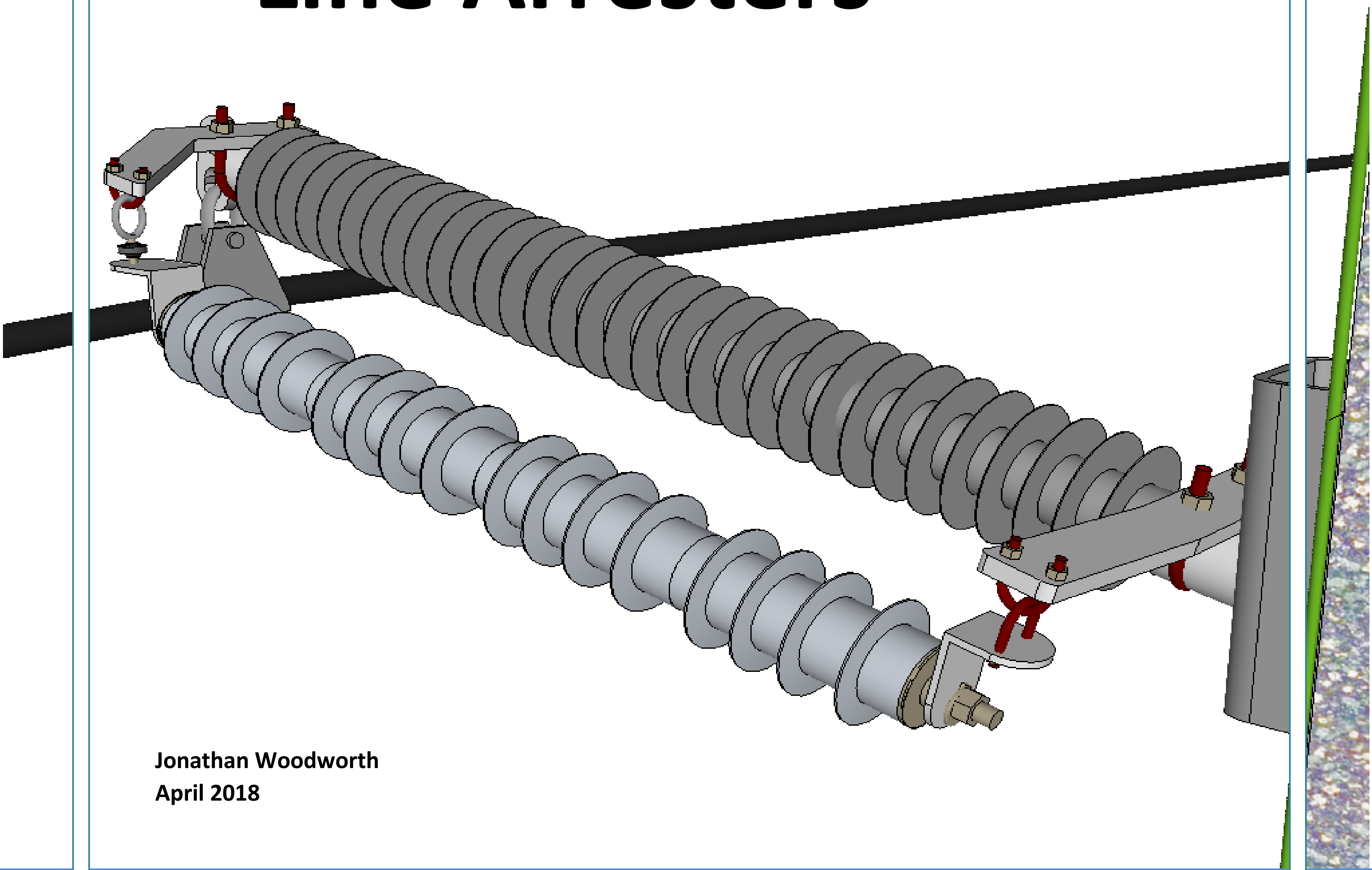
ArresterWorks

Improving Power System's Performance with Line Arresters



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Introduction

Non-gapped and Gapped Transmission Line Arresters (NGLA or EGLA) are the biggest opportunity for reliability improvement in transmission systems. However, the value of the TLA transcends this most common application. This ArresterFacts is about the 10 applications of transmission line arresters that can be used to improve power system's performance.

The Transmission Line Arrester

An NGLA is an arrester applied in parallel with transmission line insulators to prevent insulator flashover as shown in Figure 1. The EGLA which operates essentially the same as NGLA (See article in INMR Q2 2015) is shown in Figure 2. When either of these TLA arrester types is used, if the phase it is attached to is struck by lightning or experiences a switching surge, it conducts the excess current and charge to ground. If the TLA is applied to a shielded line, it quite often conducts current from the down ground onto the phase to avoid a backflash. If a forward flash occurs, it is easy to visualize the event, but with a backflash, it is not so easy. To help understand the backflash, Figure 4 can be used as a reference.

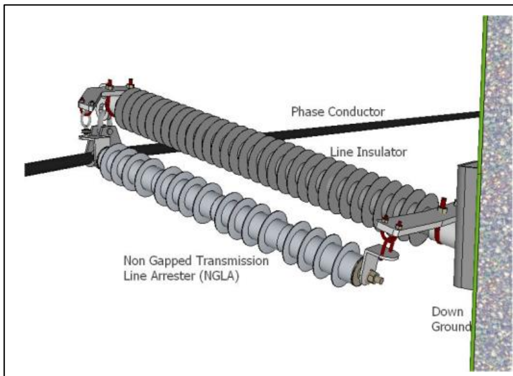

Figure 1: Non-Gapped Transmission Line Arrester (NGLA)

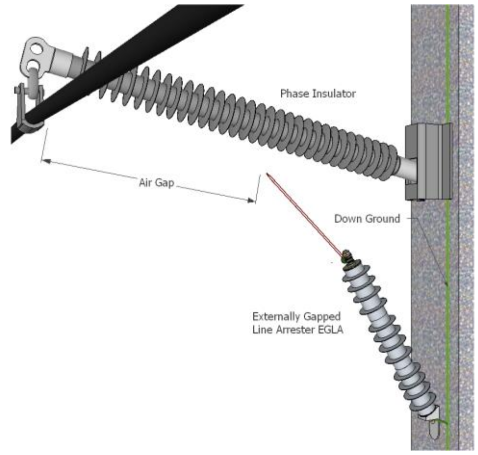

Figure 2: Externally Gapped Transmission Line Arrester (EGLA)

Before going into the TLA examples, it is important to discuss what is sometimes one of the biggest concerns of those using TLAs for the first time; the long-term reliability and maintenance of the TLA. There was a time when gapped silicon carbide arresters had questionable reliability. However, in this mature MOV arrester era, reputable suppliers have consistently achieved arrester failure rates that are close to that of insulators. US manufacturers recent experience in failure rates are in the 200 parts per million (ppm) range and this is most likely the same of most reputable manufactures worldwide. With this level of reliability there should be no hesitation on the part of new users of line arresters due to reliability.

Regarding maintenance, there is none—simple as that, install them and forget them is the norm. If, however you wish to monitor the TLA population, thermal imaging is recommended. Also, in the near future, more versatile continuous health monitoring of arresters will be available. See Hubbell's US patent application on thermal sensing inside arresters. (US020160265978A1 20160915)

1. Lowering clearances on EHV systems above 345kV

The National Electrical Safety Code (NESC, IEEE C2-2012) specifies horizontal and vertical clearances of unguarded parts and clearance to live parts of extra-high-voltage (345 kV and above) power systems. Basic clearances are specified, which can be adjusted based on switching surge amplitudes. If line clearances are found inadequate to meet NESC criteria, TLAs can economically control the switching surge amplitudes with a few installations along the line. For example, on a 500kV system, maximum crest operating voltage (line to neutral) is 449kV. If the switching surge (line to ground) voltage is 808kV, switching surge factor is 808/449.1 = 1.8 pu.

In Table 124.1 part B of the latest NESC (IEEE C2-2012), clearances are given for switching surge factors ranging from 1.8 to 2.7 pu for a 500 kV power system. The clearance for a 1.8-pu switching surge max is much less than for a 2.7-pu surge. This can make a significant difference in the width of a right of way, saving thousands of dollars in the project. This is discussed in detail in a paper presented at the INMR World conference in 2013 by James Hunt of SRP on this subject.

Table 1 shows just how much of an impact arresters can have on clearance requirements. If a 345kV system is insulated very high for contamination or other reasons, the clearances can be reduced by as much as 57% by using arresters. Note that EGLA designs in this case would need to be designed for switching surges and not only lightning surges.

Note that other constraints on line clearances

Table 1

EHV System Clearance Examples With and Without Arresters Installed

System Voltage Line to Line (kV)	Insulated to Line BSL (kV)	Switching Surge Factor pu	Clearance without Arresters (Inches)	Clearance with Optimal Arrester (inches)		Clearance Reduction with Arresters (inches)		% Reduction in Clearance with Arresters	
	per IEEE 1427	per IEEE 1427	per IEEE 1427	NGLA 258/209kV SSL =515kV SSF 1.75	EGLA 258/209kV SSL ≈ 386kV SSF = 1.31	NGLA	EGLA	NGLA	EGLA
362	550	1.86	50	47	35	3	15	-6%	-30%
362	650	2.2	61	47	35	14	26	-23%	-43%
362	825	2.79	81	47	35	34	46	-42%	-57%
362	1050	3.55	110	47	35	63	75	-57%	-68%
				NGLA 420/335kV SSL =832kV SSF of 1.86	EGLA 420/335kV SSL ≈ 624kV SSF = 1.40				
550	900	2	91	84	63	7	28	-7%	-31%
550	1050	2.34	110	84	63	26	47	-23%	-43%
550	1300	2.89	150	84	63	66	87	-44%	-58%
550	1550	3.45	195	84	63	111	132	-57%	-68%

however may affect the minimum attainable level. ARC Flash requirements area known to be more stringent than standard clearances at certain voltages. Comfort levels of workers in smaller clearances also needs consideration. Furthermore, mechanical considerations such as ice, wind and sag need to be considered when lowering clearances.

2. Substation and Transmission Line Voltage Uprating

The conversion of existing transmission lines and substations to higher voltages is a viable alternative with the use of line arresters. Uprating of 69-230 kV transmission lines through the uses of arresters has been implemented with positive results.

Voltage uprating involves increasing the operating voltage while maintaining the original insulation level. Existing substations can be uprated to a higher voltage level by replacing circuit breakers, transformers, and other voltage-sensitive equipment without having to completely rebuild the substation. By installing line arresters in specific locations such as the line entrances, the clearances at the lower voltage level will be acceptable at the uprated voltage level. This has been accomplished at several locations in the United States. Voltage uprating has been accomplished on the following systems according to IEEE Standard 1427.

a) 115 kV, 550 kV BIL class substations converted to 230 kV
b) 69 kV, 350 kV BIL class substations converted to 138 k
c) 69 kV, 350 kV BIL class substations converted to 115 kV

The financial benefits provided with uprating are significant because the costs associated with uprating a substation to a higher voltage level are generally less than rebuilding the entire substation. With line arresters and voltage uprating the substations can also use with compact bus spacing's which also has economic benefits in areas where land costs are expensive. Where the land necessary to build a substation with conventional clearances is not available, the compact substation is a viable alternative. Community acceptance of a new substation may be enhanced by using a compact bus design that

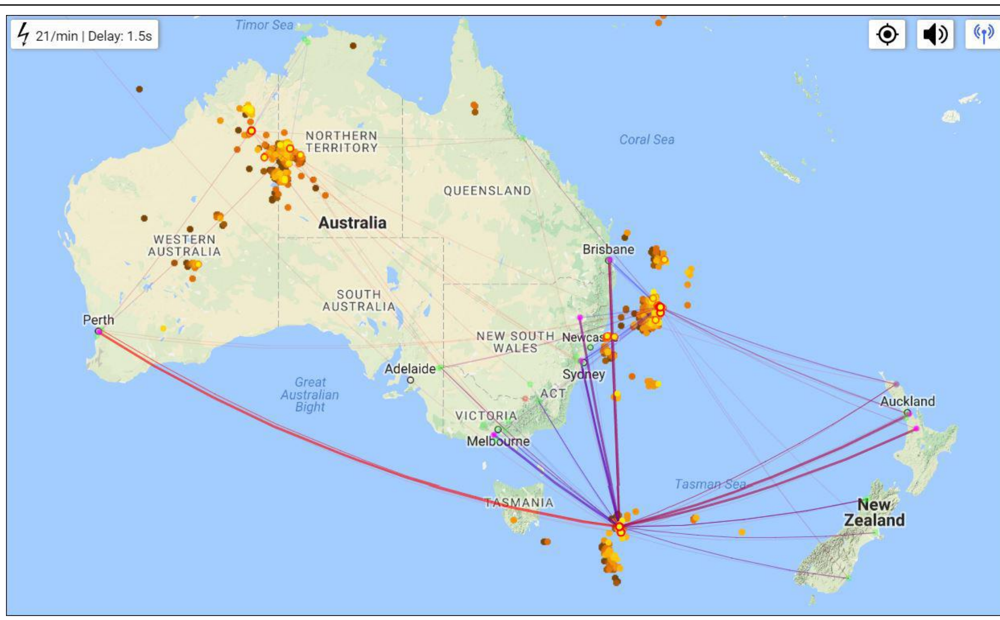

Figure 3: Lightning activity over a 1 hr period in Oct 2016. (www.lightningmaps.org) On the most recent strikes lines are drawn between the strike and the sensor. Note how distant a strike can be

occupies a smaller footprint than that for an equivalent conventional substation. Smaller clearances when uprating a system can also lead to lower bus heights, which can lead to lower costs for aesthetic treatments such as walls and other barriers if these measures are required. Additions to existing substations are in some cases difficult to make due to lack of space for installing the new equipment. Employing the lower clearances by using line arresters in a substation can make it possible to add new equipment with the assurance that proper electrical clearances are maintained. See IEEE Standard 1427 for more information on this subject.

3. Temporarily Reduce Minimum Approach Distance (MAD) On power lines, there are times when maintenance needs to be completed on towers and or lines with the system energized. When workers do find themselves near high voltage transmission lines they must be aware of the minimum approach distance to the line. The minimum approach distance is defined as the closest distance a worker or conductive tools held by a worker is permitted to approach an exposed energized conductor. Since the minimum approach distance is determined by the maximum switching surge level of lines above 345kV and lightning surges on lines below 345kV, this level can be affected by a temporary installation of arresters. This is still in the experimental stages at utilities, but in the very near future, it is likely that arrester will be utilized to temporarily change the MAD. The line arrester due to its minimal weight is a perfect candidate for this application. In this case an EGLA arrester may be more suited for this application since the lightning and switching residual voltage of an EGLA can be as much as 25% lower than and EGLA. In both cases, however the minimum approach distance can be reduced to a level that in some cases can allows access to the towers without an outage where otherwise an outage would be required. At the October meeting of IEEE Surge Protective Devices Meeting a working group task force was created to develop guidelines for the use of arresters to reduce MAD

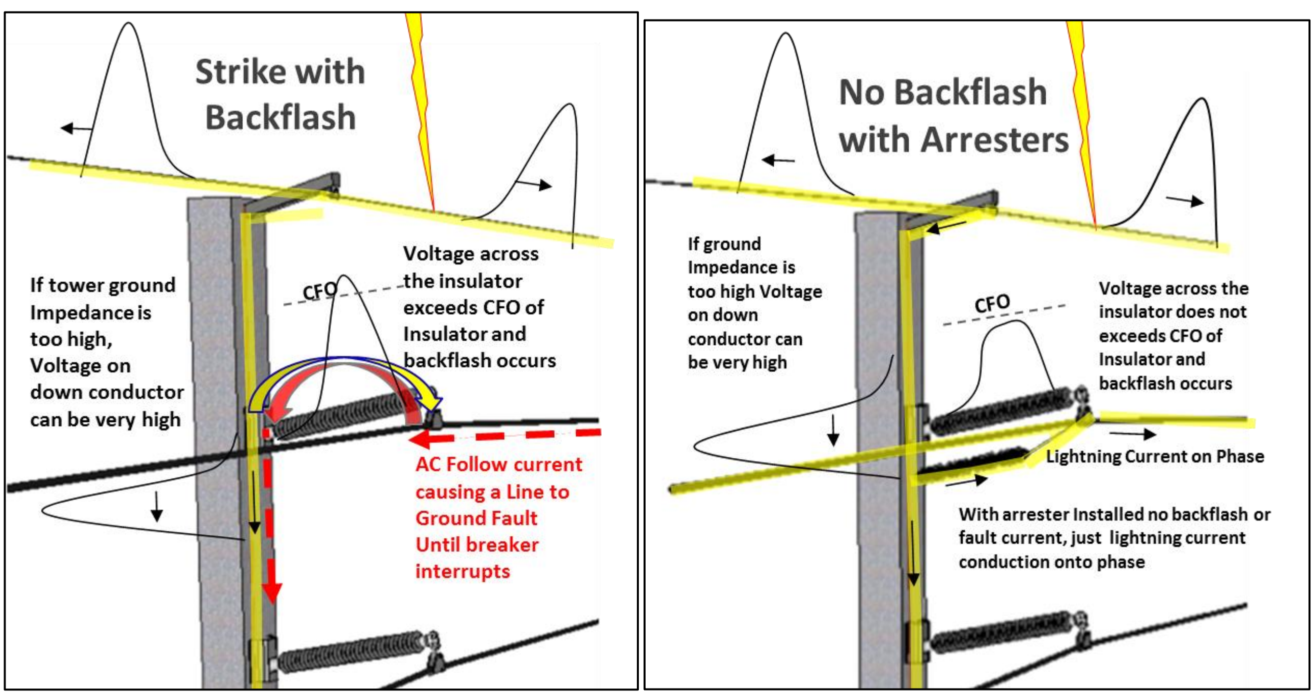

Figure 4: Back flashover overview (See Backflash Video)

for utility workers. They should have a recommendation in the next year.

4. Lower Lightning-Induced Momentary Outages

There are several reasons why a transmission line might not need TLA protection, especially if the line has a lightning induced outage rate of zero. However, for the rest of you, the TLA can make a big difference in outage rates caused by backflash on your transmission lines. The map as shown in Figure 3 from www.lightningmaps.org, is a great resource to get a feel for the lightning hit rate in your area of interest. Vaisala is also an excellent supplier of lightning data that is used by many utilities.

If you have a transmission line that has a high rate of outages due to lightning, you are most likely a victim of backflash. The most common cause of a backflash is when there is a lightning strike to the overhead shield wire, and the tower ground impedance is too high. It is referred to as a back flashover since it is in the opposite direction of flashovers produced in a direct strike to a phase. The back flashover is usually followed by a standard forward flashover of the insulator, providing a path for power frequency current (fault) that requires a breaker operation to terminate. Figure 4 shows a graphic overview of the backflash.

If you wish to reduce the backflash rate of a transmission line, there are two ways to do it. The first and most often used method is to improve the tower ground resistance. Up until 20 years ago, it was the only option. For the past 20 years, however, surge arrester installation has also become a means to improve the lightning performance of transmission lines.

With arresters, there are several methods employed to mitigate lightning on shielded lines. The first is to run a study of the system and determine whether the addition of just a few arresters will reduce the outage rate dramatically. This method uses fewer arresters and costs less than the full protection scheme. A second and less often used method is to install surge arresters on every phase of every tower. This method will make the system lightning proof. Georgia Transmission Corp routinely improves their outage rates with arresters, as described in an article, titled "High Tech Sleuths at US Utility Saw Success Battling Lightning." (See INMR Article Q4 2008)

A third method called Sectionalized arrester protection, is when arresters are used to protect only a certain area prone to outages due to lightning. If this is the case, the surge arresters can be installed only in that area. The high outage rate can be reduced to zero by installing arresters in these areas. Common areas of high outage rates include mountain tops, dry planes, and rocky soil.

5. The Compact Line[1]

A compact transmission line may best be defined as one that "looks like the common and acceptable distribution lines now running through urban areas." The compact transmission line often features the following:

Figure 5: Compact 69kV line. Every phase on every tower is arrester protected.

- Single-pole structures
- Relatively short spans (30–150 m)
- Armless or single-arm construction
- Reduced separation between phases
- Suitability for narrow right-of-way or roadside installation

According to W. A. Chisholm, et al., "These features make the compact line designs suitable for use in congested urban areas. There are other benefits compared to multiple distribution lines that could provide similar power transfer. Rebuilding an existing circuit at a higher voltage level on the same right-of-way may be the only feasible way to increase capacity. The compact designs may have lower capital and maintenance costs, lower line losses, and may achieve important reductions in electric and magnetic fields. Compact design also tends to simplify some mechanical issues. When armless or single-arm construction with post insulators is selected, conductors are fixed at each pole. This simplifies tension stringing, thermal rating, wind loading, and other design and construction issues. The short spans of a compact design reduce the magnitude of high-temperature sag, galloping and large-amplitude conductor motion. In many cases, line tension can be reduced, relaxing pole strength requirements and concerns about aeolian vibration damage."

An excellent example, shown in Figure 5, is a compact line found in the city of Lakeland, Florida, where they have been in use for more than 20 years for their 69-kV system. The main purpose of this system was to reduce the visual impact of the line and make it more like a distribution system.

[1] W. A. Chisholm, J. G. Anderson, A. Phillips, J. Chan, "Lightning Performance of Compact Lines," International Symposium on Lightning
Protection, Nov. 9–13, 2009, Brazil

6. Open Breaker Scenario Protection

Station class arresters are universally applied at transformers in substations, but the protection of open breakers in substations is applied less than

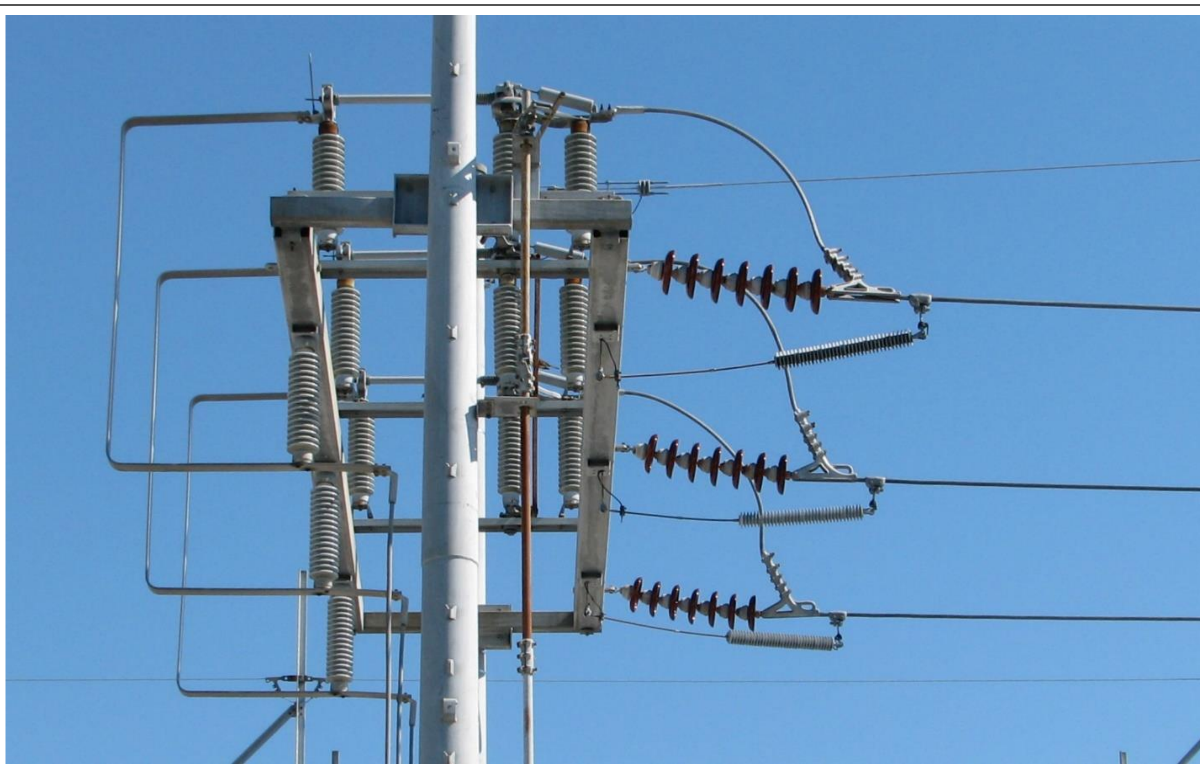

Figure 6 TLAs as Line Entrance Arresters to Protect Open Breaker

Tower Type	System voltage (kV)	Total line cost per mile	OHGW Elimination Savings	NGLA Costs Lightning Proof	Net Capital Savings	% Capital reduction
H-Frame	115	$ 900,000	$ 83,280	$ 31,200	$ 52,080	5.8%
H-Frame	230	$1,050,000	$ 98,780	$ 55,200	$ 43,580	4.2%
H-Frame	345	$1,200,000	$ 114,280	$ 74,400	$ 39,880	3.3%
Steel Pole	115	$ 990,000	$ 79,440	$ 24,800	$ 54,640	5.5%
Steel Pole	115	$1,590,000	$ 131,580	$ 49,600	$ 81,980	5.2%
Steel Pole	230	$1,160,000	$ 93,840	$ 45,600	$ 48,240	4.2%
Steel Pole	230	$1,890,000	$ 157,580	$ 91,200	$ 66,380	3.5%
Steel Pole	345	$1,330,000	$ 108,240	$ 64,800	$ 43,440	3.3%
Steel Pole	345	$2,190,000	$ 183,580	$ 129,600	$ 53,980	2.5%
Lattice Tower	115	$1,420,000	$ 119,680	$ 49,600	$ 70,080	4.9%
Lattice Tower	230	$1,680,000	$ 142,880	$ 91,200	$ 51,680	3.1%
Lattice Tower	345	$1,920,000	$ 164,680	$ 129,600	$ 35,080	1.8%

Table 2: Table 15 of NYSERDA report on cost savings using arresters in place of OHGW

50% of the time. The use of arresters at the line entrance of a station is for protection of the bushing of an open breaker. During normal operation, the breaker in the substation is closed and both bushings are partially protected by the arresters at the transformer. But during a multi-strike event where the breaker opens to clear a fault, the second or third stroke of the flash can enter the station while the beaker is still open clearing the fault. This second stroke then can flashover the line side bushing of the breaker with high potential of long term damage. Of course, this scenario has a low probability of occurring, if you would like to know the level of risk, a study can be done for the specific station and its surrounding lines. Line arresters are not generally used for this application, but they certainly can be. Figure 6 shows a space saving efficient installation of line arresters as line entrance arresters. It is important to note that the ground resistance of the pole where the line arresters are installed should be the same as the substation. If the first tower out from the station is used, it should not be too far from the station or it will not effectively protect the breaker.

7. Lower New Line Construction Costs [2]

A subtle but potentially significant benefit of using line arresters instead of an overhead ground wire is construction cost savings. Final report on NYSERDA project 28816 covers this topic in detail[2]. In the report, the cost savings for several different systems were investigated. As shown in Table 2, in every case, transmission lines with arresters in the place of OHGW cost less initially and going forward. Table XV of the report indicates that construction cost savings are between 1.8% and 5.8% of total cost of the line for various line-type studies. This is for installation of arresters on all phases of every tower that in effect makes the line lightning proof. If only the top phase is equipped with arresters then the top phase acts as an OHGW, and the savings are even greater.

[2] "Reduction of Transmission Line Losses by Replacement of Shield Wires with Arresters", Troy, NY: New York State Energy Research and Development Authority, 2014

8. Extending the Life of Breakers in the Station

The application of TLAs along a transmission line reduces the stress on and extends the life of breakers in the substation. Transmission lines protected from lightning by shield wires will still experience single line to ground faults when there is a back flashover of an insulator due to high ground resistance or an extra-high-current lightning stroke. When this happens, a breaker

Tower	Voltage (kV)	# of Circuits	# of Shield Wires	Load (MW)	Load Current (A)	Shield Current (A)	Shield Loss per mile (W)	Shield Loss per 100 miles (MW)	NPV over 30 years per 100 miles
H-Frame	115	1	1	131	662	19.1	892	0.0892	$ 480,499
			2			24.9	1,519	0.1519	$ 818,248
	230			264	663	17.2	1,727	0.1727	$ 930,293
	345			791	663	23	2,586	0.2586	$ 1,393,015
Single Pole	115	1	1	131	662	24.9	1,519	0.1519	$ 818,248
			2			13-20	1,494	0.1494	$ 804,781
		2	1	262	660	48.9	5,842	0.5842	$ 3,146,943
			2			42-42	8,588	0.8588	$ 4,626,146
	230	1	1	264	663	27.6	1,868	0.1868	$ 348,523
			2	263	662	17-14.3	1,214	0.1214	$ 653,952
		2	1	527	662	45.2	4,986	0.4986	$ 2,685.837
			2	527	662	40.7	8,117	0.8117	$ 4,372,430
Lattice Tower	115	1	1	131	662	28.1	1,937	0.1937	$ 1,043,415
			2		661	13.8-20.5	1,494	0.1494	$ 804,781
		2	1	262	660	40	3,922	0.3922	$ 2,112,686
			2		660	37.5	6,851	0.6851	$ 3,690,467
	230	1	1	264	663	21.7	1,145	0.1145	$ 616,784
			2		662	21.4-27.8	3,010	0.3010	$ 1,621,414
		2	1	527	662	49.1	5,899	0.5899	$ 3,177,647
			2		662	40.7	8,117	0.8117	$ 4,372,430

Table 3: Cost savings from using arresters instead of OHGW

between the fault and power source will need to operate to interrupt the current flow, however had the line had TLAs installed the breaker operation would not be necessary. Since breakers have a finite number of operations before maintenance is required, any reduction in the number of operations will extend the life of the breaker.

9. Reducing Cost of Emergency Standby Capacity

Some utilities must deal with significant risk of lightning outages in the summer. For example, if a power source is a long distance from the urban center where most of the power is consumed, and if the transmission lines pass through high-lightning areas, the risk of a momentary outage can be very high. One means of mitigating this type of risk is to run local generators and depend less on the lower-cost distant source. If arresters are used on the transmission line in addition to the present OHGW, the probability of a lightning induced outage becomes zero. The cost of installing several hundred miles of arrester protection is very likely to be much less than the cost of running higher-cost local generators. This application of arresters can generate enormous savings for the end consumer and an equal amount for the utility.

10. Lowering System Losses

This application is more for new construction but could be applied to older lines if the OHGW should age out. It is a well-known fact that OHGWs can generate losses on the system if they are grounded at the tower tops. The losses are inductive in nature from the load flowing in the phase conductors. The closer the OHGW is to the phase conductors, the higher the losses. This loss analysis is covered in detail in a NYSERDA report.[2] The losses are dependent on the type of line, number of shield wires, and the current load on the system. As you can see from Table 3 for single-pole, two-circuit 115-kV lines, a lifetime savings of heavily loaded lines can result in $4.6 million per 100 miles of line.

Conclusion

As shown here, both the NGLA and EGLA can improve power systems in many ways. It can not only make a line lightning proof but also lower construction costs, increase system reliability, reduce the size of a right of way, and much more. Those responsible for power system reliability or planning can make a significant difference when considering the possibilities offered by this arrester type.

ArresterFacts are a compilation of facts about arresters to assist all stakeholders in the application and understanding of arresters. All ArresterFacts assume a base knowledge of surge protection of power systems; however, we always welcome the opportunity to assist a student in obtaining their goal, so please call if you have any questions. Visit our library of ArresterFacts for more reading on topics of interest to those involved in the protection of power system at:

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Comments on this ArresterFacts are welcome. Feedback will always be answered.
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