines. The development of the Metal-Oxide Varistor (MOV) disc in 1967 opened a new doorway for overvoltage protection. Advancement of the MOV technology pioneered an evolution in arrester design and functionality. It also commenced the use of line surge arresters, although for a short time in porcelain housings.

Hubbell Power Systems, Inc. (HPS) first introduced gapless MOV polymer housed line surge arresters (LSA) in 1988 under the Ohio Brass® brand. The practice of applying polymer line surge arresters was quickly adopted following the introduction of the first MOV polymer housed distribution arrester in 1987. Since the line surge arrester introduction nearly thirty years ago, millions of line surge arresters have been installed at varying system voltages around the world.

Numerous case studies and application testimonials have been provided on the successful usage of line surge arresters, at events such as the Insulator News and Market Report (INMR) World Congress. However, the adoption of line surge arresters is an uncertain concept for some utilities, even though the technology has proven itself time and time again. Other interruption mitigation practices can be preferred due to a more extensive product history.



Figure 1: Installation of polymer housed line surge arresters in late 1980's

In the United States, Pennsylvania Power & Light (PPL) Electric Utilities serves 1.4 million customers across the state of Pennsylvania. PPL operates and maintains 8,530 km (5,300 miles) of transmission lines. Line voltage within their network ranges from 69 to 500 kV. Over 5,149 km (3,200 miles) of their network is composed of 69 kV transmission lines.

In 2013, PPL initiated a transmission reliability and performance improvement campaign. To accomplish this, the utility understood reducing their Momentary Average Interruption Frequency Index (MAIFI) would be a critical step. Lowering the MAIFI factor would help serve customers better and improve system reliability. Several options were considered, such as upgrading existing Overhead Shield Wires (OHSW), completely rebuilding the problematic lines and adding line surge arresters.

## LINE SURGE ARRESTERS

Since the introduction of line surge arresters in 1988, polymer housed line surge arresters have been applied across various climates, voltage ranges and structure configurations. The implementation of polymer housed line surge arresters is still a relatively new technology compared to more traditional methods for improving transmission line reliability, such as:

- Implementation of an OHSW
- Upgrading an existing OHSW shield angle
- Increasing line insulation
- Improve ground footing resistance
- Complete line rebuild to incorporate the aforementioned concepts

Line surge arresters are widely available and in use across the globe and have been grouped into two categories in recent years:

1. Gapless Arresters: which have been referred to as a transmission line arrester (TLA), line surge arrester (LSA), line arrester (LA) and non-gapped line arrester (NGLA)
2. Externally Gapped Line Arrester (EGLA)

For purposes of this paper the discussion will focus on the technology herein referred to as a line surge arrester. The design and features of line surge arresters vary greatly depending on each application. Custom solutions are necessary to ensure proper clearances, arrester temporary overvoltage capability, external environmental forces and installation methods are properly considered and evaluated.

HPS provides line surge arresters through the Protecta\*Lite® system. Custom solutions are available as an assembly of polymer arresters and insulators or as an arrester alone. Hardware specific for each application is included to allow installation on utility specific structures and systems. More than a half million Protecta\*Lite systems are guarding distribution and transmission lines worldwide.

Over the last 30 years, line surge arrester design enhancements have been implemented through work with end users. Some modifications have included improving the mechanical connections to prevent breakage of the line or ground

connections and ground lead disconnecter. Line and ground connections have been strengthened using hot dip galvanized steel chain, rather than just a flexible lead wire. Other enhancements have focused on allowing a full degree of motion for installed line surge arresters. The full degree of motion allows the installed arresters to pivot during windy conditions without binding.

### DETERMINING THE ISSUE

Lightning severity is generally assessed by considering the Ground Flash Density (GFD) for a particular region. The severity for an area varies drastically when considering different locations, such as California versus Florida in the United States. The state of Pennsylvania, where PPL is located, has a moderate flash density in comparison to a more severe state, such as Florida. Typically, the peak season for lightning activity in Pennsylvania runs from May through September.

Vaisala is an international company founded in 1936. Today, the company is a world leader in many measurement fields, such as lightning tracking. Vaisala offers real-time lightning data for accurate and early detection of severe weather. Weather monitoring from Vaisala indicates an average GFD for the state of Pennsylvania varies from 1 to 8 flashes per square km annually. Based on historical lightning data PPL assumes a GFD of 2.7 flashes per square km annually. The GFD can vary annually depending on ever changing weather conditions.

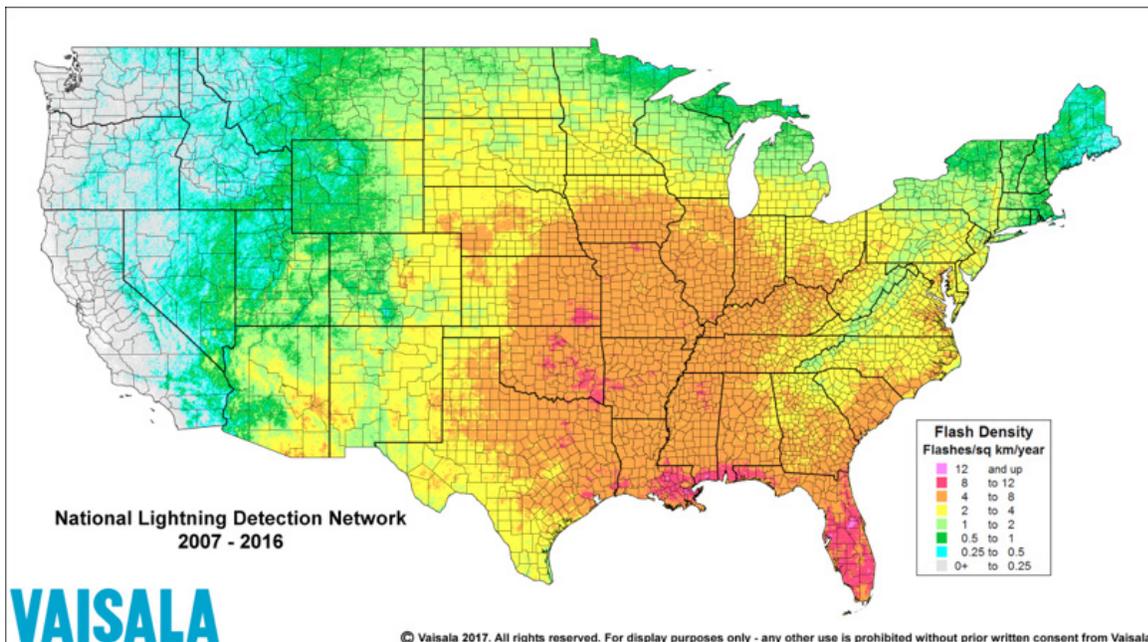


Figure 2: United State average lightning flash density map (2007-2016)

PPL's service territory features some older transmission lines which use an OHSW that doesn't meet current standards. Depending on when the lines were constructed, an OHSW probably wasn't standard practice for utilities. Today, 138kV circuits employ OHSW as standard practice. Furthermore, through assessment, the MAIFI was found to be intolerable for both 69 and 138 kV PPL lines.

Utilities are able to reduce the probability of a lightning strike directly terminating the phase conductor through use of an OHSW. The reduction in probability of a direct lightning strike correlates to a reduction in lightning induced interruptions and improved system reliability. It is possible to retrofit current lines with an OHSW by adding a bayonet to unshielded lines. In some instances, however, wooden poles may not be capable of handling the added load.

It is possible that even when an OHSW is designed and implemented properly, the line may still experience issues due to other impeding factors. Specifically, utilities have experienced issues with lines or structures that have high soil resistivity and ground footing resistance. If lightning strikes the OHSW with poor grounding conditions, a potential increase is experienced across the line insulators. At this point, a flashover from the tower to phase conductor can occur.

Ground footing resistance within PPL's service area was estimated to be greater than 50 Ohms. Current design criteria for PPL mandates structure grounds of 25 Ohms at each structure. The majority of existing structures utilize a single ground rod. The quantity and depth of ground rods can improve the ground footing resistance; however, the improvement can vary with time.

Based on their current outage activity, PPL determined they needed a solution to improve overall line performance across their service territory. Lowering the number of interruptions would directly benefit customers with a more reliable power source, while also reducing wear and tear on existing equipment.

## MODELING AND DESIGN

Through assessment of the transmission lines, PPL determined that interruptions were caused by lightning. The utility's engineers were able to model their application using the Transmission Line Workstation application developed by The Electric Power Research Institute, Inc. (EPRI).

During evaluation, PPL considered completely rebuilding some of the problematic lines which would be a significant investment. However, the utility decided to install line

surge arresters to achieve the protection and reliability they required without the overhaul of transmission lines. A significant reduction in annual interruptions was predicted if the utility were to install on the top and bottom phases of every circuit and tower. Initial research focused on the worst performing 69 kV circuits. PPL took the project a step further by analyzing the use of line surge arresters on every phase of every tower.

Based on prior use of line surge arresters, PPL dictated the design needed to be versatile to allow use on multiple structure configurations. Arrester protection was required on wood poles, steel lattice towers and steel monopoles. PPL engineers worked directly with HPS to create a custom Protecta\*Lite system arrester for their application.

PPL chose a design with high level of product adaptability to increase productivity during installation, while also minimizing inventory management. The line surge arrester design featured two shackles on the line and ground end attachment points. This feature added a high degree of flexibility to prevent a potential mechanical failure. The connecting hardware could bind and fail due to high winds, without the added mobility. PPL provided additional connection hardware to align with current standards and stocked inventory.

In an effort to coordinate with existing substation arresters, a 57 kV Maximum Continuous Operating Voltage (MCOV) arrester was chosen for the 69 kV applications. This MCOV ensured the arresters temporary overvoltage (TOV) capability would be adequate for the system. Further modeling efforts revealed a MOV disc consistent with a heavy duty riser class arrester was appropriate for the application.

After a successful design of the 69 kV arresters, the focus shifted to applications at 138 kV. A similar modeling effort was followed to determine the appropriate arrester MCOV and type, as well as placement. Through designing the line surge arrester implementation, PPL concluded the use of arresters on all three phases of every structure would yield the performance they desired.

Results of the system study concluded a station class type arrester was required for the 138 kV circuit. The design also provided enhanced mechanical strength. According to arresters currently being used in the utilities substations, the arresters for the 138 kV applications were sized at 106 kV MCOV. This method also eliminated TOV issues that were experienced in prior installations utilizing 84 kV MCOV line surge arresters.

\* EPRI is a US based independent, nonprofit organization that focuses efforts on public interest energy and environmental research. Software similar to Transmission Line Workstation in use today includes: T-Flash, EMTP-RV, and ATP-EMTP and Sigma-SLP.

## INSTALLATION

Based on prior experience, the utility understood arrester placement and connections lengths were critical to ensure good performance. Arrester placement is important to ensure the desired protection level is achieved. If the line and ground connections did not incorporate appropriate slack for conductor movement the leads could suffer a mechanical failure. Maintenance was then required to repair and reconnect the arrester.

Therefore, PPL sized the arrester lead connections during installation which also ensured one design could be used on a variety of structures and line configurations. To ensure a robust connection, a galvanized steel chain was used in tandem with the standard #4 AWG copper arrester lead wire. The high level of flexibility added time to the installation process, but it also ensured each arrester was appropriately configured for the given application. PPL engineers were present to train line crews and answer questions during installation and to ensure arresters were installed according to design specifications.

The 69 kV arresters were installed with the system energized to ensure a minimal impact to customers. PPL incorporated a hotline clamp in the design to complete the installation. However, on the 138 kV systems available clearances and weight of the line surge arresters mandated these arresters were installed with the system de-energized. A typical installation for 69 kV and 138 kV applications are shown in Figure 3 and 4, respectively.



Figure 3: Typical 69 kV line surge arrester application



Figure 4: Typical 138 kV line surge arrester application

Since starting the reliability improvement project in 2013, PPL has purchased and installed over 27,000 line surge arresters on 69 kV lines and over 1,500 line surge arresters on 138 kV lines.

## LINE ARRESTER PERFORMANCE

Since 2013, momentary interruptions have been completely eliminated on transmission systems protected with line surge arresters. The reliability project was expanded to cover 138 kV lines with similar effectiveness. Prior projects involving line surge arresters were sporadic and only included lightning protection on select structures and service areas.

Lightning induced interruptions have decreased on 69 kV circuits from 138 in 2011 down to just 11 in 2017 (through June). Similarly, interruptions on 138 kV circuits have decreased from 26 to 0 in 2017. The interruptions PPL has experienced across their system occurred on lines that are not protected using line surge arresters. PPL estimates that collective annual interruptions will be in the range of 20 to 25 by the end of 2017. The 2017 estimate is a significant improvement from 164 interruptions that occurred in 2011. Annual momentary interruptions are summarized in Table 1 for over 5,633 km (3,500 miles) of PPL 69 and 138 kV transmission lines.

	2011	2012	2013	2014	2015	2016	2017 (through June)
69 kV	138	121	81	78	50	34	11
138 kV	26	15	8	2	1	2	0

Table 1: Annual momentary interruptions due to lightning

A major

lightning storm occurred in 2016 and all the lines retrofitted with line surge arresters were protected. During the same storm, an unprotected section of a 69 kV transmission system without line surge arresters experienced 11 momentary interruptions. PPL is currently in the midst of a 12 year program to track transmission reliability and performance.

## MAINTENANCE

Since starting the widespread installation of their line surge arresters, PPL has not experienced a lightning induced interruption on protected lines or a lightning related failure of any installed line surge arresters. The rare issues that have occurred were external flashovers attributed to avian interference. Two occurrences were confirmed via a bird carcass at the site of flashover. These issues were concentrated on the 138 kV systems and were attributed to installation practices.

An investigation revealed birds were compromising the phase-to-ground clearance of the installed arrester and davit arm. In these cases, the installed arrester either pulled the jumper loop in closer to the upper support members or the arrester grading ring reduced the phase-to-ground clearance on the lower davit arm. When a bird perched on the bottom

phase davit arm the air gap between the lower phase and the arrester grading ring was compromised. This issue has been isolated on the middle phase.

Phase-to-ground clearances have not been an issue on any 69 kV applications. The problem was mitigated on future installations by adjusting the line connection length during installation. An additional instance was confirmed to be the culprit of a bird streamer.

## REVENUE ENHANCEMENTS

During the evaluation phase PPL considered rebuilding problematic 69 kV lines to improve line reliability and performance. A new line would benefit from a dual OHSW and be built to current standards. The new lines would have a near zero degree shield angle. However, a detailed analysis revealed retrofitting the line with line surge arresters would be a more economical option.

The cost for constructing a new line varies depending on a number of factors including line design, altitude, topography and even the number of crews used during line construction. However, the cost can be estimated using commercially available data. In 2014, a utility in California estimated that a new double circuit 69 kV transmission line could cost upwards of \$2M per mile.

After determining line surge arresters were the more economical solution for their problem, PPL needed to determine appropriate arrester placement. Installing arresters on the top and bottom phases of each circuit and tower would yield a significant reduction in lightning induced interruptions. The goal was taken a step further using arresters on all three phases to completely eliminate the chance of an interruption caused by lightning. Since line crews were already planning to install arresters on every tower, the solution was justifiable.

Typical use of line surge arresters is classified as an operation and maintenance expense, but widespread use of line surge arresters can be defensible as a capital expenditure with proper justification. For PPL, the use of line surge arresters was able to offer a significant reduction in their MAIFI factor, while extending the life of critical assets. Applying arresters to all phases of each tower supported the justification. The use of line surge arresters will extend the life expectancy of PPL protected transmission lines for another 30 years.

There are more benefits available through the use of transmission line arresters. One example is less wear and tear on existing equipment and assets. When an overhead line experiences an external flashover, a breaker operates to interrupt the flow of current. Breaker maintenance is required after a specified number of operations are performed. Utilizing transmission line arresters would reduce the number of breaker operations, save maintenance costs and further extend the life of utility assets. Savings are also realized by reducing the number of insulators that may experience an external flashover. An external power arc could lead to a breakdown in insulator string integrity.

## CONCLUSION

A utility can significantly improve the reliability and performance of transmission lines utilizing polymer housed line surge arresters. Line surge arresters need to be carefully designed for each application to ensure adequate protection and mitigate potential issues. Proper handling and good installation practices help to ensure superior performance. Following these guidelines will ensure optimum performance and longevity of line surge arresters. A solution to the age old problem of lightning induced insulators flashovers is within reach with line surge arresters. Hubbell Power Systems, Inc. has been developing custom line protection solutions with Protecta\*Lite® systems arresters for nearly 30 years.

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## **BIOGRAPHY**

Ryan Freeman graduated from the University of South Carolina in 2011 with a Bachelor of Science in Mechanical Engineering. He joined Hubbell Power Systems, Inc. (HPS) in 2011 as a Graduate Rotation Program (GRP) Design Engineer. His first year with HPS involved design projects with various business units including Arresters, Insulators, Cable Accessories, Switching and Enclosures.

After completing the GRP in 2012, he transferred to the Arrester Business Unit in the role of Design Engineer. Ryan is currently an Application Engineer with the Arrester Business Unit, responsible for marketing HPS surge arresters. His primary responsibility includes management and design of the line surge arrester family, Protecta\*Lite® Systems.

Ryan has been a member of IEEE since 2012. He is a member of the IEEE 693 Seismic Design for Substation Working Group (WG). He is also involved with CIGRE WG C4.39 "Effectiveness of line surge arresters for lightning protection of overhead transmission lines".



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