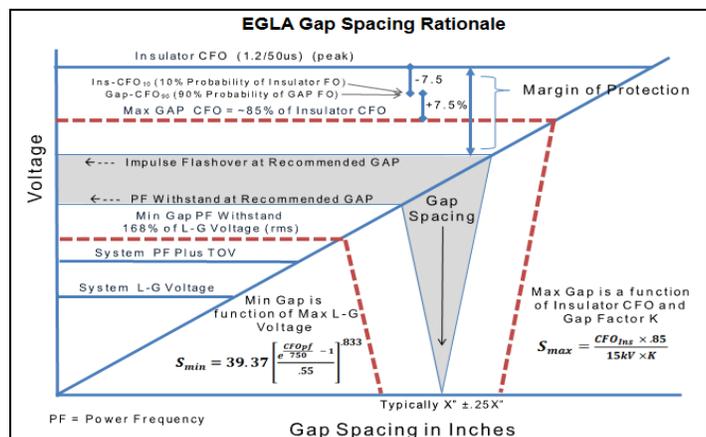
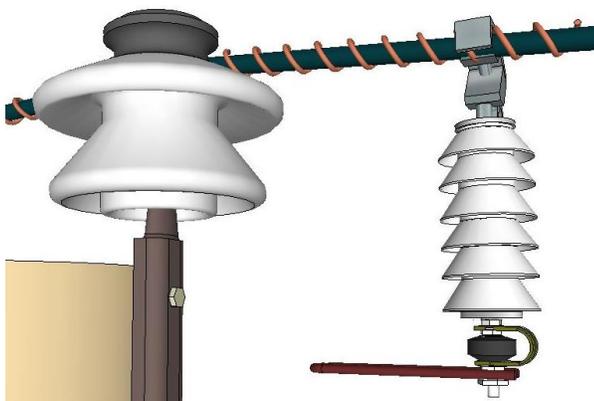
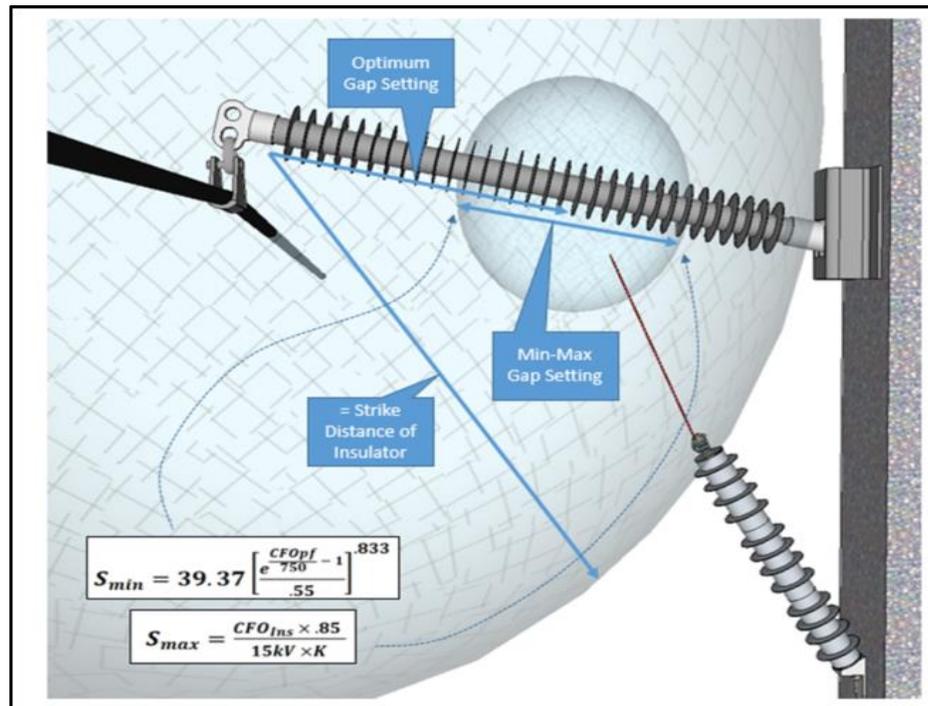


ArresterWorks

The Externally Gapped Line Arrester EGLA



August 2016
Jonathan Woodworth

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Jonathan Woodworth ArresterWorks

A lightning proof transmission line has been attainable since the early 1990s, when the polymer housed transmission line arrester was first introduced by Hubbell Power Systems. According to IEEE Std. 1410 [4] and IEEE Std. 1243[5], the installation of arresters on every phase of every tower of a shielded line will result in zero lightning induced flashovers of insulators. This is essentially a lightning proof line; however, line designers have not adopted this strategy for improving line performance for numerous reasons. The most cited reason for not applying arresters on transmission lines for lightning protection is that the arresters themselves are a potential reliability reducing factor and would require too much maintenance. The dominant line arrester that has been used for the last 20 years is the non-gapped line arrester which has demonstrated that this is not a real concern. The NGLA is, in fact, highly reliable and only occasionally have there been failures. Despite this, it is clear that another approach to the lightning proof concept is necessary to reduce the concerns of line designers. To that end, the EGLA and its unique characteristics are discussed in detail in this paper in an effort to increase the confidence level in line protection with arresters.

The EGLA Concept

The EGLA is an arrester design that dates back to the earliest stages of surge protection on power lines. In later years it became an internal gap, but performed the same basic function. The reason for this long history is that a simple air gap has excellent capabilities when used to withstand voltage and predictable breakdown at a very specific voltage level. It is no accident that arrester designs over the years have continued to use this device. Even today there are millions of arresters in service that are using an air gap to hold off the line voltage until a surge appears. In the presence of a surge they sparkover and assist in the task of protecting equipment on power lines.

When highly nonlinear metal oxide varistors (MOV) are connected in series with the age-old gap, the combination takes on very unique features not

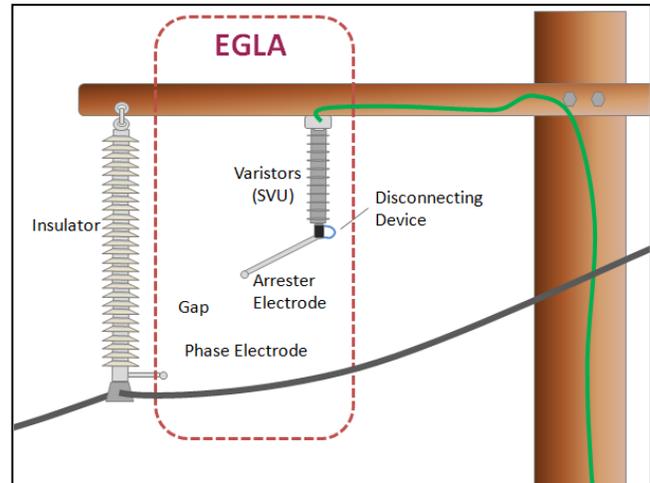


Figure 1: Externally Gapped Line Arrester mounted on a 115kV transmission line

previously seen in gapped arresters of earlier designs. It is these unique and repeatable characteristics that make the externally gapped MOV arrester the ultimate in distribution and transmission line protection.

The EGLA as shown in Figure 1 has been applied in Japan, Europe and Mexico as an IEC certified device for a number of years. The IEC type EGLA differs in that it is designed to protect lines from lightning only. This lightning only application is achieved by increasing the gap spacing to a level that will not sparkover in the presence of switching surges. For systems above 230kV, the IEC type EGLA does not need larger varistors to handle the energy associated with switching surges. The IEC type EGLA is characterized by a larger gap section and smaller tolerance in the gap dimension than the EGLA discussed in this paper. The IEC type EGLA is also an arrester recognized in the IEC community and has a test standard specifically written for it [6].

Note the EGLA is referred to as a line arrester, which means it is designed to be applied on lines to eliminate insulator flashovers and not for the protection of sensitive oil insulated equipment such as transformers. Because it is only used to eliminate insulator flashover,

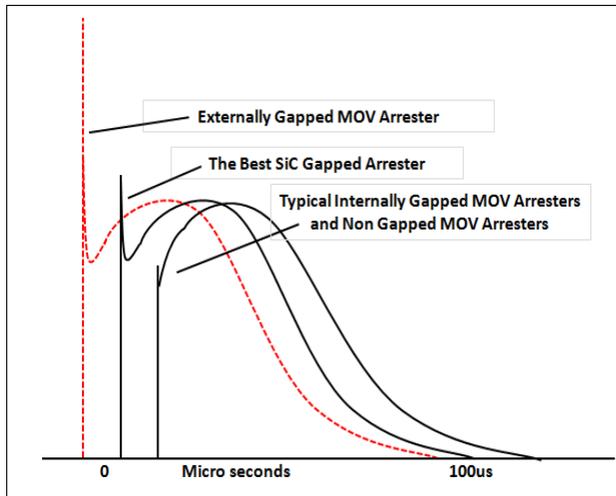


Figure 2: Front-of-Wave characteristics of various arrester types

the front-of-wave sparkover of this type of arrester is irrelevant and not an application issue. Figure 2 contrasts the front-of-wave characteristics of various types of arresters.

How it Works

The well-coordinated gap and varistor work in conjunction to turn the arrester on and off. In spite of the high sparkover characteristic of the gap, it is more than adequate for protecting the self-restoring insulation of line insulators, whether on a distribution system or a 500kV transmission system.

When a lightning surge from a direct strike travels along the line and reaches a standard insulator not protected by an arrester, it will flashover the insulator. The lightning induced flashover will cause a fault on the power system.

A fault can be prevented by using an EGLA to protect the insulator. Lightning is directed through the arrester, which turns on immediately because the voltage is above the sparkover of the gap and turn-on point of the varistors. Immediately following the lightning charge transfer, the varistors terminate all current flow and there is no power frequency follow current or fault.

The robustness of line insulator withstand characteristics, as well as its self-restoring capability, make the EGLA a perfect candidate for its protection.

The Gap Function and Design Criteria

The gap of all externally gapped arresters is a critical component in determining the turn on voltage of the arrester. It is important that the gap of the EGLA be large enough to withstand typical voltage swings during temporary overvoltage events, but small enough that it will always sparkover before the protected insulator flashes over. Figure 3 is a graphic that outlines considerations used to determine the gap setting of the EGLA that sparks over for both switching and lightning surges.

The minimum acceptable gap setting of an EGLA is determined by three factors: the system voltage, expected temporary overvoltage levels (TOV), and a safety factor. The maximum acceptable gap is set by two factors, the CFO of the protected system plus safety factors.

Minimum Gap Spacing Rationale and Equations

For the EGLA that is capable of both switching and lightning, the gap needs to be spaced so that no AC power frequency voltage swing will spark it over. (See Annex A for Lightning only EGLA) To achieve this withstand level, the gap is set to withstand the maximum expected temporary overvoltage level plus 20% more for a safety margin. The maximum temporary overvoltage of a system can be determined accurately with transient modeling, or it can be estimated with prior knowledge of the source transformer grounding configurations.

This procedure is similar to the MCOV rating selection of standard MOV type arresters. TOV factors recommended for this procedure are presented in the table below.

Because there is no current flow through the arrester prior to flashover of the gap, the arrester does not influence the gap flashover voltage. The minimum AC Power frequency voltage that EGLA gap will flashover is:

$$CFO_{pf} = \left(\frac{E_{sys}}{1.73} \right) TOV_{factor} \times SF_1 \quad (\text{Eq 1})$$

Where:

CFO_{pf} Min power frequency flashover voltage (kV rms)

E_{sys} Max line to line voltage (kV rms)

TOV_{factor} TOV factor based on Table 1
 SF1 Safety factor (typically 1.2)

The minimum gap spacing is then set from the minimum critical flashover voltage as determined in Eq 1.

$$S_{min} = 39.37 \left[\frac{e^{\frac{CFO_{pf}}{750}} - 1}{.55} \right]^{.833} \quad (\text{Eq 2})$$

Where:

S_{min} gap spacing in inches

Note: This applies for Gaps <79" (for spacing >79" a gap factor is used)
 [1] [2]

Circuit Type	TOV Factor
4 wire solid ground	1.25 -1.35
3 wire grounded at source	1.4
3 wire impedance grounded	1.5 - 1.73
3 wire delta	1.73

Table 1: TOV factors for various neutral configurations

Maximum Gap Spacing Rationale and Equations

The maximum gap spacing is set so there is little risk that the insulator will flashover during a lightning surge. In order to achieve this, the CFO of the insulator being protected must be known and the CFO of the gap set at a safe level below the CFO_{ins}. The relationship of the CFO_{gap} and the Insulator CFO_{gap} is shown in Fig 3. The minimum Margin of Protection is defined as

$$Min_{MOP} = GapCFO_{90} \leq InsCFO_{10} \quad (\text{Eq 3})$$

Where:

- Min_{mop} is the minimum margin of protection
- $GapCFO_{90}$ is the voltage level that represents a 90% probability of gap flashover.
- $InsCFO_{10}$ is the voltage level that represents a 10% probability of insulator flashover.

The recommended value for Gap CFO₉₀ is 7.5% above gap CFO. The recommended value for Insulator CFO₁₀ is 7.5% below the insulator CFO. [5 –section 8.4]

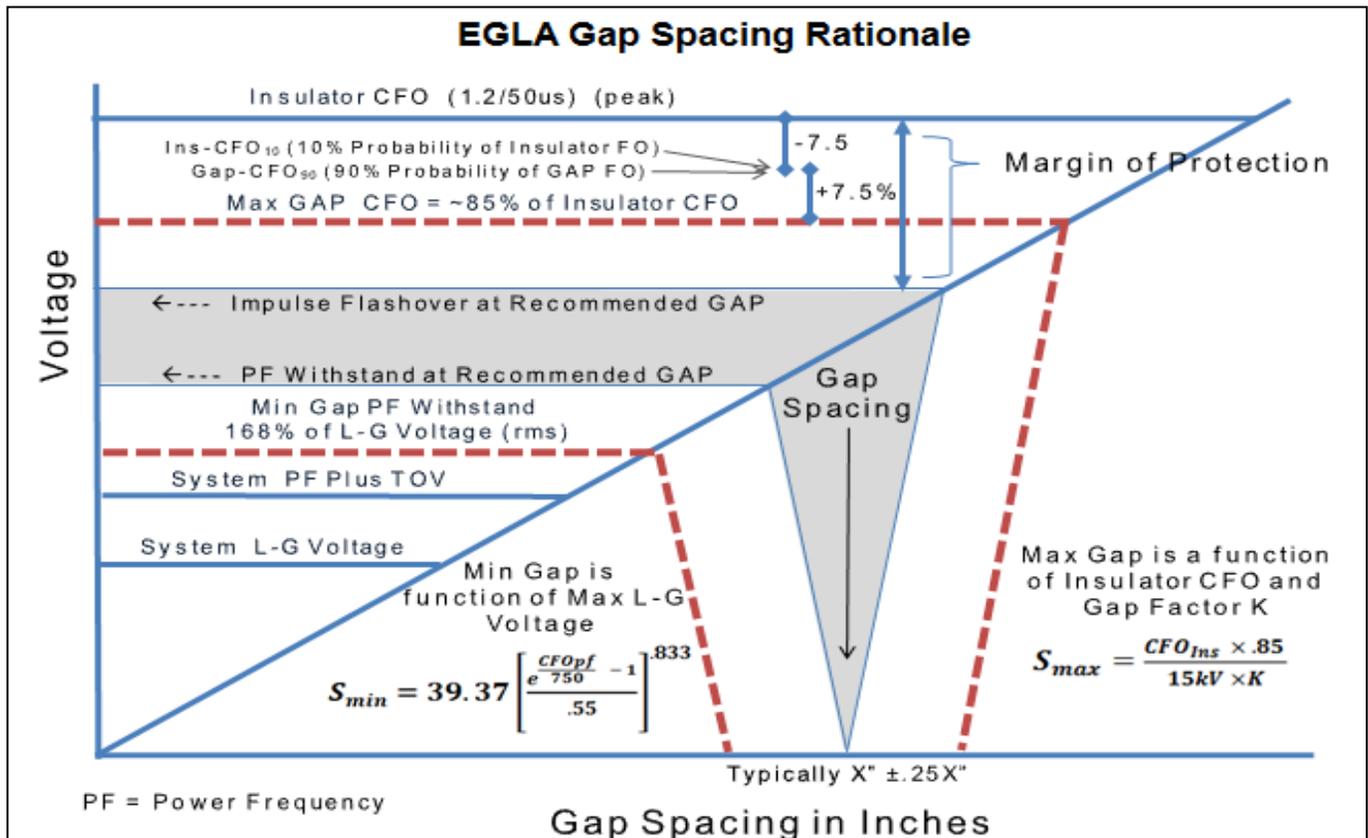


Figure 3: A graphic representation of the gap spacing rationale.

Given the above relationship of Max Gap CFO, once the CFO of the insulator is known, the Gap CFO can be calculated as 85% of Insulator CFO to meet the Minimum Margin of Protection. It is a generally accepted fact that the impulse breakdown voltage of air is 560kV/ft or 15kV/inch at STP.

Eq 3 then describes the relationship of Gap spacing in inches and Gap CFO

$$S_{max} = \frac{CFO_{Ins} \times .85}{15kV \times K} \quad (\text{Eq 3})$$

Where:

- S_{max} is the maximum Gap spacing in inches
- CFO_{Ins} CFO of insulator in kV peak
- $V_{breakdown}$ Pos Impulse breakdown voltage of Air which is accepted as 15kV/inch at STP
- K Gap factor (1 for rod to plane gaps)

Other Gap Spacing Considerations

Fortunately, if a faster surge arrives at the arrester/insulator, both devices will flashover at higher voltages, so once the spacing is set for a standard wave, it will work for faster waves.

If the installation is applied at higher altitudes, the gap spacing will increase as a function of air pressure.

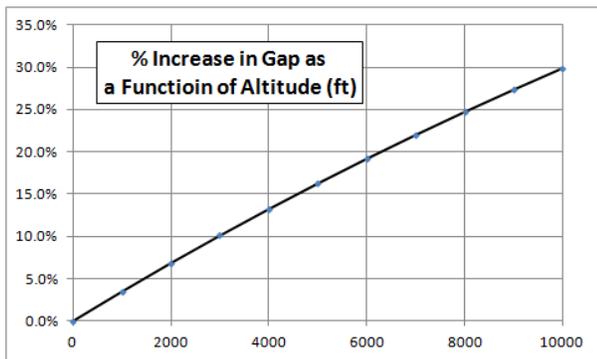


Figure 4: Altitude and gap spacing relationship

If the electrodes or the arrester can move relative to each other, a second safety factor must be factored in to the equation to account for this movement.

The gap may be affected by environmental conditions, but so is the insulator in parallel with the arrester. Again fortunately if the gap is set to flashover before the protected insulator, it will remain so in most weather conditions. If the parallel insulator is affected by

pollution so severely that it flashes over at power frequency, the arrester cannot affect this or protect against this.

Lead Management Considerations

As with all transmission line arresters, lead management is a significant consideration. In the case of the EGLA the electrodes are generally shorter than leads and electrode management is less of a challenge than leads of an NGLA.

Arrester Overload Considerations

In arrester overload situations, the optimum configuration would be to use a disconnect or a failure indicator, as shown in Figure 5 and 6.

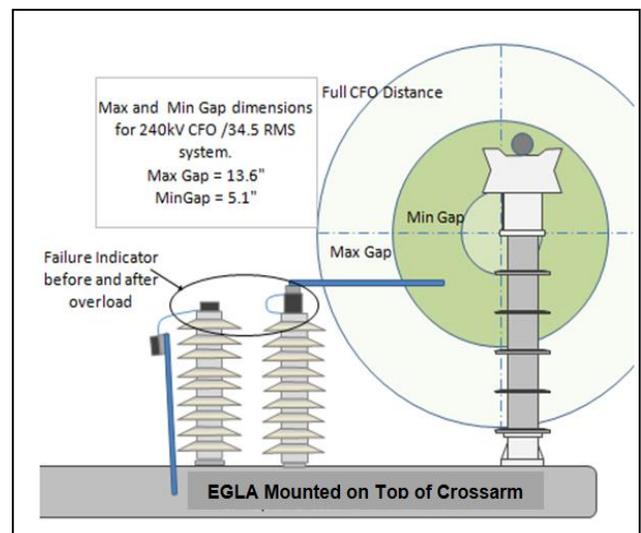


Figure 5 EGLA mounted to result in full CFO recovery if overloaded This configuration will move the electrode after the overload so that the insulator CFO is fully recovered

Effect of Incorrect Gap Spacing

Incorrect gap spacing may cause an array of problems. These issues vary depending on if the spacing was below the minimum level or above the maximum level.

If the gap spacing is installed below the minimum level, the risk of flashover during a temporary overvoltage event increases. This could lead to arrester damage or failure.

If the gap is installed with its separation above the maximum recommended level, it may allow the insulator to flashover before the gap sparks over. While this will not cause an arrester failure, it may allow the

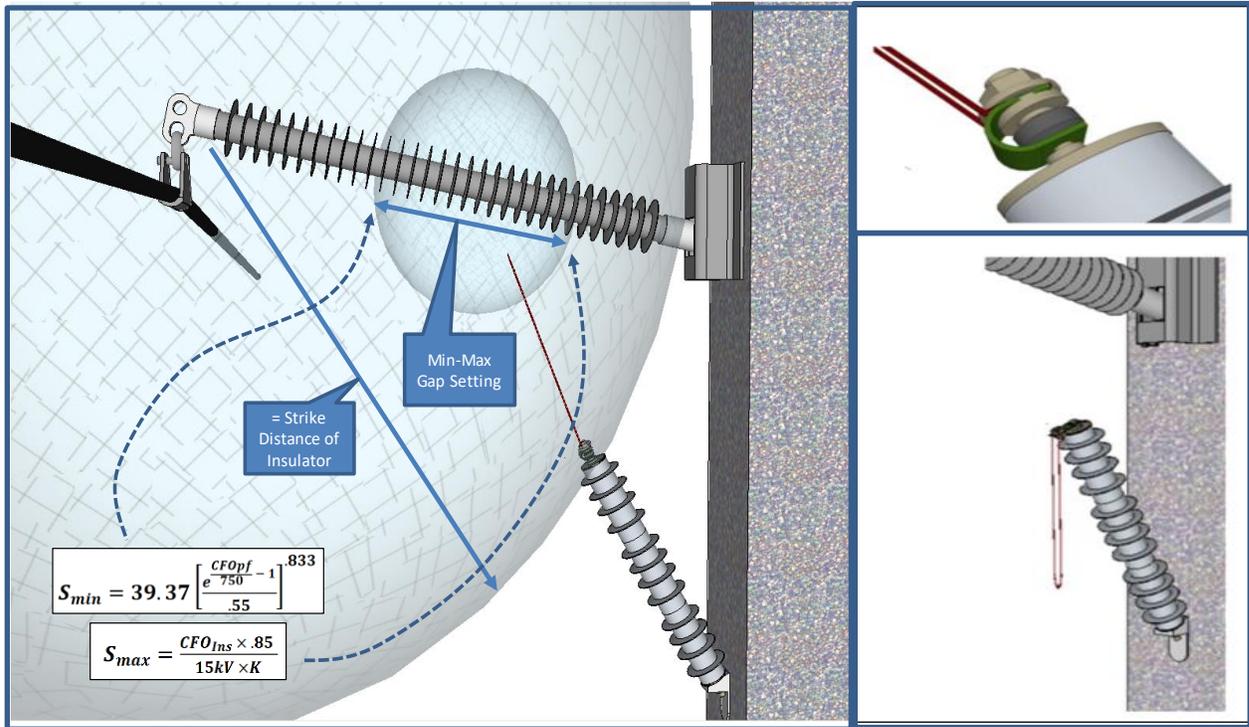


Figure 6: A graphic representation of the gap spacing rational and overload with a failure indicator

EGLA GAP Characteristics for Lightning and Switching Surge Type												
Sys Voltage (kV)	Recmd ECLA MCOV (kV rms)	CFO (kV)	Max ECLA Sparkover (kV) Gap Factor of 1	Max Gap (mm)	AC L-G (kV)	Min Gap 20% Safety Factor and 1.4pu TOV (mm)	Recmd Gap (mm)	Gap Spacing Tolerance (± mm)	GAP AC Sparkover Voltage at Recmd Gap (kVrms)	Gap Impulse Sparkover at Recmd Gap (kVp)	Gap Sparkover as % of Insulator CFO	
13.2	9	125	106	180	8.0	58	119	60.8	31	70	56%	
25	16	150	128	216	15	100	158	58.1	44	93	62%	
35	22	150	128	216	21	133	174	41.5	49	103	69%	
46	29	215	183	309	28	168	239	70.8	70	141	66%	
69	42	290	247	417	42	238	328	89.5	101	194	67%	
115	72	462	393	665	70	375	520	145.2	168	307	66%	
138	84	700	595	1008	84	442	725	282.8	238	428	61%	
161	98	920	782	1324	98	509	917	407.4	302	541	59%	
230	140	1095	931	1576	140	714	1145	431.0	374	676	62%	

Table 2: Gap Data for System Voltages 13.2kV to 230kV (Assuming a Gap Factor of 1)

insulator to flashover, resulting in a momentary or long term outage. Fortunately, the ECLA gap spacing is quite flexible. For further insight, examine the various system voltage and gap settings presented in Table 2.

Electrode Function and Design Considerations

Though the electrodes may seem like a simple component of this arrester, they are definitely not so.

The EGLA electrodes provide the following functions:

1. Creates a durable location on the arrester or phase conductor for the arc, caused by the surge, to land upon without damage.
2. Allows for adjustability of the gap spacing.
3. Offers a surface that is equidistant from the opposite electrode for various insulator or arrester motion.
4. Produces a shape that has consistent and predictable flashover
5. Generates full CFO to the system upon failure if the electrode and EGLA is equipped with a disconnecter, as shown in Figure 5&6.

Note that every EGLA needs at least two electrodes. Sometimes the second electrode can be part of the existing system and not an actual part of the arrester.

The electrodes must meet numerous requirements to provide the aforementioned functions. These requirements are as follows:

1. Mechanical strength
2. Non-aging finish
3. Shape conducive to the system voltage and the potential swinging of the arrester or phase conductor.
4. Conductivity adequate for surges but not power frequency current
5. Acceptable failure mode
6. Wind withstand

Electrode Mechanical Strength

The mechanical strength requirement stems from the need to remain in the initial configuration for the life of the arrester. At a minimum, the electrode needs to be self-supporting. During its life, the electrode should be able to sustain events that will stress the material, such as bird perching, wind, and ice. A flexible electrode is acceptable as long as it does not take on a permanent reshape, which would allow for a change in the original spacing.

Electrode Finish and Material

It is important that the material and surface finish not oxidize with time. If the gap oxidizes radically, it could change the sparkover voltage. It is recommended that stainless steel, brass, or aluminum be used for the electrodes. Galvanized steel is an option, but the point where the arc impinges can become rusty. The electrode needs to be a conductor, but its conductivity is not important. If it is a poor grade conductor but meets all other requirements, it is acceptable.

Phase Electrode Consideration

As stated earlier, it is not always necessary to have an electrode on the phase side of the gap. If the phase electrode is a large part of the insulator fitting, as seen in Figure 4, then it is obvious that nothing more is needed. However though not necessary, it may be prudent to use a rod gap at both ends of the gap to make flashover more predictable.

It is important to note that the current through the EGLA is restricted to the surge current. If a conductor has armor covering the conductor near the insulators to handle lightning flashovers, it may not be necessary to

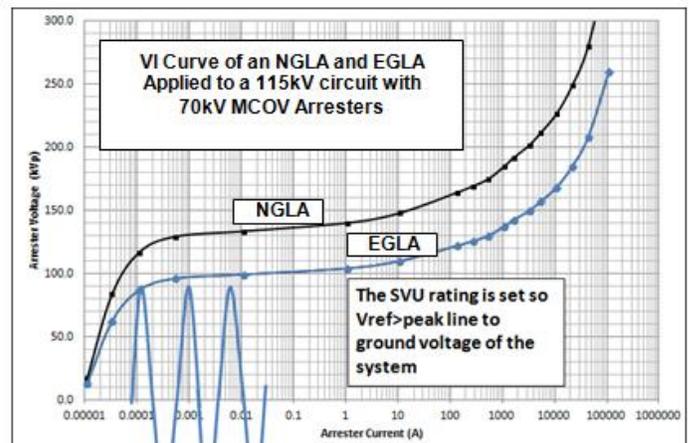


Figure 6 By superimposing the AC voltage on the VI curve of the SVU,

make any other accommodations. Always ask the basic question: "If there was no arrester located at an insulator, how would a flashover and power arc be accommodated?" The answer will assist in the decision about a phase electrode.

Series Varistor Unit (SVU) Considerations

The varistor component, also known as series varistor unit or SVU, is comprised of non-linear MOV disks. The SVU has one basic function in this arrester, and that is to limit the surge current. In effect, it terminates the surge event as the surge drops in voltage. The SVU is for all practical purposes a non-gapped arrester.

Voltage Rating of SVU

When selecting the voltage rating of the SVU, the most important consideration is the maximum line to ground voltage the system will experience. As demonstrated in Figure 5, the turn on level of the SVU is set just above the peak line to ground voltage of the system. As a general rule of thumb, the 1mA Vref of the SVU must equal or exceed the peak line to ground voltage.

The discharge voltage of the EGLA is the sum of the voltage across the gaps, the varistors, and the leads. In most cases, this voltage is lower than a standard arrester and can easily clamp the voltage well below the CFO of the protected insulator.

Energy Considerations of the SVU

There are three fundamental system protection schemes that need to be taken into account when determining the energy handling capability of an EGLA arrester: shielded systems below 230 kV, shielded systems 230 kV and above, and unshielded systems.

Shielded systems below 230kV

For shielded systems below 230kV that are not equipped with large cap banks, the energy handling requirement from the lightning surge usually exceeds the switching surge requirements. Distribution class arresters are most commonly used for this application.

Shielded systems above 230kV

For this system type, the switching surge energy handling capability needs to be considered. For longer lines, the switching surge capability can exceed the lightning charge transfer requirements. A basic system study or rule of thumb equations from C62.11 can be used to make the determinations. It is quite possible that

station class disks will need to be used for this application.

Unshielded Systems

For distribution systems that are typically unshielded, a standard distribution arrester will suffice for the SVU of an EGLA. For higher voltage systems where current sharing between arresters is an option, higher charge transfer disks may need to be used for the SVU.

SVU Housing and Leakage Distance

Because the SVU does not have a voltage stress along its surface, it does not need the long term power frequency withstand capability that is required of normal arresters. Normally arresters have a voltage stress along their surface for the lifetime of the arrester. This stress demands that the arrester have a longer surface distance than the internal components normally require. The only time the SVU experiences a voltage stress is during a surge clamping event; at all other times the voltage difference between the two ends of the SVU is virtually zero.

Because there is no voltage stress along the length of the SVU during its life time, the leakage distance can be equal to the strike distance for most applications. For more potentially contaminated environments, the leakage distance may need to be a small percentage longer. Less material in this case is an area of opportunity to make the arrester a more sustainable product.

Besides providing leakage distance, the housing is also the major environmental seal of the SVU. Moisture ingress in the presence of voltage stress is a major challenge for the housing of an SVU. Even though the AC stress is minimal, the need for a very well-sealed SVU is paramount.

Wildlife Guarding

For arresters applied above 46kV, the SVU becomes long enough to not be concerned about animals stretching from ground to phase electrode. However, animals can get across the gap and the resulting leakage current will likely not be good for the animal but not cause an outage. It is not likely that the arrester will fail, because the current is limited by the varistors.

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Books:

[1] Hileman, A.R., *Insulation Coordination for Power Systems*, Marcel Dekker, Inc., New York, 1999, ISBN 0-8247-9957-7. , pg 79 Eq 57

Standards:

[2] IEC Standard 60071-2- 1996 “*Insulation co-ordination - Part 2: Application guide*” Annex G1

[3] IEEE Std. 1410 “*IEEE Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines*”

[4] IEEE Std. 1243 “*IEEE Guide for Improving the Lightning Performance of Transmission Lines*”

[5] IEC Standard 60099-8 “*Surge arresters - Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV*”

EGLA Arrester Voltage Rating Considerations

The voltage ratings of NGLA arresters can be confusing to the novice because the standards and data sheets for ungapped arresters routinely discuss two ratings: the MCOV and the Duty Cycle Rating. The only rating that matters to users, however, is the MCOV or U_c in the IEC area.

For the EGLA, the only voltage rating that matters is the MCOV. This is the maximum voltage the arrester can withstand over its life and still withstand TOV events as they arise. This level is claimed by the manufacturer and has been verified in the operating duty test.

An 8.4kV MCOV of an EGLA is the equivalent of an 8.4kV MCOV ungapped arrester. The 70kV MCOV rating of an EGLA is exactly the same as the 70kV MCOV rating of an ungapped arrester.

Benefits

The benefits of this type of arrester are numerous. Because of the gap, there are zero losses and there is no chance of a long term fault because of the arrester. The arrester construction is more sustainable to the environment due to less material. The life of the arrester is nearly infinite due to the minimal AC voltage stress on the SVU. A subtler benefit is the fact that less rubber can be used on the housing because leakage distance is optional. Also, with no voltage applied to the varistor after an impulse, the varistors do not need such sophisticated formulations and processing.

Summary

With the use of this type of arrester on transmission lines and distribution lines two issues can be resolved, a lightning proof line can be achieved and the maintenance and reliability issues that linger with line designers in regard to the use of arresters should be resolved.

Acknowledgements

Many thanks for significant input from project partner Ceralink Inc. of Rensselaer NY. A special thanks to John Williamson of J. Williamson Engineering Inc for his helpful comments. Also a special thanks to Dan Ward of Dominion Virginia Power for his input and critical review.

Also See EGLA Gap Calculator at ArresterWorks.com

Input Cell
Output Cell
EGLA Arrester Gap Spacing Calculator 2.0
 by ArresterWorks

Maximum Gap Distance

Application Altitude	0	ft
Insulator CFO Per Catalogs (At sea level)	500	kV
Altitude Correction Factor	1.000	
Insulator CFO At Altitude	500	kV
Max GAP CFO (85% of Insulator CFO)	425	kV
Max Gap (at altitude)	28.3	inches
Max Gap (at altitude)	720	mm

Recommended Gaps Spacing at Altitude in inches and mm

Based on Max Expected AC Voltage	21.5	inches
	6.8	+/- inches
Based on Max Expected Switching Surge	23.9	inches 358.3
	4.4	+/- inches
Based on Max Expected AC Voltage	527.8	mm
	166.4	+/- mm
Based on Max Expected Switching Surge	585.1	mm
	109.0	+/- mm

Minimum Gap Distance based on Power Frequency Withstand

System Voltage Line-Line	115	kV rms
Regulation Error	5	%
Maximum Line to Ground Voltage	70	kV rms
TOV Factor	1.4	for solidly grounded circuit. 1.73 for all others
Safety Factor	20	%
Minimum AC rms Flashover Voltage	117	kV rms
Min Gap Distance Sea Level	14.75	inches
Altitude as entered above	0	ft
Altitude Correction Factor	1.000	
Min Gap Distance at Altitude	14.75	inches
Min Gap Distance at Altitude	375	mm

Minimum Gap Distance based on Maximum Expected Switching Surge

System Voltage Line-Line	115	kV rms
Regulation Error	5	%
Maximum Line to Ground Voltage	98	kV peak
Max Switching Surge in PU of System Voltage	2	
Safety Factor	13	%
Minimum Switching Surge Flashover Voltage	221	kVpk
	19.4	inches
Altitude as entered above	0	ft
Altitude Correction Factor	1.000	
Min Gap Distance at Altitude	19.4	inches
Min Gap Distance at Altitude	485.8	mm

EGLA Gap Calculator by ArresterWorks

Annex A

Calculating the Minimum Gap distance for EGLA used for lightning surges only

The EGLA available as certified to IEC 60099-8 is designed and tested to only respond to lightning surges for all voltage ratings. This means the gap is set wide enough to not allow any sparkover for switching surges. The value of the minimum gap setting is thus set based on the expected maximum switching surge the arrester is expected to see.

The equation A1 is used for this calculation.

$$G = 39.37 \left[\frac{e^{(SS/1080)} - 1}{.46} \right]$$

Where

G = Gap Distance in inches

SS = Maximum Expected in Switching Surge in kV

The resulting characteristics are given in Table A1

EGLA GAP Characteristics for Lightning Only											
Sys Voltage (kV)	Recmd EGLA MCOV (kV rms)	CFO (kV)	Max EGLA Sparkover (kV) Gap Factor of 1	Max Gap (mm)	AC L-G (kV)	Min Gap 13% Safety Factor and 2.2pu SS (mm)	Recmd Gap (mm)	Gap Spacing Tolerance (± mm)	GAP Switching Impulse Sparkover Voltage at Recmd Gap (kVpk)		Gap Sparkover as % of Insulator CFO
13.2	9	125	106	180	8.0	51	111	61.9	68		54%
25	16	150	128	216	15	100	152	56.4	93		62%
35	22	150	128	216	21	133	172	37.0	103		69%
46	29	215	183	309	28	168	239	60.0	146		68%
69	42	290	247	417	42	238	338	64.0	207		71%
115	72	462	393	665	70	375	558	82.0	342		74%
138	84	700	595	1008	84	442	777	194.0	476		68%
161	98	920	782	1324	98	509	986	291.0	603		66%
230	140	1095	931	1576	140	714	1290	230.0	789		72%

Table A1: Gap Data for System Voltages 13.2Vk to 230kV (Assuming a Gap Factor of 1) for EGLA designed to 60099-8