

# IEEE Guide for the Connection of Surge Arresters to Protect Insulated, Shielded Electric Power Cable Systems

Sponsor

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**Abstract:** This guide suggests surge arrester installation methods at distribution cable terminal poles in order to minimize the total impressed transient voltage on medium-voltage distribution cables. Grounding electrode techniques, pole ground values, and system ground grid values are not addressed or considered in this document.

**Keywords:** cable, lead length, margin of protection, surge arresters

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# Introduction

(This introduction is not a part of IEEE Std 1299/C62.22.1-1996, IEEE Guide for the Connection of Surge Arresters to Protect Insulated, Shielded Electric Power Cable Systems.)

This guide concentrates on the connection of surge arresters for distribution system terminal pole applications in order to minimize the total impressed transient voltage that the cable system can experience during surge current discharge. It is not the intent of this guide to recommend the use of surge arresters, as that is addressed in IEEE Std C62.22-1991, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems. Pole or system grounding values and techniques are not addressed. Practical, simple examples are provided in an informative annex to estimate margins of protection depending upon the arrester installation technique used.

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## 1. Overview

### 1.1 Scope

This guide suggests surge arrester installation methods at distribution cable terminal poles in order to minimize the total impressed transient voltage on medium-voltage distribution cables. Grounding electrode techniques, pole ground values, and system ground grid values are not addressed or considered in this document.

### 1.2 Purpose

Historical surge arrester installation techniques for cable system protection may not have provided required margins of protection. Variables include the terminal-pole arrester characteristics, connection lead length inductive voltage drop and cable system open and mid-point arrester utilization. Different protection schemes are presented to assist the user who is designing overvoltage protection for cable systems to estimate available margins of protection. Margin of protection calculation cases for simple cases, which do not consider multiple reflections or the effects of cable taps, are included as practical examples in Annex A.

## 2. Cable damage

Medium-voltage cables are connected to overhead distribution lines and subjected to surge conditions. Overvoltage may contribute to failure or reduction in cable life [B7], [B8]. It is apparent cable life may be extended with improved surge protection [B7], [B8], [B9]. Significant aspects of cable surge protection include

- a) Appropriate arrester at the terminal pole,
- b) Minimum connection lead length,
- c) Determination of the system BIL, with possible derating for aged systems, and
- d) Use of open point and midpoint arresters, as necessary, to maintain desired margins of protection.

### 3. Lightning overvoltage and cable system effects

#### 3.1 Lightning surges on the overhead distribution system

Medium voltage cables can be subjected to severe transient overvoltages as a result of lightning striking on, or near the overhead distribution system to which the cable is connected. Lightning strokes terminating on the overhead distribution line are called direct strokes. Strokes to ground, or to other objects such as trees or structures, in the vicinity of the overhead line produce electromagnetic fields that can induce substantial overvoltages. These strokes, which do not strike the line but are sufficiently close to induce overvoltages, are called induced strokes.

##### 3.1.1 Direct strokes

For a direct stroke, the voltage on the overhead line is the product of the line surge impedance and the stroke current magnitude. The surge impedance of a typical distribution line is approximately 400 Ω. Unless the stroke is to an open end of a line, the surge current can propagate in both directions away from the stroke location. Therefore, the stroke current is divided in two, and the line voltage is

$$e_f = \frac{I_{\text{stroke}} \cdot Z_{\text{line}}}{2} \quad (1)$$

where

$e_f$  is the voltage to ground of the struck overhead line conductor  
 $I_{\text{stroke}}$  is the lightning stroke current magnitude  
 $Z_{\text{line}}$  is the surge impedance of the overhead line

Because lightning stroke crest currents are on the order of tens of kiloamperes, crest line voltage for a direct stroke is on the order of megavolts. This voltage level greatly exceeds typical distribution line insulation levels, and line flashover usually results. An exception is when the line is protected by an arrester within a short distance from the stroke location.

Voltages developed on an unprotected line prior to flashover propagate along the line as traveling waves. At the surge impedance discontinuity of the overhead line to cable transition, part of the wave is reflected and not all of the surge propagates into the cable. The voltage, which propagates into a cable, from an overhead line terminated into the cable without a transition point arrester, can be calculated by

$$e_{\text{cable}} = \frac{2 \cdot Z_{\text{cable}}}{Z_{\text{line}} + Z_{\text{cable}}} \cdot e_f \quad (1A)$$

where

$Z_{\text{cable}}$  is the surge impedance of the cable

Assuming a typical cable surge impedance of 40 Ω, only about 18% of the incoming surge voltage would enter the cable because of the surge impedance discontinuity. However, because the voltage on the line prior to flashover could be 1000 kV or more, the voltage passing through to the cable can be excessive.

##### 3.1.2 Voltages following overhead line flashovers from direct strokes

Flashover of the overhead line does not eliminate the source of overvoltage applied to the cable. At the stroke location, both the overhead phase and neutral conductors will be elevated to the same potential with

respect to ground after flashover. Unless the neutral grounding impedance at the struck location is low, both conductors will have a large voltage with respect to remote earth. For example, a 50 kA stroke to a location where the neutral is grounded through 50  $\Omega$  will elevate the phase and neutral to 2500 kV.

Voltage waves propagate away from the struck location along both the phase and the neutral. At adjacent locations where the neutral is grounded, there will be a reduction in the neutral voltage. The voltage on the struck primary conductor is reduced through inter-phase coupling, but not to the same extent as the neutral-voltage reduction. As a result, the voltage difference between the primary and neutral increases. This phase-neutral voltage is impressed on the cable at the overhead line to cable transition, modified by the cable surge impedance discontinuity. The voltage magnitudes from this phenomenon alone can be excessive, even if the line were to flashover instantly at the stroke location.

This same phenomenon occurs when an overhead line flashover is averted by a surge arrester on the struck phase near the stroke location. The neutral is elevated to the same potential as the phase, minus the arrester discharge voltage. The voltage difference tends to increase at adjacent neutral ground locations. Arresters at locations other than the cable termination point do not protect the cable.

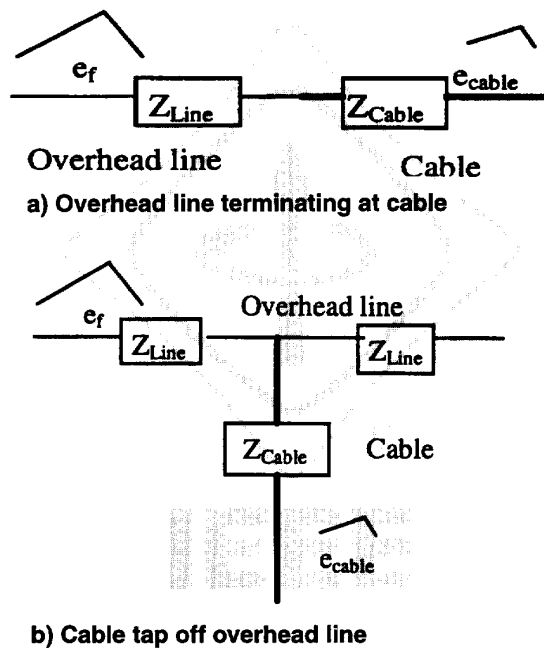


**Figure 1—Surge impedance discontinuity for overhead line terminating at cable and for cable tap off of an overhead line**

### 3.1.3 Induced lightning surges

The majority of lightning surges that occur on a distribution line are induced, particularly when the line is shielded by nearby trees and structures. Induced surge voltages on the overhead line are usually several hundred kilovolts, or less. At the cable transition, the impedance discontinuity allows only a portion of the induced surge voltage to propagate into the cable. Equation (1A) applies to the calculation of the cable voltage for the case where the overhead line terminates at the cable transition. For the common case of a cable tapped off of a continuing overhead line, the percentage of voltage refracting onto the cable is slightly less. Considering the magnitude of induced surges and the voltage reduction due to the surge impedance discontinuity

between an overhead line and a cable, induced surges are not generally critical to medium voltage cable insulation as compared to the discharge voltage produced by a surge arrester at the cable termination discharging a direct stroke.

### 3.1.4 Surge impedance discontinuity with surge arrester

An arrester located at the discontinuity junction appears as a virtual voltage source to the cable system, provided that the refracted voltage is sufficient to drive the arrester into conduction. The arrester discharge voltage propagates into the cable.

## 4. Surge arrester operation

### 4.1 Surge arrester discharge voltage

Surge arresters respond to overvoltage by diverting surge current to the ground and limit the surge voltage on the system. Surge arresters develop a discharge voltage across their terminals, which is a function of the magnitude and waveshape of the discharge current wave, arrester class, design, and voltage rating.

### 4.2 Lead length

One significant variable under user control is total connection lead length. This is comprised of the line lead and the ground lead. Line lead length is the distance from the phase conductor tap connection to the line terminal of the arrester. The ground lead length is the distance that the surge current flows from the arrester ground terminal to the common ground/neutral connection with the cable metallic shield. Refer to Figure 2.

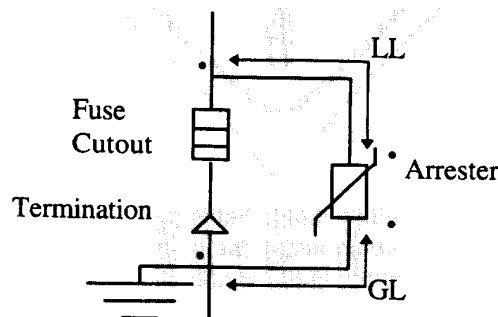


Figure 2—Line lead and ground lead voltage drop during discharge contribute to total impressed transient voltage

## 5. Cable system surge arrester protection schemes

### 5.1 Terminal pole arrester scheme

The maximum surge voltage produced by an arrester on the terminal pole is the sum of the arrester discharge voltage (also known as lightning protection level) and the inductive voltage drop  $\left[ L \frac{di}{dt} \right]$  of the connection leads. This voltage can reflect at the open point of the cable run and double in magnitude. By keeping the total connection lead length as short as possible, the total impressed transient voltage developed by the