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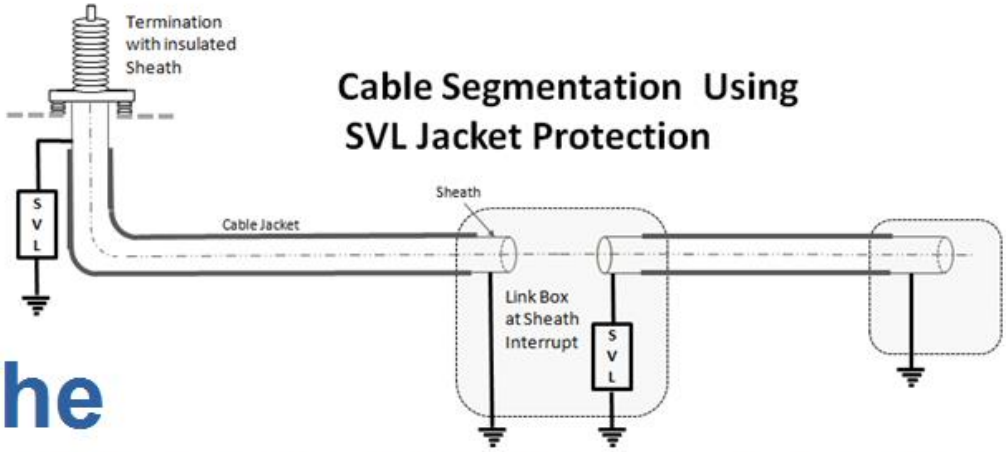

The Sheath Voltage Limiter

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ArresterFacts 032

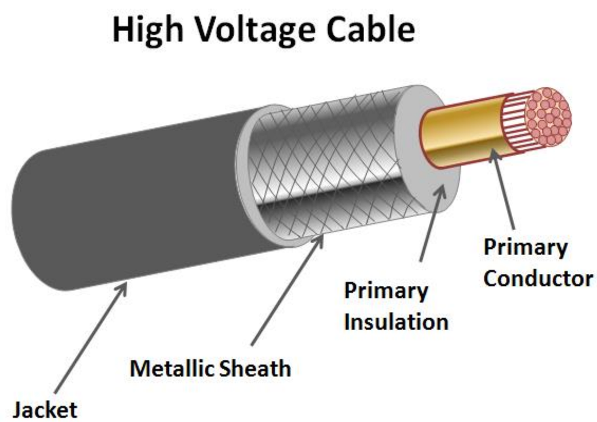

Figure 1: Simple HV cable showing polymeric jacket that is in some cases requires surge protection.

Introduction

High voltage cable for underground transmission has been in use for many years; however, in the past decade the demand for longer lines and higher current capacity have increased which in turn has required new methods of loss prevention. Reliability of these lines is more important now than ever, as the customers become more intolerant of outages. This means that surge protection of the underground cables is increasingly more important. All of these factors lead to the growing use of surge arresters on cable systems. The surge protection scheme for a high voltage cable sheath is unique in the surge protection world, as you will see from this article. The main purpose of the sheath voltage limiter (SVL), as discussed herein, is to protect the outer jacket of the cable from electrical stresses caused during transient events.

High voltage cable comes in many forms; however, for sake of keeping it simple, we will discuss single core HV cable with a metallic sheath and a polymeric sheath jacket, as shown in Figure 1.

HV Cable System Overview

There are many positive factors fueling the installation of underground cable, but there is a negative environmental effect that needs special attention when installing this type of system, namely losses. Because cable is often installed with metallic sheaths, current is induced onto the sheath from the primary conductor. This induced sheath current flows directly to earth and is a 100% loss. In the process of flowing to earth, it also can raise the temperature of the cable, which becomes a limiting factor in the overload capability of the system. A common means of reducing the losses in a cable system is to segment the cable sheath as shown in Figure 2. When segmentation is used to interrupt the flow of induced sheath current, accommodations need to be made to limit the induced voltage on the sheath during transient

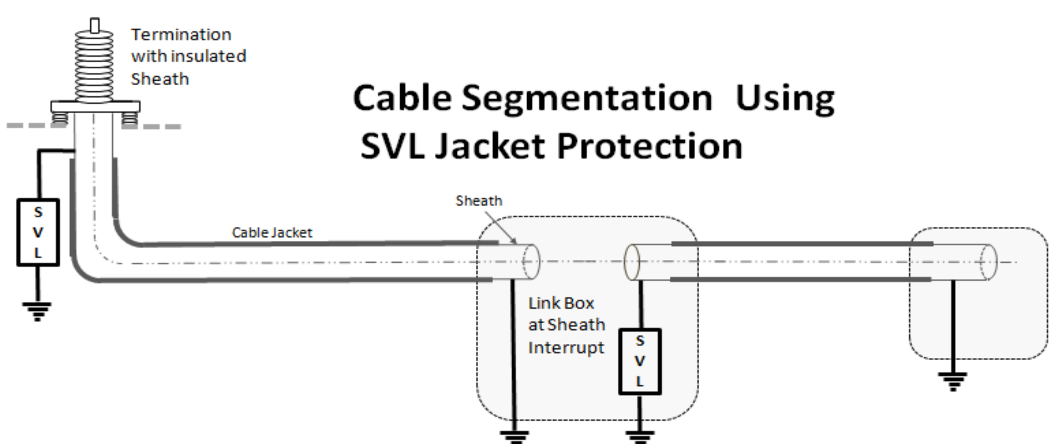

Figure 2: Common loss reduction method in cable systems using segmentation and Sheath Voltage Limiters

events. If the sheath voltage is not limited, the

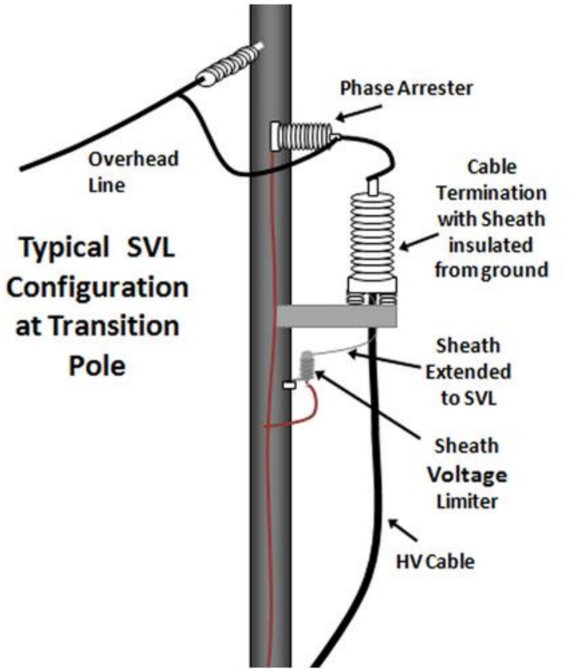

Figure 3 Typical configuration of SVL on Riser Pole

voltage difference between the sheath and earth can exceed the withstand voltage of the cable jacket. If the cable jacket is punctured due to excessive voltage across it, it can become a source of moisture ingress into the cable, which can only lead to longer term dielectric and failure issues.

There are numerous configurations used in cable systems to reduce losses such as cross bonding of the sheaths and transpositioning of phase conductors. However, segmentation is considered the most effective but requires surge protection of the cable jacket when it is implemented. The link box is a universally used junction box that accommodates surge protectors and a point to crossbond sheaths. This box is usually sealed and found in manholes or cabinets. Figure 4 shows a common link box setup that provides a location for the sheath voltage limiters as well as cross bonding of the sheath. The phase conductors do not enter link boxes; only the sheath or sheath extension.

Figure 4: Link box with 3 SVL's and cross bonded sheaths

The SVL

A sheath voltage limiter (SVL) is a surge arrester with a different name. It functions as an arrester and in most cases; it is in fact a re-labeled distribution arrester. Two examples of sheath voltage limiters are shown in Figures 5 and 6. In Figure 5, it can be seen that the arrester has no sheds. This is because this particular design can only be used in the dry environment of a link box. The SVL shown in Figure 6 has sheds similar to an arrester because this model is designed for outdoor use.

Figure 5: Sheath Voltage Limiter with typical ratings .8-4.8kV Uc (MCOV) used inside link boxes. (Courtesy of Tridelta)

Figure 6: Sheath Voltage Limiter with typical ratings 4-14kV Uc (MCOV) for use in outdoor environment. (Courtesy of Tridelta)

Selecting an SVL

As stated in the introduction to this article, the purpose of a sheath voltage limiter is to clamp or limit the voltage stress across the cable jacket. If the cable sheath is grounded at both ends, the voltage stress across the jacket is quite low during steady state and relatively low during transients; however, if the cable is segmented to reduce losses or there are link boxes along the cable at transposition/cross bonding locations, it is important to install the SVL at these locations to eliminate any possibility of insulation breakdown of the cable jacket or link box insulation. There is no standard method prescribed by IEC or IEEEE for selecting the optimum rating for cable sheath/jacket protection. The following method is one used by this author after discussion with cable suppliers, arrester suppliers, and with the aid of transient modeling of the systems to actually determine the effects of a surge during transients.

Steps to Select the Optimum Sheath Voltage Limiter

Step 1: Determine the voltages that will appear on the sheath during transient events

Step 2: Select AC Rating and TOV Rating

Step 3: Check Margin of Protection of the Selected Rating

Step 4: Check that the Energy Rating of the SVL is adequate

Step 5: Check mounting and failure mode for fit and function

Figure 7: Steps that can be used to determine the rating of an SVL

This analysis assumes sheath segmentation with is a single point bond (earthed at one end of the sheath) and an open point at the other end of the sheath.

Sheath Voltage from Power Frequency Sources

Because the sheath of a cable is in such close proximity to the conductor, the voltage appearing on an open sheath can be substantial. This induced voltage is directly related to the current flowing through the phase conductor. This relationship applies during steady state and during faults. Figure 8 displays an example where a 17kA fault results in 3800V rms on the sheath. The most common rationale in selecting an arrester for protecting the sheath is to select an SVL with a turn-on level above the worst case induced power frequency voltage. This means the SVL does not need to dissipate any energy during a temporary overvoltage (TOV) caused by faults. For overhead arresters, this is generally not the rule and in those cases, the arresters are sized to conduct current during the TOV but not enough to cause it to fail. The overhead sizing rationale utilizing an arrester's TOV capability is not used for SVL selection unless it is necessary to achieve a better margin of protection.

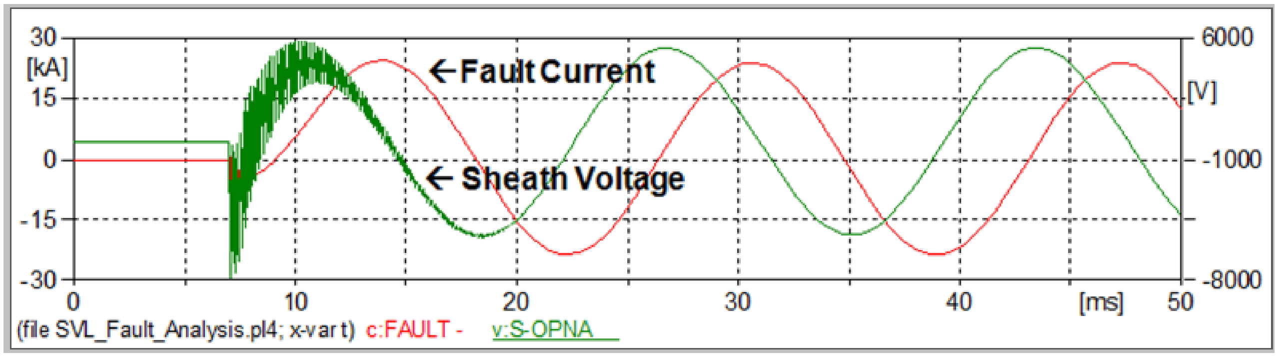

Figure 8 17kA fault resulting in 3800 Volts on Sheath

Sheath Voltage Calculations

The steady state voltage gradient is the voltage that will appear along a 1km length of a sheath with 1000 amps flowing continuously. This voltage is a function of the configuration of the cable in the trench and the cable dimensions. There are two basic trench configurations: trefoil and flat. The trefoil configuration is comprised of three cables that are positions equal distance apart such that the cross section forms a equilateral triangle. If the flat configuration is used, all cables are laid such that they are in the same plane and the same distant apart. If the voltage gradient is not supplied by the cable manufacturer for the configuration to be used, it can be calculated as follows. These equations and method are derived from charts found in IEEE 575 "Guide for Bonding Sheaths and Shields of Single-Conductor Power Cables Rated 5 – 500 kV":

$$E = k\left(\frac{S}{d}\right)^n$$

Where

E is the Sheath Voltage gradient in V/km/kA
k is constant
S is center to center distance between cables in meters
d is diameter of sheath in meters

For Trefoil and center conductor of flat layout

$$E = 75 \times (S/d)^{.466}$$

For outer conductors of flat layout

$$E = 107 \times (S/d)^{.369}$$

Once the voltage gradient is known for 1 km at 1000 amps, the voltage that will appear at the open end of a segment during a fault event can be easily calculated. It is important to know this voltage level because the SVL voltage rating (Uc) needs to be set just above this level so that the arrester does not conduct during a fault event. If the arrester conducted during a fault event, it would need a much higher energy handling capability than generally available for distribution type arresters. If it is later found in the sizing process that a lower level Uc is needed, a transient analysis will likely be needed to determine the Uc and energy rating of the SVL.

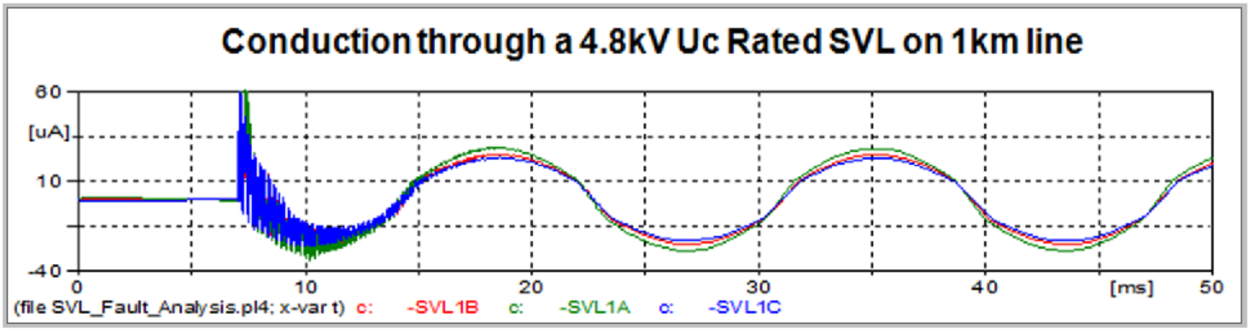

Figure 9: Current conduction through properly sized SVL

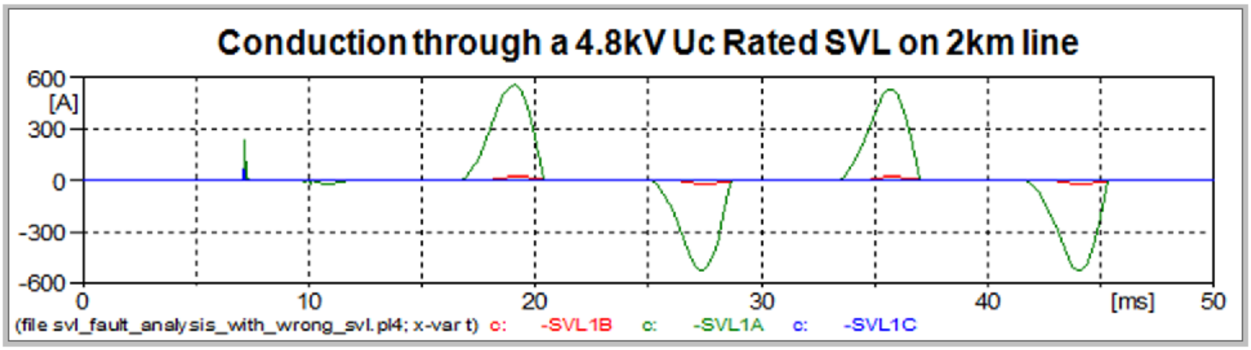

Figure 10: Current through improperly sized SVL with peak levels in the 600amp range per half cycle

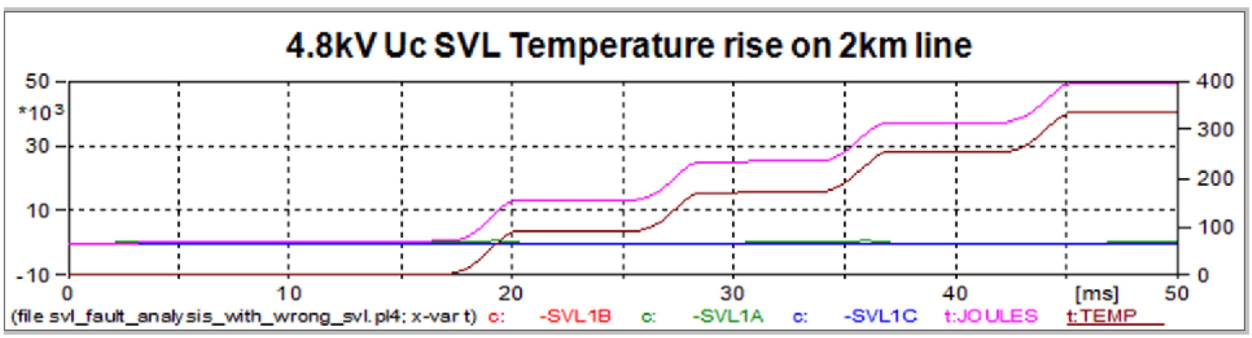

Figure 11: Temperature rise of an improperly sized SVL showing eminent failure if the breaker does not interrupt the fault immediately

Assuming that the margin of protection will be adequate, then the Uc (MCOV) rating of the SVL will be greater than or equal to the voltage at the open point (E_{open}).

$$Uc \geq E_{open} = \text{Voltage Gradient} \times \text{segment length} \times \text{max expected fault current}$$

Where: Voltage gradient is V/km/1000A
Length is in km
Fault current is in kA

Using the above method, if a voltage gradient on a particular system is 200v/km/kA and a line is 2 km long with a potential of 17.5kA, then the minimum acceptable Uc rating for the SVL would be 7000 volts.

Note that if the line was only 1 km long, the minimum Uc for the SVL would be half that of the 2 km long line and could be 3500V minimum.

Figure 9 shows the current flow through an appropriately rated SVL on a 1 km line with the previously mentioned voltage gradient and fault current. It can be seen that only micro-amps flow through the SVL, which is exactly what is desired;

however if the same SVL is applied to a similar line but is 2 km long, the current through the SVL is significant, as shown in Figure 10, and the immediate temperature rise to failure is shown in Figure 11. Therefore, when sizing SVL Uc ratings, one cannot choose one rating for all link boxes unless the lengths of all the segments are the same. If the SVL is chosen correctly in this manner, it will not be required to absorb any significant level of energy during a fault on the system.

Protecting the Jacket from Switching Surge

The jacket and the sheath interrupts are the weakest insulation in a HV Power Cable system. Figure 12 shows the withstand levels of the jacket and sheath interrupt per IEEE 575.

Typical BIL withstand of Sheath Interrupt and Jacket **kV peak (1.2x50 us wave)**			
System kV	Across Halves	Each Half to Ground	Jacket
69-138	60	30	30
161-240	80	40	40
345-500	120	60	60

Figure 12: Lightning Impulse withstand of sheath interrupts and cable jacket.

The switching surge impulse withstand of the sheath interrupt and the jacket are assumed to be similar to other insulator types and are 83% of the lightning impulse withstand rating (BIL).

When there is a switching surge event on the phase conductor of a cable, the current through the phase conductor induces a voltage on the sheath in the same way it does at steady state and fault events, even though the wave shape is significantly different. Since the voltage and current on the phase conductor during a switching surge is not sinusoidal or even a simple impulse (see Figure 13), it is not possible to accurately predict the resulting voltage and current on the sheath.

The only way to accurately determine the actual voltage and current on the sheath is though transient simulations of real life tests. Since real world tests are not practical, transient simulations are the only real option. After running many of these simulations, a few rules of thumb have surfaced:

1. If the SVL is selected to ride through a fault event with minimal to no serious conduction, then the switching surge energy withstand capability of a 10kA rated distribution type arrester is adequate. If the SVL is not dimensioned to

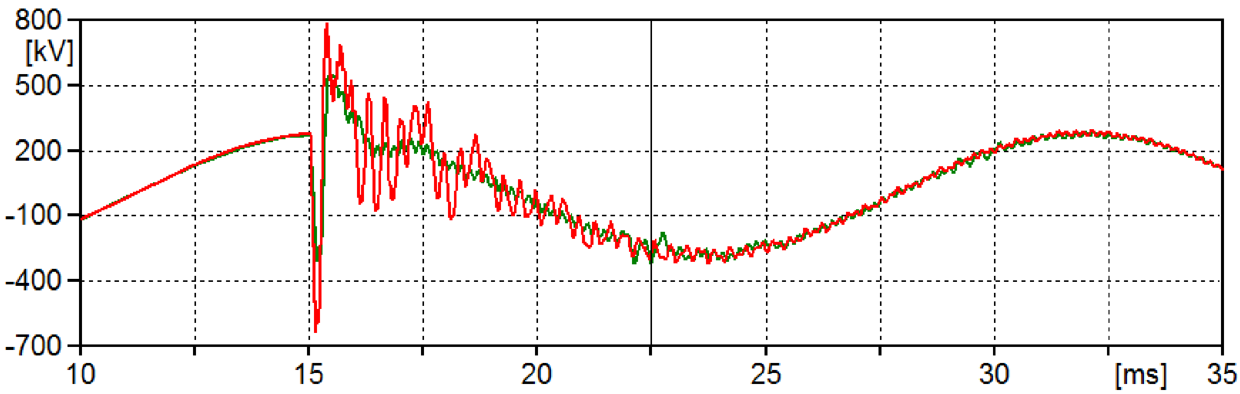

Figure 13: Switching Surge on Phase Conductor of a 345kV cable with (green) and without (red) arrester protection on the phase

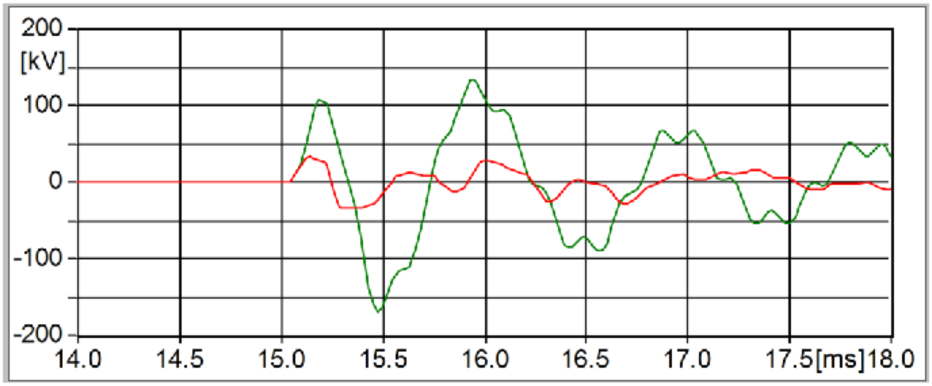

Figure 14: Switching surge voltage inducted on to Sheath of a 345kV Cable with and without SVL protection.

- 3pu switching surge on phase conductor.
- Green w/o SVL and Red with SVL.

ride through the fault, then station type arresters may need to be used.

2. If the 1000 amp switching surge residual voltage is not available, then the 1.5kA 8/20 lightning impulse residual voltage can be used for the margin of protection calculation.

In the case study used to create Figure 14, the switching surge voltage on the sheath without SVL protection would rise to greater than 100kV. Per Figure 12, this is more than 40kV above what the jacket or interrupt insulation can withstand, representing certain failure of the cable jacket. In this case, with a 9.6kV Uc SVL, the voltage on the sheath is limited to 33kV maximum.

To calculate the margin of protection during a switching surge, it is recommended that the 1000A switching surge residual voltage be used. Since switching surge residual voltage is not a mandated test for distribution type arresters, the 1000A residual voltage may not be available. If it is not available, a reasonable substitute for the switching surge voltage is the 8x20 residual voltage at 1.5kA. For the 9.6kV SVL used in the above study, the V_{1000} = 1000A 30/75us residual voltage is 28.4kV. From Figure 12, we can see that the BIL withstand level of the jacket for a 345kV line is 60kV. This means the switching surge margin of protection (MP2) for this case is: MP2 = ([(BIL x .83) / V_{1000}]-1) x 100 = 75%

Protecting the Jacket from Lightning Surge
When lightning strikes the overhead line before the transition pole, the surge is clamped by the arrester that is universally mounted at that location. Most of the surge current is diverted to earth at this pole; however, a surge voltage of significant magnitude can travel into the cable with a moderate level of current also entering the cable. Figure 15 shows the voltage and current entering a 345kV cable with a 100kA strike a few spans away.

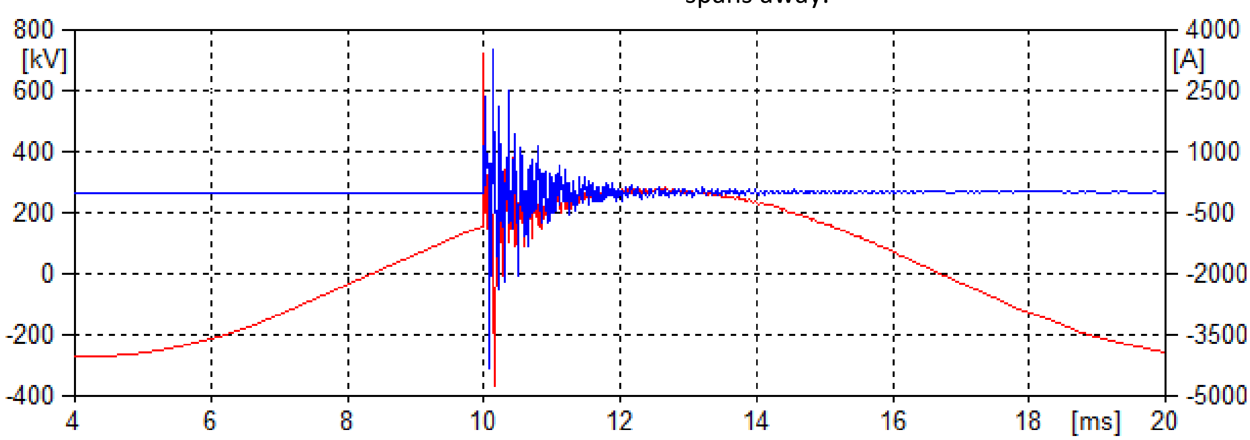

Figure 15: Shows the voltage and current on the phase conductor of a 345kV cable with a 100kA surge to the phase a few spans away from the transition pole

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: http://www.arresterworks.com/arresterfacts/arresterfacts.php

About the author:

Jonathan started his career after receiving his Bachelor's degree in Electronic Engineering from The Ohio Institute of Technology, at Fermi National Accelerator Laboratory in Batavia, IL. As an Engineering Physicist at Fermi Lab, he was an integral member of the high energy particle physics team in search of the elusive quark. Wishing to return to his home state, he joined the design engineering team at McGraw Edison (later Cooper Power Systems) in Olean, New York. During his tenure at Cooper, he was involved in the design, development, and manufacturing of arresters. He served as Engineering Manager as well as Arrester Marketing Manager during that time. Jonathan has been active for the last 30 years in the IEEE and IEC standard associations. Jonathan is inventor/co-inventor on five US patents. Jonathan received his MBA from St. Bonaventure University.

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