JUNE 2019

Shielded surge arresters

Applied in underground distribution systems

Customer presentation

ABB

Agenda

Definitions

Standards

Types of arresters

Protection on underground distribution systems

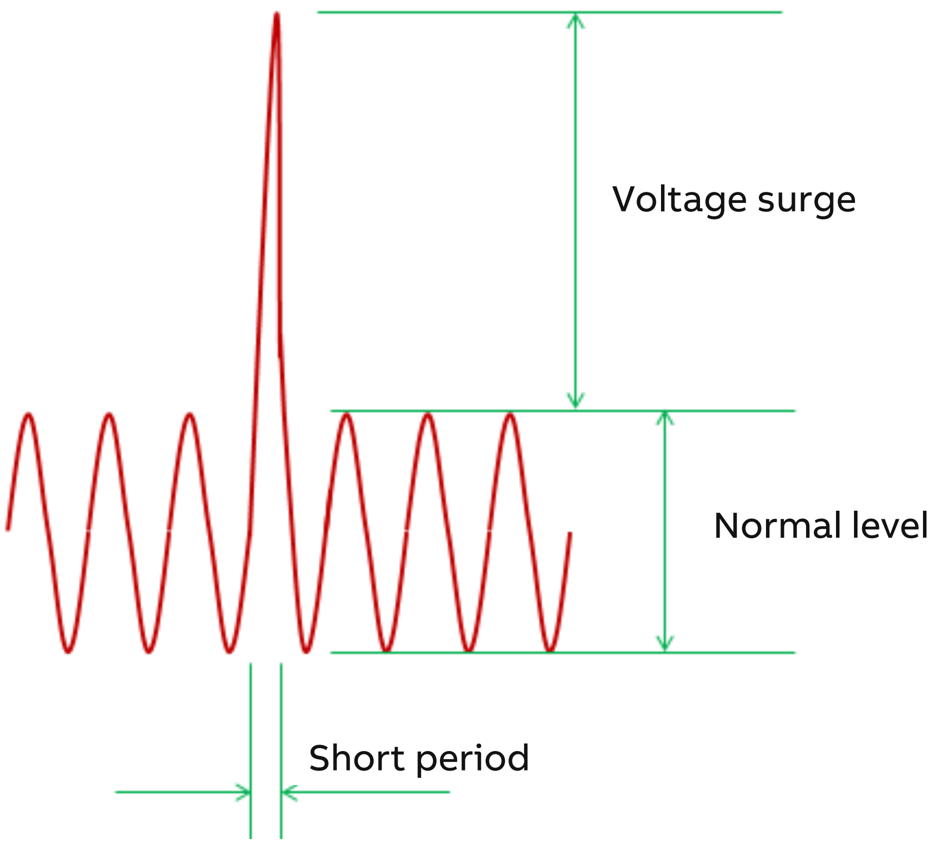
Definitions

What is a surge?

A surge, or transient, is a sub-cycle overvoltage with a duration of less than a half-cycle of the normal voltage waveform. Surges can damage, degrade or destroy electric/electronic equipment.

What can result from surges in distribution systems?

- Breakdown of insulation
- Aging of insulation (pre-damage)
- Malfunction



Definitions

Causes of surges

Switching surges

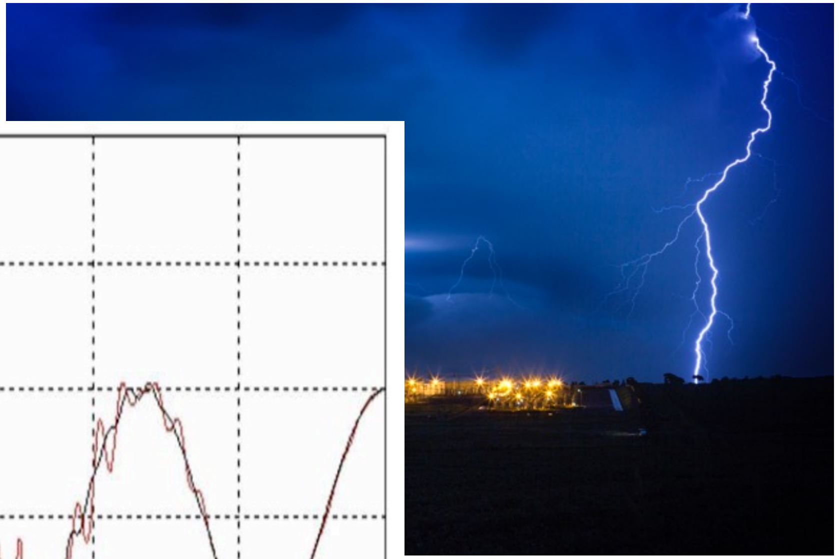
- Demand power load switching
- Utility power load correction
- Capacitor bank switching (the most common switching phenomena)

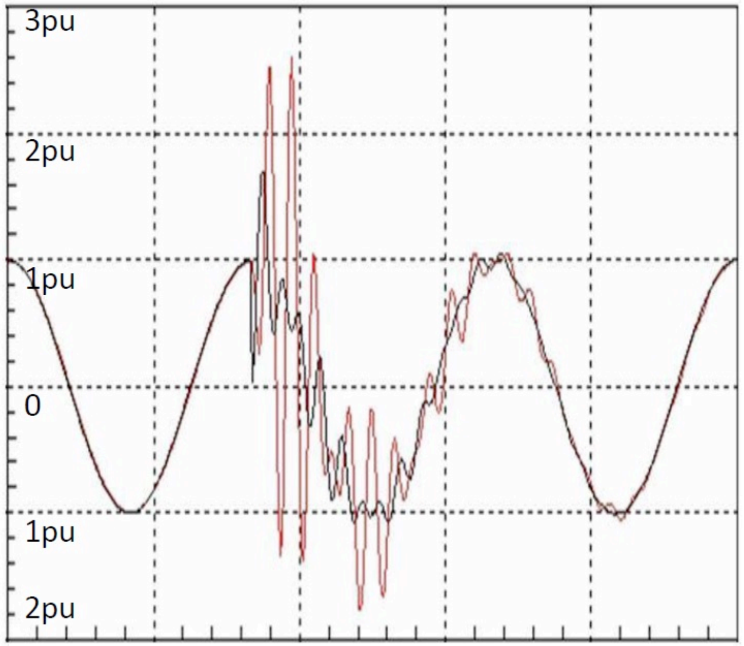
Lightning surges

- Nearby lightning strikes
- Direct lightning strike on the power lines (the majority lead to faults)

Severity of transients in distribution

On 15.0 kV class, typical transients are:
~10.0 kV to 80 kV with duration of ~8 to 20 μs

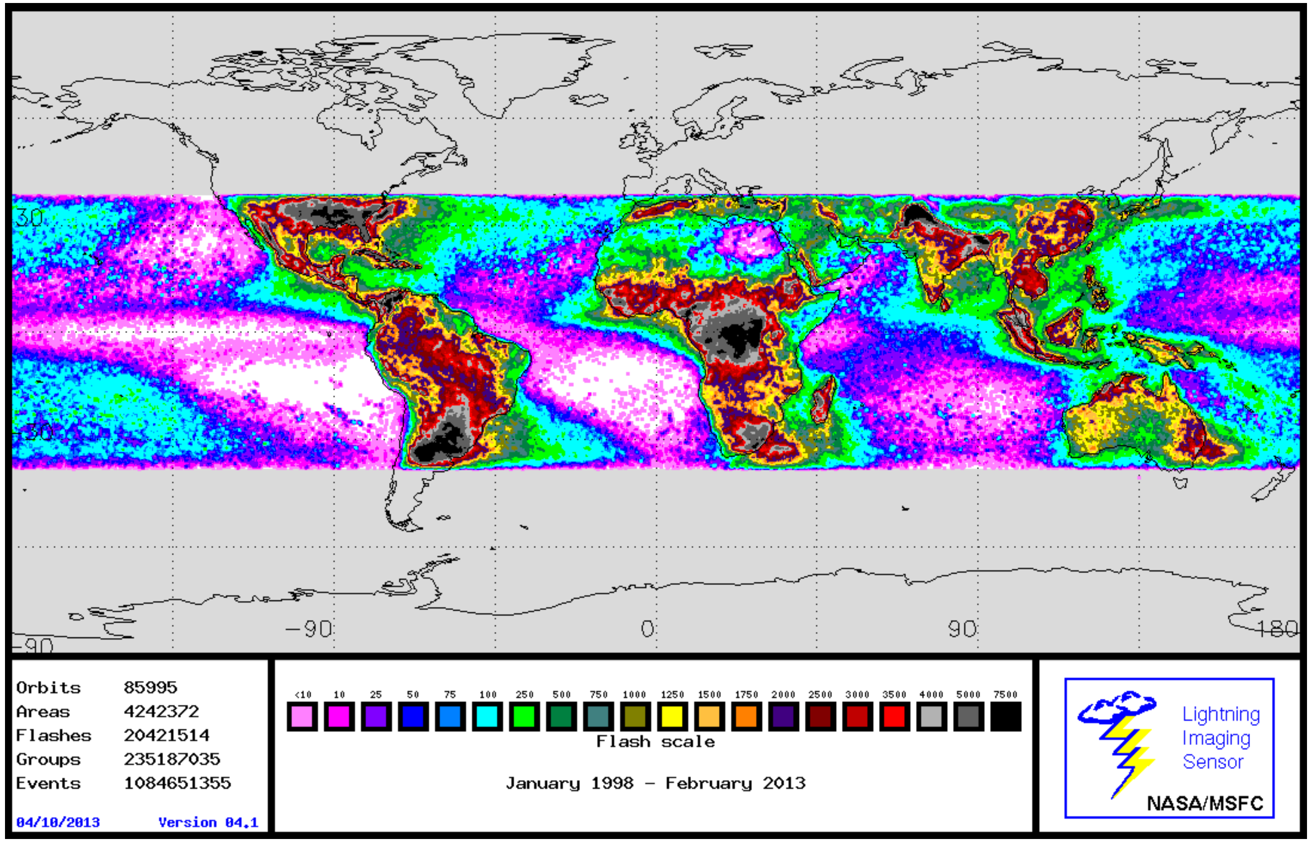




Switching surge

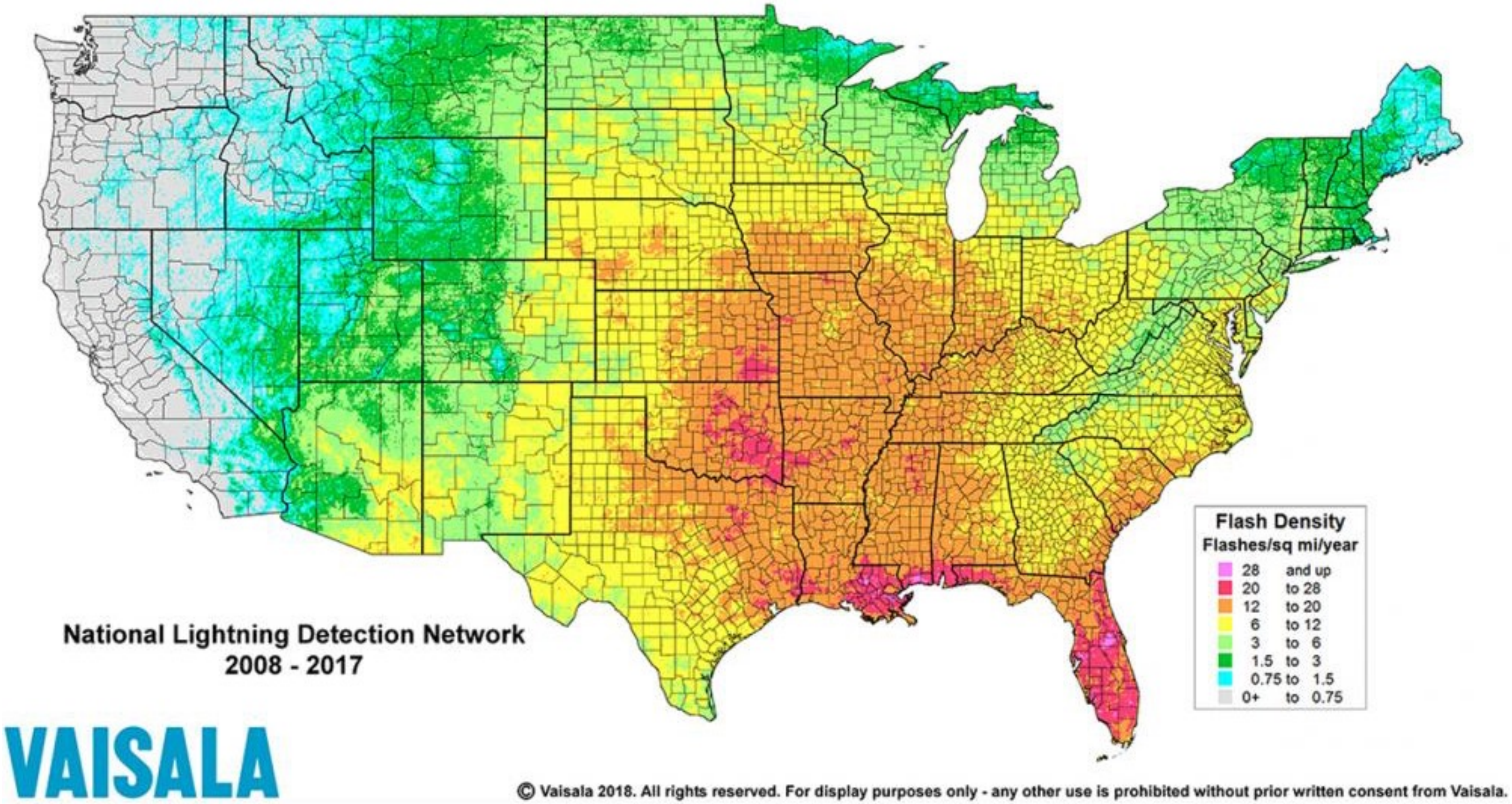
Definitions

Global lightning density



Definitions

US lightning density



Source: www.vaisala.com/en/products/data-subscriptions-and-reports/data-sets/nldn

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Definitions

Economic considerations

Accurately applied surge protection reduces:

- Outage of lines and substations
- Interruptions of critical manufacturing processes, which demand high voltage stability
- Costs due to interruptions in the energy supply
- Costs for the replacement and repair of electrical equipment
- Aging of insulation (e.g., cables)
- Maintenance work

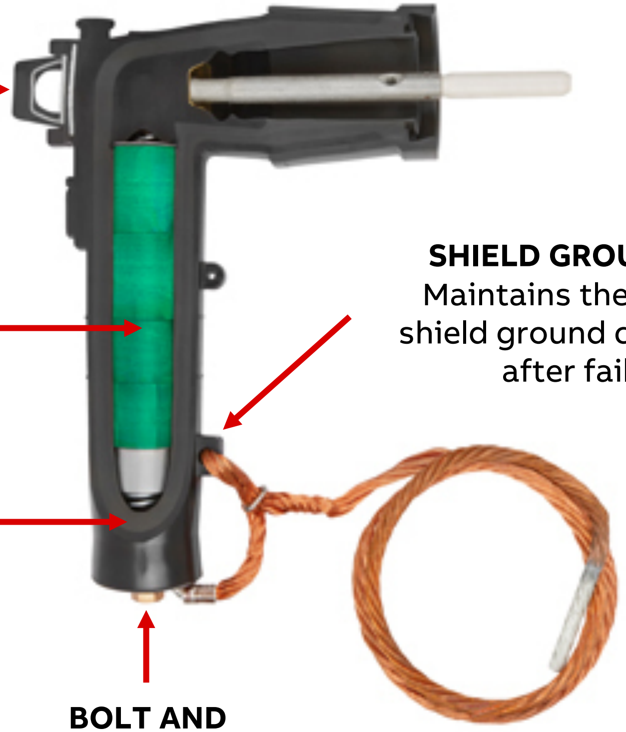
The aim of overvoltage protection is to guarantee an uninterrupted supply of electrical energy with high voltage stability to the greatest degree possible.

Definitions

Surge arrester

A surge arrester is a protective device for limiting surge voltages on equipment by discharging or bypassing surge current. It limits the flow of power following current to ground and is capable of repeating these functions as specified.

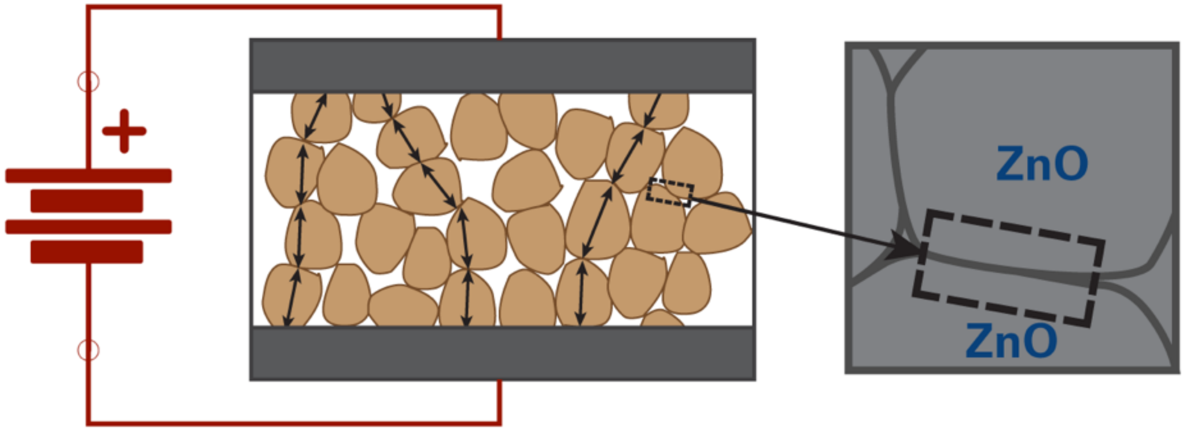
Surge arresters are installed phase-to-ground on the system.



Definitions

Metal oxide varistor (MOV)

- A varistor is sometimes called a “metal oxide resistor” and is made of different metal oxides in powder form, which are compressed and sintered in the form of round blocks.
- The zinc oxide grains create diode junctions that are interconnected.
- When enough voltage activates a varistor, reaching the breakdown voltage for the junctions, it provides a low impedance path.
- This action redirects the energy away from the circuit, providing protection.

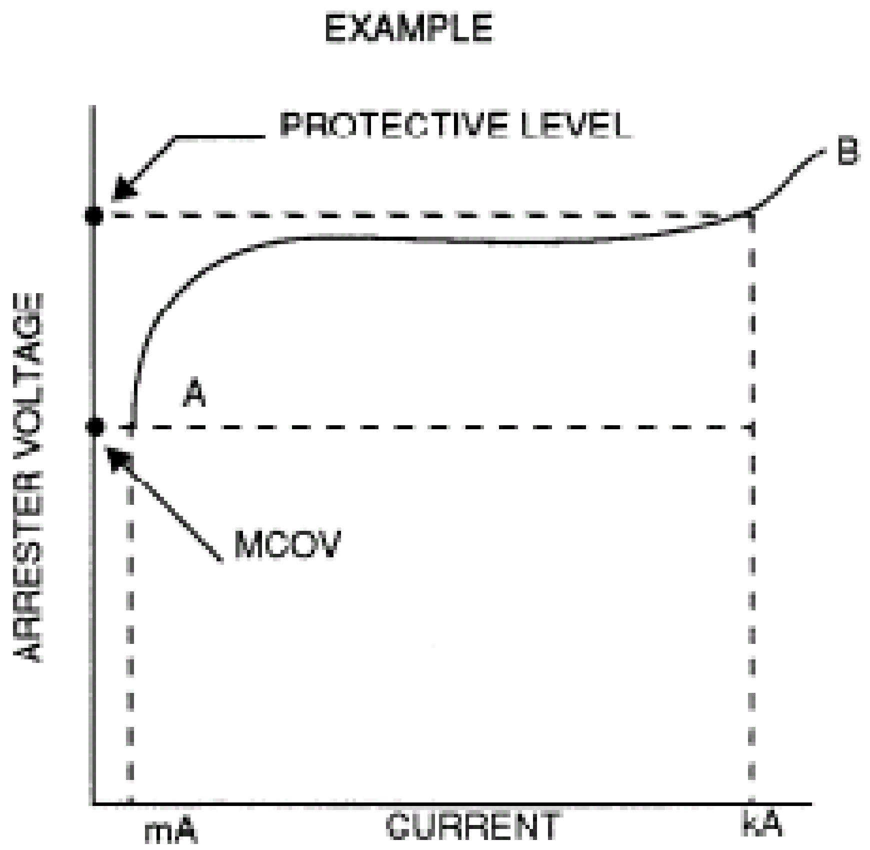


Source: https://ec.kemet.com/varistor-mov-voltage-protection

Definitions

Maximum continuous operating voltage (MCOV)

- The maximum continuous operating voltage (MCOV) of an arrester is typically in the range of 75% to 85% of the duty-cycle voltage rating.
- At MCOV, the arrester current is usually not more than a few milliamperes, typically less than 10 mA.
- If the arrester is operating at a voltage level greater than its MCOV, the metal oxide elements will operate at a higher-than-recommended temperature. This may lead to premature failure or shortened life.



Definitions

Duty-cycle rating

- Duty-cycle rating is the designated maximum permissible voltage between terminals at which an arrester is designed to perform its duty-cycle test.
- The duty-cycle test subjects an arrester to an AC RMS voltage equal to its rating for 24 minutes, during which time the arrester must withstand lightning surges at 1-minute intervals. The magnitude of the surges is 10 kA (10,000 amps) for station class arresters and 5 kA for intermediate and distribution class arresters.

Parking stand arrester (200 A)			
Part no.	**Voltage class**	**MCOV (kV RMS)**	**Duty cycle rating (kV RMS)**
167PSA-3	15 kV	2.55	3
167PSA-6		5.10	6
167PSA-9		7.60	9
167PSA-10		8.40	10
167PSA-12		10.20	12
167PSA-15		12.70	15
167PSA-18		15.30	18
273PSA-10	25 kV	8.40	10
273PSA-12		10.20	12
273PSA-15		12.70	15
273PSA-18		15.30	18
273PSA-21		17.00	21
375PSA-24	35 kV	19.50	24
375PSA-27		22.00	27
375PSA-30		24.40	30

Bushing surge arrester (200 A)			
Part no.	**Voltage class**	**MCOV (kV RMS)**	**Duty cycle rating (kV RMS)**
167BSA-3	15 kV	2.55	3
167BSA-6		5.10	6
167BSA-9		7.60	9
167BSA-10		8.40	10
167BSA-12		10.20	12
167BSA-15		12.70	15
167BSA-18		15.30	18
273BSA-6	25 kV	5.10	6
273BSA-9		7.60	9
273BSA-10		8.40	10
273BSA-12		10.20	12
273BSA-15		12.70	15
273BSA-18		15.30	18
273BSA-21		17.00	21
375BSA-24	35 kV	19.50	24
375BSA-27		22.00	27
375BSA-30		24.40	30

Source: www.vaisala.com

Definitions

Duty-cycle rating

Elbow surge arrester (200 A)			
Part no.	**Voltage class**	**MCOV (kV RMS)**	**Duty cycle rating (kV RMS)**
167ESA-3	15 kV	2.55	3
167ESA-6		5.10	6
167ESA-9		7.60	9
167ESA-10		8.40	10
167ESA-12		10.20	12
167ESA-15		12.70	15
167ESA-18		15.30	18
167ESA-21		17.00	21
273ESA-3	25 kV	2.55	3
273ESA-6		5.10	6
273ESA-9		7.60	9
273ESA-10		8.40	10
273ESA-12		10.20	12
273ESA-15		12.70	15
273ESA-18		15.30	18
273ESA-21		17.00	21
375ESA-10	35 kV	8.40	10
375ESA-18		15.30	18
375ESA-21		17.00	21
375ESA-24		19.50	24
375ESA-27		22.00	27
375ESA-30		24.40	30
375ESA-36		29.00	36

Elbow surge arrester (600 A)			
Part no.	**Voltage class**	**MCOV (kV RMS)**	**Duty cycle rating (kV RMS)**
K655ESA-10	25 kV	8.40	10
K655ESA-12		10.20	12
K655ESA-15		12.70	15
K655ESA-18		15.30	18
K655ESA-21		17.00	21
K655ESA-27		22.00	27
K655ESA-30		24.40	30
755ESA-18	35 kV	15.30	18
755ESA-24		19.50	24
755ESA-27		22.00	27
755ESA-30		24.40	30
755ESA-33		26.80	33
755ESA-36		29.00	36
755ESA-40.5		32.50	40.5

Source: www.vaisala.com

Definitions

Maximum discharge voltage

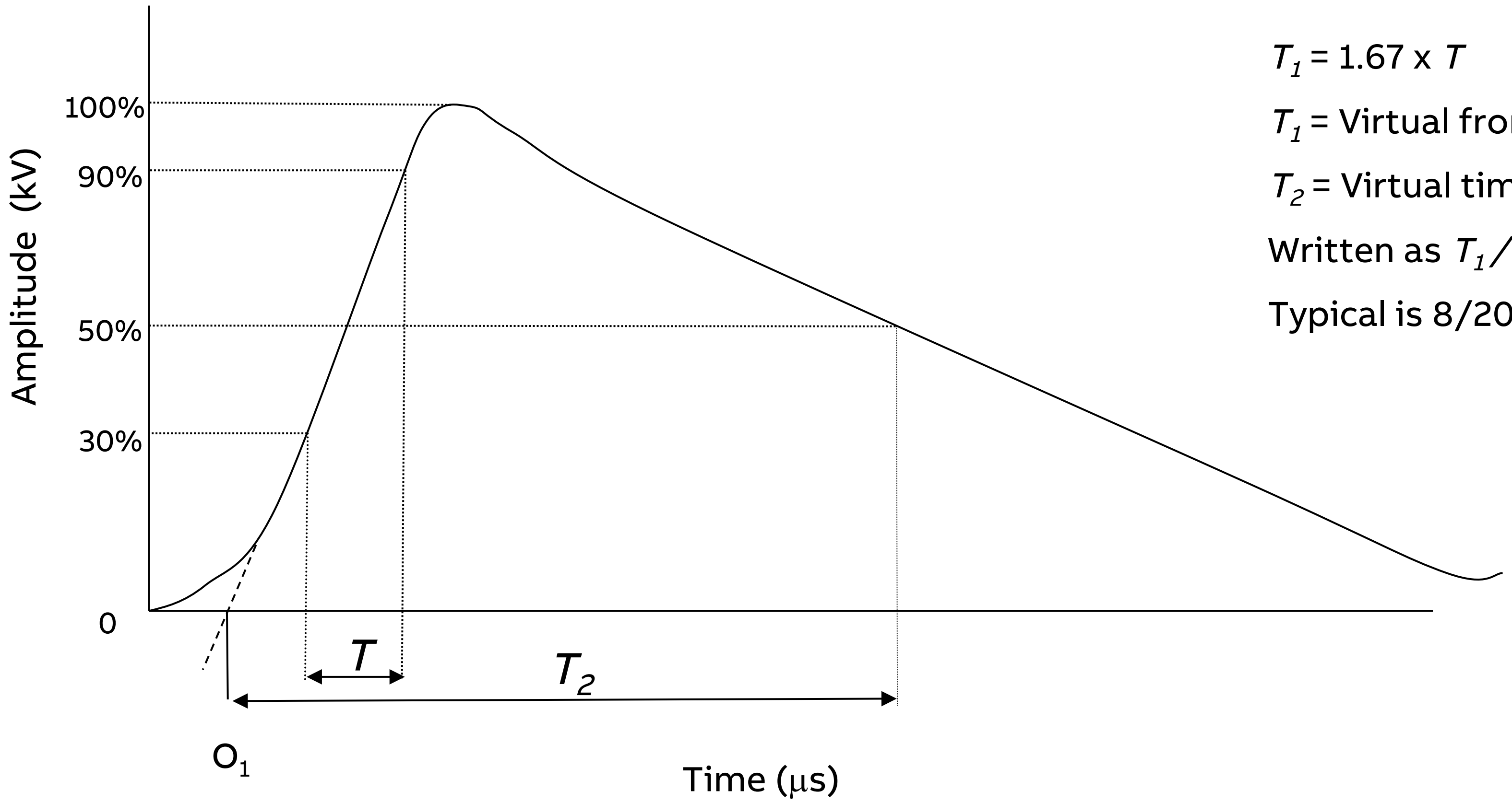
A lower level maximum discharge voltage indicates better protection.

Protective characteristics

Voltage class	MCOV (kV RMS)	Duty cycle rating (kV RMS)	Maximum discharge voltage (kV crest) 8 x 20 microsecond current wave				
			1.5 kA	3 kA	5 kA	10 kA	20 kA
15 kV	2.55	3	8.06	8.48	8.74	9.36	10.40
	5.10	6	16.12	16.95	17.47	18.72	20.80
	7.60	9	24.18	25.42	26.20	28.08	31.20
	8.40	10	28.21	29.66	30.57	32.76	36.40
	10.20	12	32.24	33.90	34.94	37.44	41.60
	12.70	15	40.30	42.38	43.68	46.80	52.00
	15.30	18	48.36	50.85	52.41	56.16	62.40
25 kV	2.55	3	8.06	8.48	8.74	9.36	10.40
	5.10	6	16.12	16.95	17.47	18.72	20.80
	7.60	9	24.18	25.42	26.20	28.08	31.20
	8.40	10	28.21	29.66	30.57	32.76	36.40
	10.20	12	32.24	33.90	34.94	37.44	41.60
	12.70	15	40.30	42.38	43.68	46.80	52.00
	15.30	18	48.36	50.85	52.41	56.16	62.40
	17.00	21	56.42	59.32	61.14	65.52	72.80
35 kV	8.40	10	28.21	29.66	30.57	32.76	36.40
	15.30	18	48.36	50.85	52.41	56.16	62.40
	17.00	21	56.42	59.32	61.14	65.52	72.80
	19.50	24	64.48	67.80	69.88	74.88	83.20
	22.00	27	72.54	76.28	78.62	84.24	93.60
	24.40	30	80.60	84.75	87.35	93.60	104.00
	26.80	33	88.66	93.23	96.09	102.96	114.40
	29.00	36	96.72	101.70	104.82	112.32	124.80
	32.50	40.5	108.81	114.41	117.92	126.36	140.40

Definitions

Protection on underground distribution systems — impulse wave example



$T_1 = 1.67 \times T$

T_1 = Virtual front time

T_2 = Virtual time to half

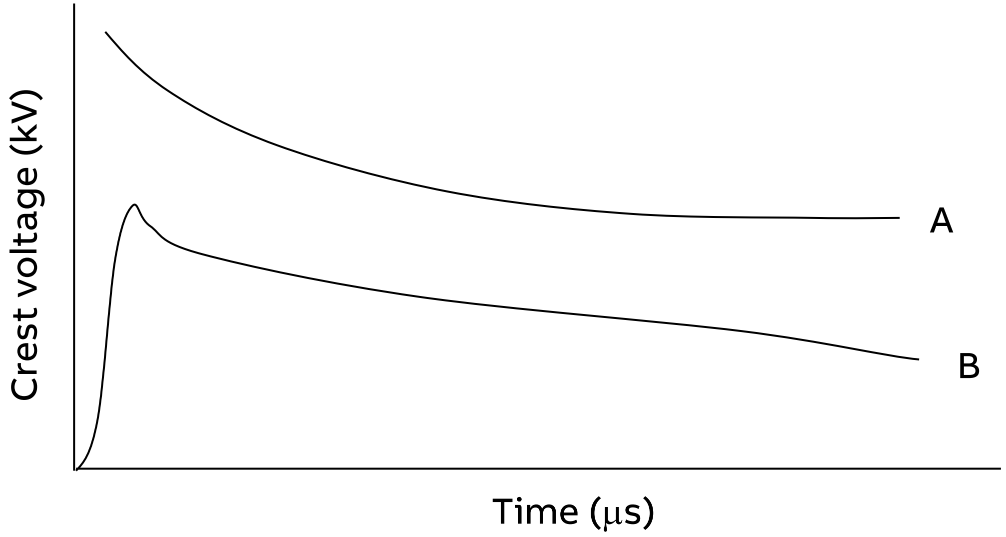
Written as T_1 / T_2 wave

Typical is 8/20 wave

Definitions

Protective levels

- The protective level of an arrester is the maximum crest voltage that appears across the arrester terminals under specified conditions of operation.
- Curve A: Demonstrates the strength of insulation on equipment.
- Curve B: Is the protective level provided by an arrester.



Definitions

Cable BIL deterioration and temporary overvoltage (TOV)

Cable BIL deterioration

The progressive weakening of cable insulation will lead to cable deterioration and eventually its failure. Each surge impulse on the cable will contribute with other factors toward cable insulation strength deterioration. Ultimately, the cable can fail with an overvoltage level below the cable's basic impulse level (BIL) rating.

Temporary overvoltage (TOV)

A TOV is an oscillatory overvoltage associated with switching or faults (for example, load rejection, single-phase faults) and/or nonlinearities (ferroresonance effects, harmonics) of relatively long duration, which is undamped or slightly damped.

Standards

Applicable standards and guides for protection of equipment (including cables) on underground systems

C62.11

– 2012

- IEEE standard for metal oxide surge arresters for AC power circuits (>1 kV)

C62.22

– 2009

- IEEE guide for the application of metal oxide surge arresters for alternating-current systems

Std 386™

– 2016

- IEEE standard for separable insulated connector systems for power distribution systems rated 2.5 kV through 35 kV

Types of arresters

According to IEEE Std C62.22-2009

Types

– Station (utility/power company) — What voltage level?
– Intermediate (utility users/power company)
– Distribution (utility/power company)

Classes

a) Heavy-duty class: An arrester most often used to protect overhead distribution systems exposed to severe lightning currents.

b) Light-duty class: An arrester generally installed on and used to protect underground distribution systems where the major portion of the lightning strike current is discharged by an arrester located at the overhead line/cable junction.

c) Normal-duty class: An arrester generally used to protect overhead distribution systems exposed to normal lightning currents.

Protection on underground distribution systems

Key points

- The use of surge arresters is not an exact science, and there are many variables involved in protecting the system.
- Reliable surge protection for underground distribution circuits should incorporate some margin of protection to take into account unknowns variables. IEEE C62-11 recommended protective margin for impulse coordination is 20% (for transmission and distribution applications).
- Surge voltages enter the underground system from the overhead feeder at the riser pole.
- The magnitude of surge voltage entering the cable is limited by the arrester on the riser pole.
- Surge voltage in excess of the protective level of the riser pole arresters can occur on the cable and at equipment locations remote from the riser pole because of amplification by reflection from the open point.
- When the ongoing surge from the riser pole arrester meets an endpoint in the underground circuit, it will double in magnitude at that point in the circuit. This is known as the **voltage doubling effect**.

Protection on underground distribution systems

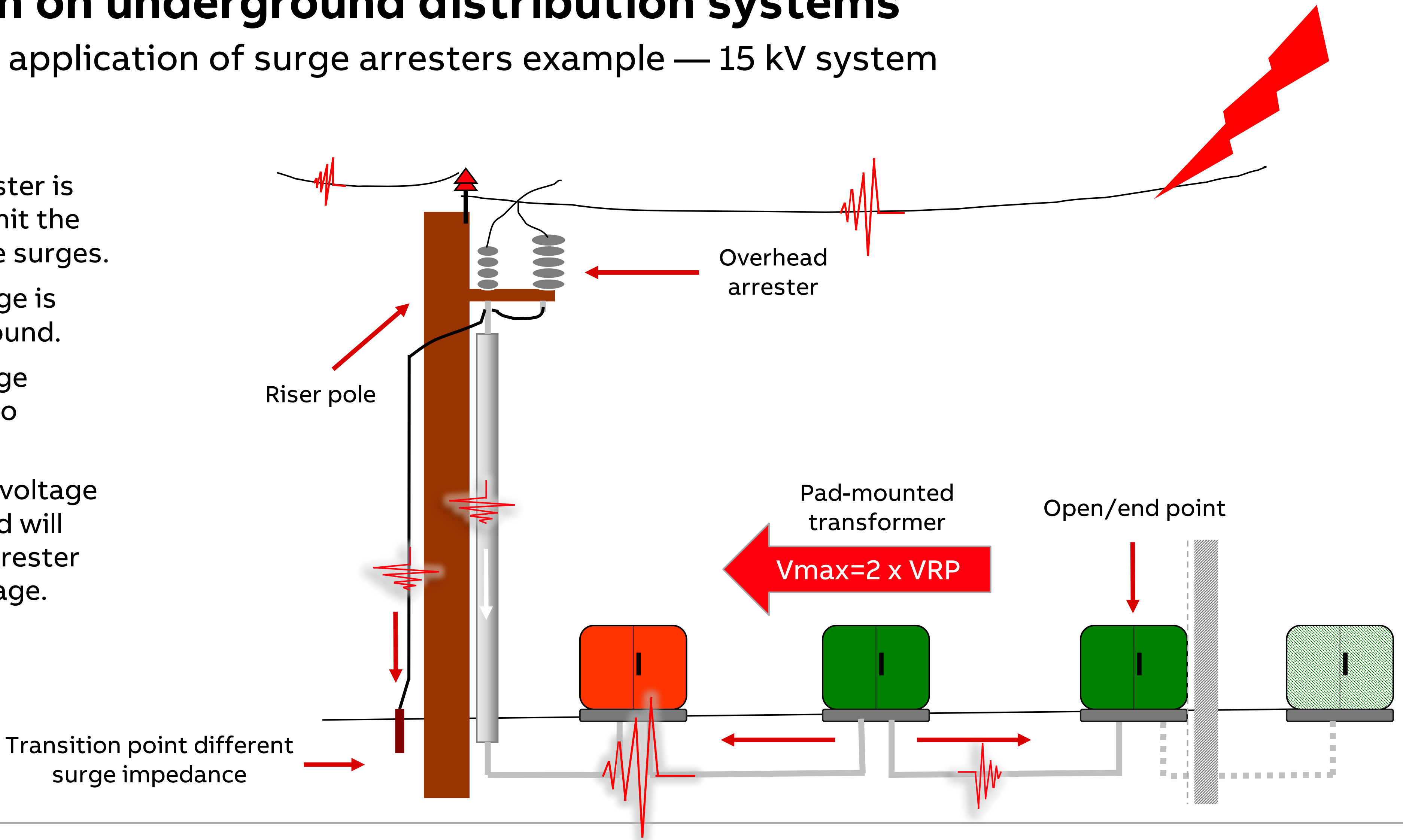
Location and application of surge arresters example — 15 kV system

- Assume no attenuation. This assumption becomes conservative for cable lengths greater than 3,000 ft (900 m).
- Assume that incident voltages will double at open points and terminating transformers.
- The 10 kA crest surge is used when considering protection schemes for a shielded system.
- Suitable margin of protection is 20%.
- The BIL of the system is equal to 95 kV.

Protection on underground distribution systems

Location and application of surge arresters example — 15 kV system

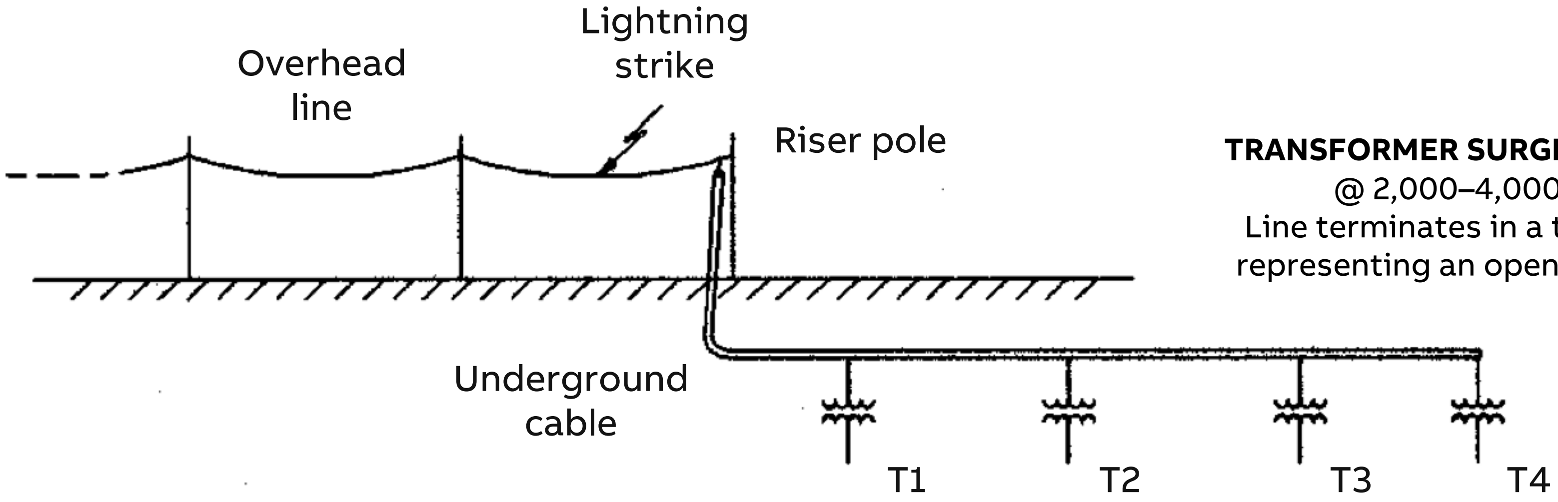
- Overhead arrester is designed to limit the system voltage surges.
- Part of the surge is diverted to ground.
- Part of the surge is let through to the system.
- The maximum voltage at the open end will be twice the arrester discharge voltage.



Protection on underground distribution systems

Surge impedance change

OVERHEAD SURGE IMPEDANCE
@ 300–500 ohms/support surges of 200–500 kV
Propagation speed 1,000 ft/µs



TRANSFORMER SURGE IMPEDANCE
@ 2,000–4,000 ohms
Line terminates in a transformer, representing an open point circuit

UNDERGROUND SURGE IMPEDANCE
@ 25–75 ohms
Propagation speed of 300–500 ft/µs

  Source: Surge Protection of Cable-Connected Distribution Equipment on Underground Systems IEEE COMMITTEE REPORT

Protection on underground distribution systems

Arrester selection — 15 kV system example

Determine the maximum discharge voltage

– From the overhead arrester product specification
  - Rating of the **riser pole arrester** (10 kV)
  - Initial surge magnitude (20 kA discharge current)

– The lead length will increase surge voltage about 2 kV per foot. Lead length on the riser pole arrester (4 feet). Additional discharge voltage: 2 kV x 4 ft = 8 kV

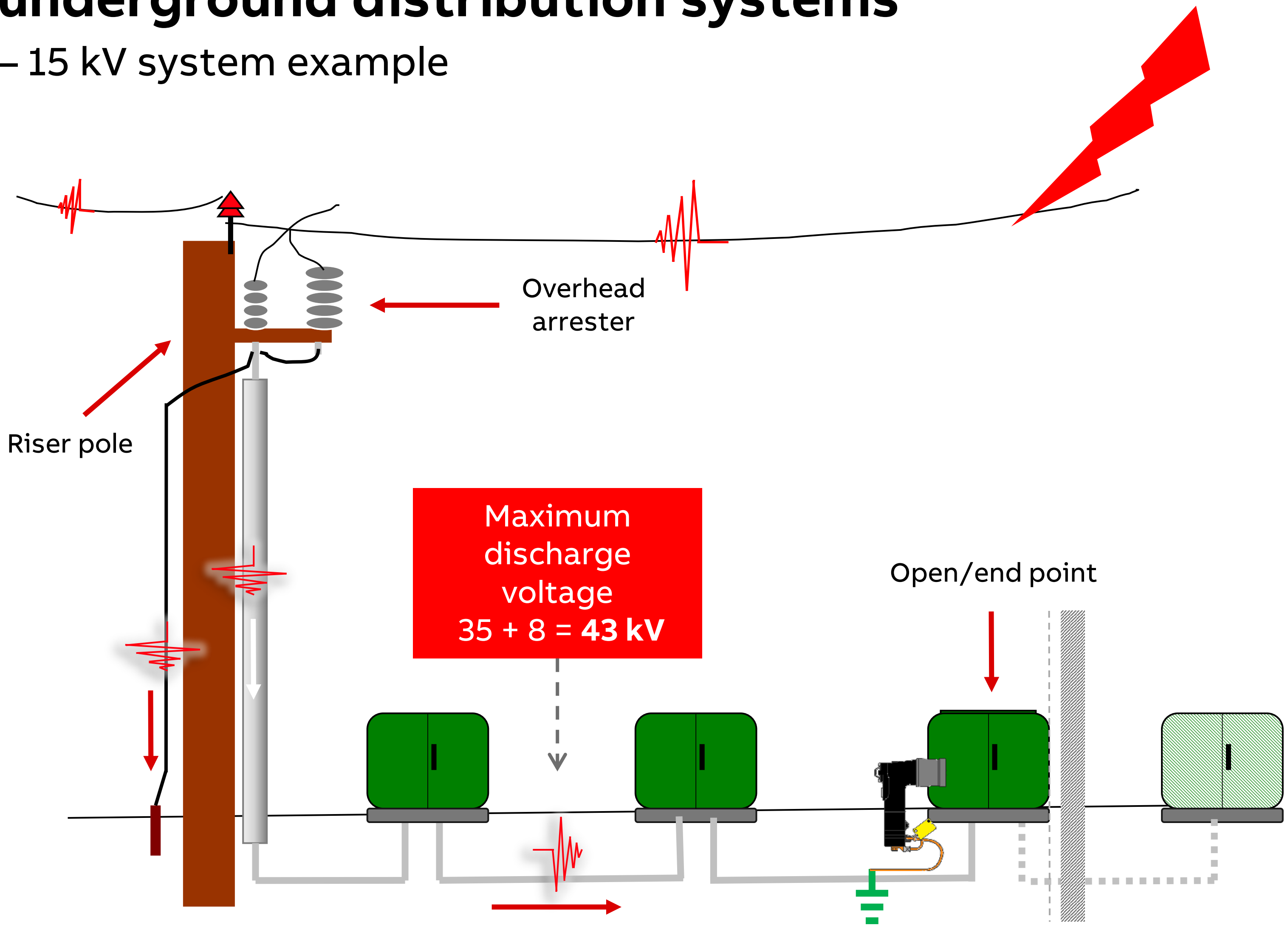
	Maximum discharge voltage (kV crest) 8 x 20 µs current wave			
Arrester rating	**1.5 kA**	**5 kA**	**10 kA**	**20 kA**
10.00	24.50	27.50	29.00	35.00
18.00	45.50	52.50	55.00	66.00
27.00	64.00	72.00	76.00	91.00

Maximum discharge voltage = 35 + 8 = 43 kV

Protection on underground distribution systems

Arrester selection — 15 kV system example

Elbow arrester applied at the open/end point.



Protection on underground distribution systems

Arrester selection — 15 kV system example

Maximum discharge voltage (MDV) with elbow arrester applied at the open/end point:

- From the elbow arrester product specification
  - Rating of the **elbow arrester** (10 kV)
  - Let-through
- Coefficient of reflection (0.5)
- MDV from the riser pole = V_{RP}

	Maximum discharge voltage (kV crest) 8 x 20 µs current wave			
Arrester rating	**1.5 kA**	**5 kA**	**10 kA**	**20 kA**
10.00	30.50	34.50	38.50	38.50
18.00	56.50	64.00	71.00	71.00
27.00	87.50	99.00	110.00	110.00

MDV with elbow arrester = V_{RP} + (0.5)* 30.5 = 58 kV

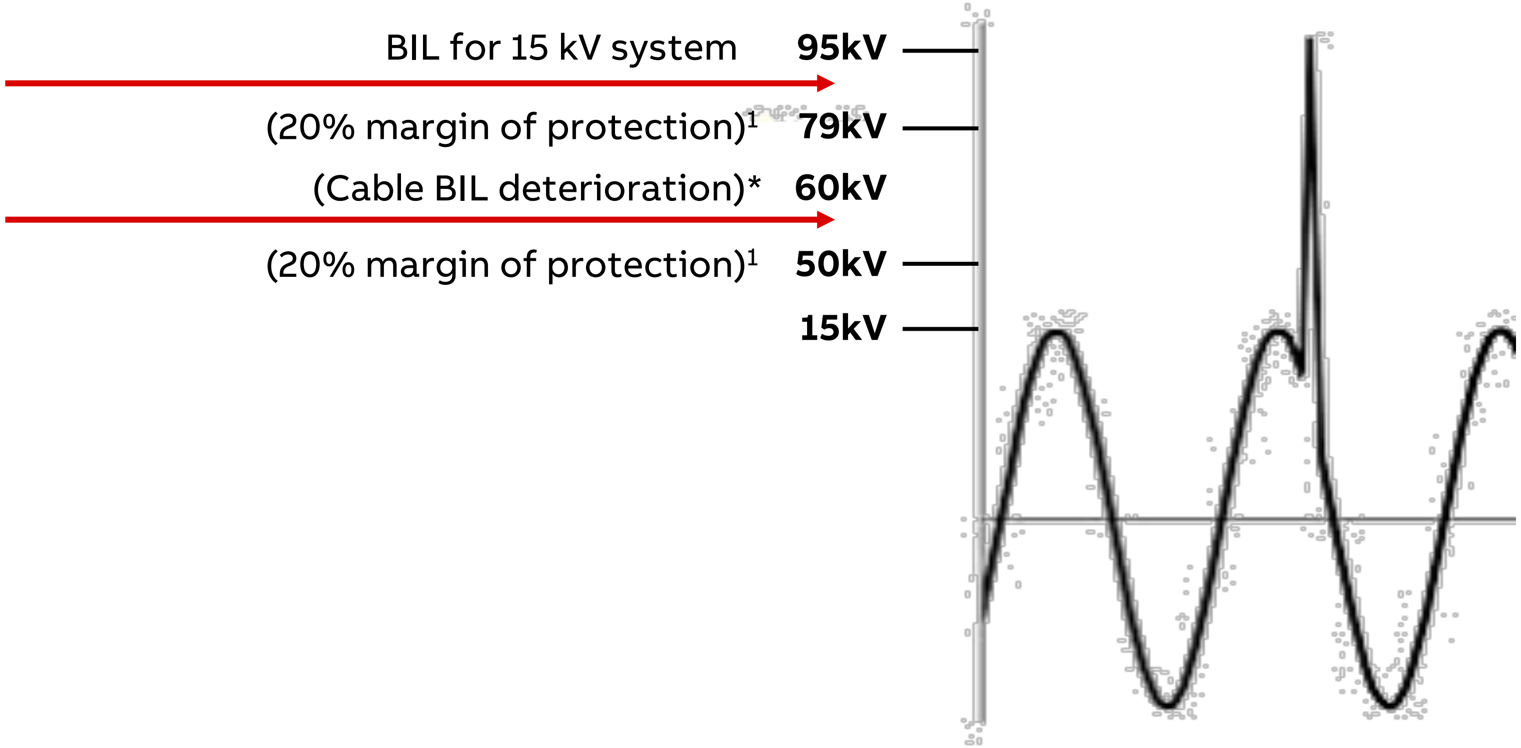
MDV without elbow arrester = 2*V_{RP} = 43 * 2 = 86 kV

Protection on underground distribution systems

Arrester selection — 15 kV system example

86 kV MDV with no elbow arrester

58 kV MDV with arrester at end point



To reduce the total surge voltage to a value below 50 kV, additional arresters are required in the system.

* 60–75 kV BIL is typical

[1] ANSI recommended. Accounts for variation of surge parameters, aging of insulation, minor installation flaws.

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