

ARRESTER LEAD LENGTH

Definition and Importance in Surge Protection of Distribution Systems

The first step in reducing voltage stress to extend the life of insulated equipment is the use of MOV arresters which have lower discharge voltage levels than silicon-carbide (SiC) designs. The 50 year old SiC design is still being produced by some manufacturers, and some utilities still use SiC arresters for the protection of pole-mounted transformers. However, most utilities have switched to MOV arresters for the protection of the more critical, and costly to replace, portions of their systems. The next step is the use of optimum connection methods for the arrester lead wires.

The highest surge voltage stress occurs when lightning strokes to the overhead line have fast rates-of-rise. An arrester discharge current which reaches its crest in 1 μ sec will produce 10% more voltage across an MOV arrester, and 30% more voltage across a SiC arrester, than will the standard 8 μ sec test waves used to establish the comparative IR discharge voltage data shown in arrester catalogs. Adding to the surge voltage across the arrester is the $L di/dt$ inductive voltage drop in lead wire carrying the surge current. Wire inductance (L) is a constant, typically 0.4 microhenries per foot. The surge current rate-of-rise (di/dt) varies with each lightning stroke



Figure 1

discharge. Multiplying the two quantities gives an inductive drop in kV per foot of wire. For example, a 10 kA discharge current cresting in 1 μ sec makes $di/dt = 10 \text{ kA}/\mu\text{sec}$, and produces a lead wire drop of $0.4 \times 10 = 4 \text{ kV}/\text{foot}$. If the 10 kA surge took 8 μ sec to crest, the inductive drop would be only 0.5 kV/foot.

It is now known that fast-rising arrester discharge currents are much more common than previously believed. Prior to 1980, lightning induced arrester discharges with rates-of-rise above 4 kA per microsecond had been measured, but were thought to be a low probability event that could be safely ignored in practice. In the late 1970's, more accurate measurements of arrester surge currents were taken which showed rates-of-rise at 13 kA/ μ sec in half of the discharges, with a maximum value of 60 kA/ μ sec. Consistent with this relatively new data, a realistic estimate for the lead wire voltage drop in arrester installations exposed to lightning is 6 kV/foot - this value is now used for calculating the protective margins under fast-front surge conditions.

Protective margin is the percent by which equipment insulation strength exceeds maximum surge voltage allowed on the system by the arresters. Insulation strength is the BIL (Basic Insulation Level) for surges cresting in the 8 μ sec time region (slow lightning), and CWW (Chopped Wave Withstand) for surges cresting in the region under 2 μ sec (fast lightning) for oil filled insulation. CWW is typically 15% higher than BIL for a given system. For cable, the CWW is assumed equal to the BIL to be conservative. Protective margin is determined by comparing insulation strength with maximum surge voltage - looking at both time regions and taking the smaller of the two margins as the realized overvoltage protection for the system.

APPLICATION

Overhead transformers are well protected with tank mounted arresters, because this installation method virtually eliminates series arrester leads. However, many URD installations use arresters mounted as shown in Figure 1. This construction practice is quite common. Such installations tend to have very long arrester leads which greatly increase surge voltage stress on switch and cable insulation. Arrester lead is the combined length of

Protective Margin, Overhead Distribution Transformers - 13.2kV 95kV BIL (110kV CWW) Insulation - Protected by 10kV Arresters 10kA Lightning Discharges						
Arrester Data			Minimum Protective Margin (%)			
Ohio Brass Type	10 KA IR (kV)		0'Lead	4'Lead	8'Lead	10'Lead
	8 msec	0.5 msec				
DA III (ND SiC)	38.0	49.0	124	51	13	1
PDV 65 (ND MOV)	36.0	41.0	164*	69	24	9
PDV 100 (HD MOV)	32.0	36.5	197*	82	30	14

* Margin based on BIL. Others based on CWW.

Table 1

Protective Margin, Underground Distribution Transformers - 13.2kV 95kV BIL Insulation - 10kV Arresters at Riser Pole Only 10kA Lightning Discharges, Surge Voltage Doubled by Reflection						
Arrester Data			Minimum Protective Margin (%)			
Ohio Brass Type	10 KA IR (kV)		0'Lead	1'Lead	2'Lead	3'Lead
	8 msec	0.5 msec				
DA IV (ND SiC)	36.0	47.0	1	-10	-19	-27
PDV 100 (HD MOV)	32.0	36.5	30	12	-2	-13
PVR (RP MOV)	26.5	28.5	67	38	17	2

Table 2

Protective Margin, Underground Distribution System - 24.9 kV 125 kV BIL Insulation - 18kV Arresters at Riser Pole Only 10kA Lightning Discharges, Surge Voltage Doubled by Reflection						
Arrester Data			Minimum Protective Margin (%)			
Ohio Brass Type	10 KA IR (kV)		0'Lead	1'Lead	2'Lead	3'Lead
	8 msec	0.5 msec				
DA IV (HD SiC)	67.0	87.0	-28	-33	-37	-40
PDV (HD MOV)	60.0	68.0	-8	-16	-22	-27
PVR (RP MOV)	48.0	51.4	22	9	-1	-10

Table 3

Protective Margin, Underground Distribution System - 24.9kV 125kV BIL Insulation - 18kV Arresters at Riser Pole Only 10kA Lightning Discharges, Surge Voltage Reflection 1.3 x MCOV						
Arrester Data			Minimum Protective Margin (%)			
Ohio Brass Type	10 KA IR (kV)		0'Lead	1'Lead	2'Lead	3'Lead
	8 msec	0.5 msec				
DA IV (HD SiC)	67.0	87.0	17	11	5	0
PDV (HD MOV)	60.0	68.0	42	33	25	18
PVR (RP MOV)	48.0	51.4	75	62	50	40

Table 4

line and ground lead wire in series with the arrester AND in parallel with the protected device (transformer in this case).

Figure 1 shows an installation with significant series arrester lead on the line side. The length of lead wire from the top of these arresters to the switch is about 4 feet. Thus, the line lead of 4 feet can be expected to add 24 kV to the arrester voltage during fast-front lightning surges.

The protective margin of the Figure 1 installation could be greatly improved by moving the line connection in such a way as to make the connection to the arrester first then to the switch.

Table I shows how the protective margins in an overhead pole-mounted installation varies with various distribution arrester types and lead lengths. ND and HD abbreviations designate Normal Duty and Heavy Duty arresters.

Utility studies of URD system performance have shown that reliability is increased by reducing surge voltage stress on transformers and cable. Surge voltage stress damage to standard URD cable is cumulative. Unlike transformer insulation, most solid dielectric cable insulation has a “memory”. Each voltage impulse contributes to deterioration and ultimate cable failure. Cable manufacturers are improving insulation compounds to retard this cumulative damage effect. However, for the many miles of cable now installed, maximum service life can be achieved by reduction of unnecessary overvoltage stress.

Surge voltage waves travel through the cable at 500 feet/ μ sec, about half the speed of light. When a surge reaches a

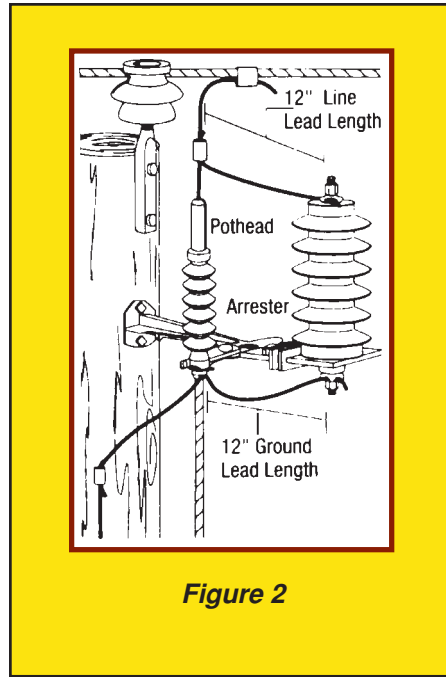


Figure 2

point of high impedance such as an open switch or transformer, it reflects upon itself, like a wave of water hitting a seawall. This doubles the voltage at the reflection point, and along the cable, as the incoming and reflective waves overlap. Even with an arrester at each high impedance point in the system, some reflection occurs in the short time it takes an arrester to “turn on” and begin limiting voltage. With an MOV arrester at the high impedance point, these partial reflections are roughly equal to 1.3 times the arrester’s MCOV rating. In either case, it is important to minimize surge voltage allowed into the system by installing, with short connecting leads, a low discharge arrester at the riser pole junction between overhead line and cable system terminator.

On 15 kV distribution systems, a good arrester at the riser pole may provide all the surge protection economically justified — based on the individual utility’s experience with cable system reliability. On 35 kV systems insulated at only 150 kV BIL, adequate surge voltage protection cannot be achieved unless any high impedance reflection points are equipped with arresters, or eliminated by using loop feed construction with no open points.

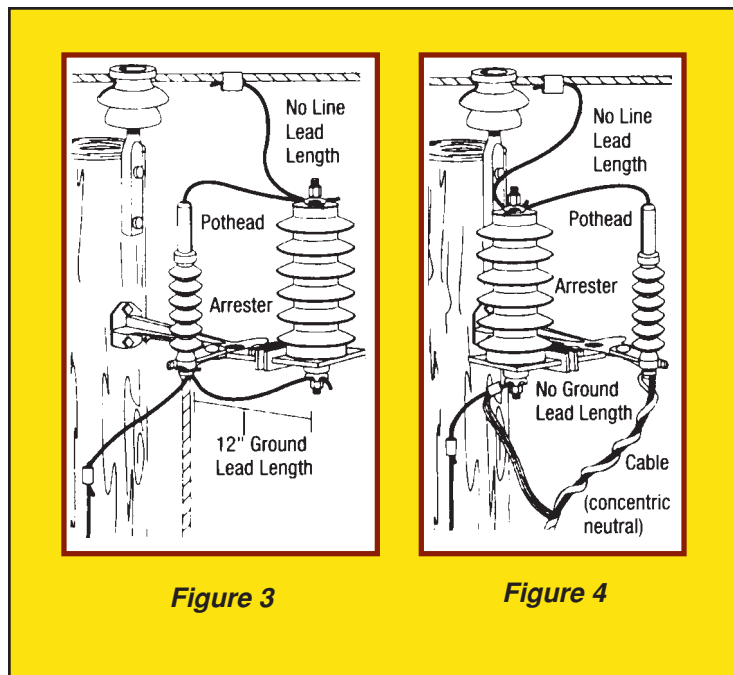


Figure 3

Figure 4

Tables 2 and 3 compare protective margins realized on two different URD systems, 13.2 and 24.9 kV, using three different arrester types. The RP abbreviation designates a Riser Pole arrester specifically designed for such applications. The 24.9 kV examples in Table 4 have arresters at the reflection points in addition to those on the riser pole. These examples are based on severe, but common, fast-front lightning

discharges which produce 6 kV/ft. inductive voltage drop in series arrester leads. Note the dramatic improvement in protective margin when lead length effect is minimized or eliminated. Protective margin examples in Tables 2 through 4 allow for some “memory” effect loss of cable insulation strength by assuming CWW is equal to system BIL.

Figure 2 shows an arrester installation which corresponds to the “2' Lead” examples in Tables 2 through 4. Again, arrester lead is the combined length of line and ground lead wire in series with the arrester AND in parallel with the protected device (cable terminator in this case). Or in other words, arrester leads are those wires which carry surge current through the arrester AND are connected across the terminator.

Figure 3 shows a similar installation except with line connection taken to the arrester and then to the terminator. This installation eliminates all arrester lead on the line side since the line connection wire carrying surge current through the arrester is not in parallel with the cable terminator.

The Figure 4 installation takes Figure 3 one step further by mounting the arrester between terminator and pole ground so the ground lead can be carried to the arrester first and then to the base of the terminator. This connection method eliminates all arrester lead and corresponds to the “O' Lead” examples in Tables 2 through 4. Here, no surge current flows in either line or ground leads between arrester and terminator. Thus, surge voltage on the cable terminator is minimized since the 111 protective benefit of the arrester is “seen” by the cable system.

LEAD LENGTH CALCULATION

The inductive voltage drop in lead-wire carrying surge current is a function of lead wire inductance, L (typically 0.4 μ H/ft), and the rate of rise of the surge current di/dr. Thus $V = (L) (di/dr)$

- (a) Using a 6 ft. lead wire and 8/20 μ s, 10 KA surge current:

$$\begin{aligned} V &= \text{Voltage drop / ft. lead length} \\ &= L di/dt = 0.4 \mu\text{H/ft.} \times 10\text{KA}/8\mu \text{Sec.} \\ &= 0.4 \times 10^{-6}\text{H/ft} \times 10\text{kA}/8 \times 10^{-6} \text{Sec.} \\ &= 0.5 \text{ kV/ ft.} \end{aligned}$$

Therefore, for a 6 ft. long lead, the voltage drop will be $0.5 \times 6 = 3 \text{ kV}$.

- (b) Using a 6 ft. lead wire and a fast rising surge current, 10kA cresting in 0.5 μ sec. For example:

$$\begin{aligned} V &= 0.4 \mu\text{H / ft.} \times 10 \text{ KA/ } 0.5 \mu \text{ Sec.} \\ &= 8 \text{ kV/ ft.} \end{aligned}$$

Therefore, for a 6 ft. long lead, the voltage drop will be $8 \times 6 = 48 \text{ kV}$.

SUMMARY

The key to installing arresters, to utilize their full protective capabilities, is to follow this procedure as closely as possible:

Carry the line and ground connections to the arrester terminals first, and then on to the terminals of the protected equipment. This applies to overhead and underground installations. With underground systems, where surge voltages cause cumulative damage in most solid dielectric cable, and protective margins are reduced by voltage reflections, it is imperative to keep arrester lead length as short as possible. ■



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