Surge Arrester Lead Length Revisited

By Waymon P. Goch

Surge arrester manufacturers always recommend that line and ground leads be as short and straight as possible in all surge arrester applications. Why?

The primary reason is inductive surge impedance. The selection of the best surge arrester for a given application can be negated by poor installation practices. The length and configuration of the line and ground leads connecting the arrester to the apparatus being protected is critical in the determination of the arrester protective levels and margins.

Modern surge arresters are designed to protect insulation from impulse over voltages that could cause flashover or damage to the insulation that is in parallel with the arrester. For distribution class arresters the primary impulse overvoltage is lightning whereas for station class arresters the primary impulse overvoltage is switching. As the class name suggests, Intermediate class arresters fall in between. The consequence of failure to protect is a function of the nature of the insulation and whether it is self-restoring (air) or non-self-restoring (solid, liquid, or composite) insulation.

Internally, the critical components of surge arresters are non-linear resistance elements; either in combination with series multi gaps or more modern gapless metal-oxide varistors (MOV). Internal gaps were necessary in older silicon-carbide arresters to limit grading current through the silicon-carbide resistance elements and to interrupt the flow of system follow current through the arrester following discharge. The composition of MOV (primarily zinc-oxide) resistance elements results in a very highly non-linear voltage / current relationship and allows the construction of gapless surge arresters.

When an overvoltage surge is impressed across the arrester terminals, the arrester begins to conduct the resulting discharge current to ground. The flow of discharge current through the arrester causes a discharge voltage to appear across the terminals of the arrester. If the arrester line and ground leads are also installed in parallel with the insulation being protected, the combined lead inductive voltage drop is additive to the arrester discharge voltage.

The inductive voltage drop in the line and ground leads is a function of the lead inductance, current rate of rise and time according to the formula: $V = L\, di/dt$.

For a straight lead wire, the inductance (L) can be assumed to be 0.4 µH/foot. If the lead wires are coiled the inductance will be significantly greater.

Arrester manufacturers' catalogs, drawings, and data will usually provide protective characteristics of their arresters, including maximum discharge voltages for several discharge currents and voltage times to crest from steep wave through switching surge. Those arrester discharge voltages plus lead inductive voltage (if appropriate) are usually plotted and compared to the corresponding insulation characteristics to determine the protective margins on insulation coordination curves similar to Fig 1. Fig 1 also illustrates the typical volt-time characteristic of most insulation. That is, the shorter the time the greater the insulation or dielectric strength.

Published arrester IR discharge voltages are normally based on a standard 8/20 impulse current wave (8 µs to crest/20µs to half crest on the tail) however, the highest voltages to which the insulation is subjected are rapidly rising steep wave impulses due to lightning. It is now known that rapidly rising impulse currents are far more common that previously thought. More accurate measurements have shown that about half have rates of rise of 13 kA/µs with a maximum value of approximately 60 kA/µs.

Consistent with this rate of rise, a lead wire voltage drop of 6 kV/ft is often used in calculating the protective levels for installations exposed to rapidly rising fast front surges.

Let's look at an example to illustrate the effect of arrester line and ground leads connected to a surge arrester and connected in parallel with insulation.

Assuming an 8.4 kV MCOV gapless distribution arrester protecting a 95 kV BIL transformer, a typical gapless heavy duty distribution class arrester might have a 0.5 µs 10 kA IR of around 36.5 kV.

Assuming line and ground lead impedance of 0.4 µH/ft, the resulting inductive voltage developed across the leads = $0.4 \times 10^{-6} \times (10 \times 10^{3}$ A $/ 0.5 \times 10^{-6}$ sec$)$ = 8 kV/ft. Thus, for every foot of line and ground lead, 8 kV must be added to the arrester IR discharge voltage when calculating the overvoltage protective margins provided by the arrester and its connections. This could be particularly important for the protection of underground cable and aged or degraded equipment.
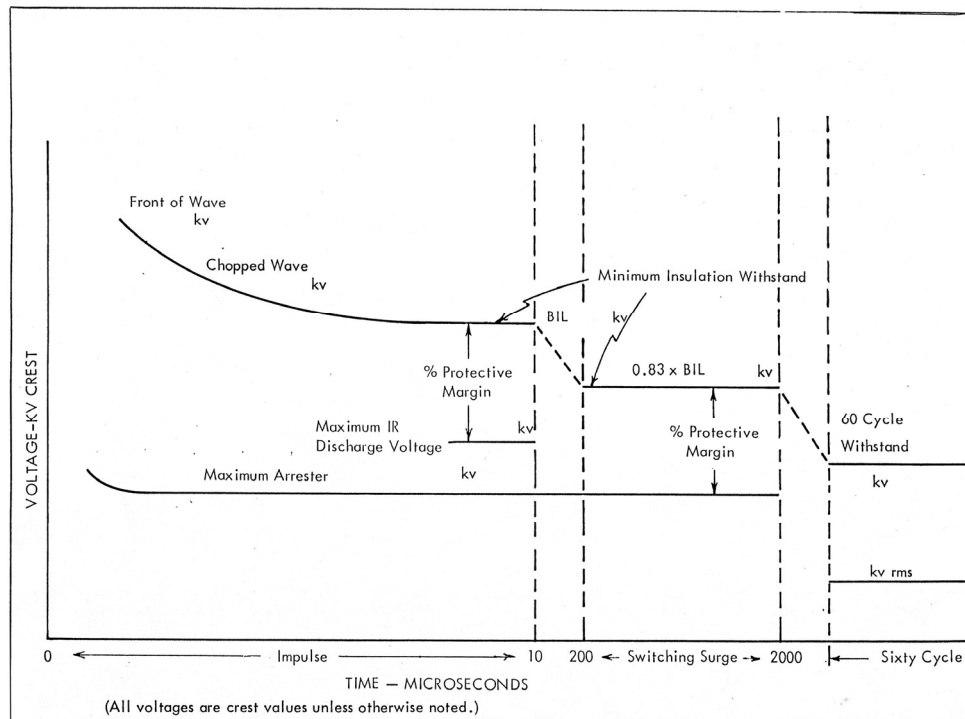

Fig. 1 Insulation Volt-Time Coordination Curve