Distribution Overvoltage Protection

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Lightning Phenomenon

- Cloud-to-ground lightning bolts are a common phenomenon - about 100 strike the Earth's surface every second
- Each bolt can contain up to 1B volts of electricity
- A single bolt of lightning can generate heat in excess of 50,000 °F
- Lightning is a random and unpredictable event, and is still not entirely understood

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Lightning and Power Systems

- Lightning is a current source
- Cloud energy released in the form of surge current
- Voltages associated with lightning are a function of the current impulse and impedance of the circuit
- Nearby lightning strokes can induce a charge on the line
- Voltage propagates as a traveling wave
- Waves are reflected and/or refracted at line impedance discontinuities
  - At an open point, the voltage wave is almost completely reflected so it doubles upon itself

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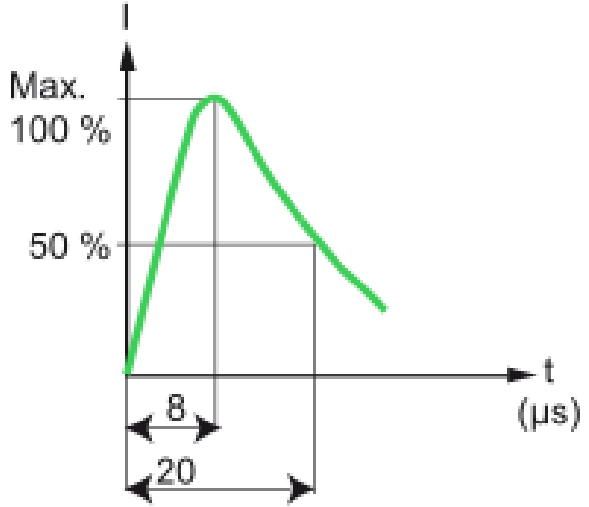
Current Wave

- 8/20 (pronounced 8 by 20) current wave is used by manufacturers to simulate lightning current to test distribution arrester designs and establish discharge voltages (also known as lightning protective level or LPL)
  - “8” is the peak rise time in microseconds
  - “20” is the fall time to reach 50% of the peak value
- Real world lightning usually has a 1 to 4 microsecond rise time



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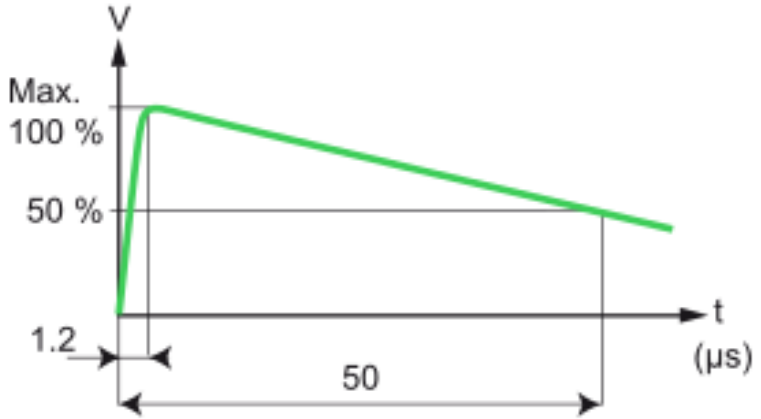
Voltage Wave (Front of Wave)

- 1.2/50 (pronounced 1.2 by 50) microsecond voltage impulse wave used to test equipment designs for basic impulse insulation level (BIL)
  - “1.2” is the peak rise time in microseconds
  - “50” is the fall time to reach 50% of the peak value
- Rise time and duration similar to lightning
- Other impulse tests:
  - chopped wave (1.15XBIL)
  - front-of-wave
  - switching surge impulse



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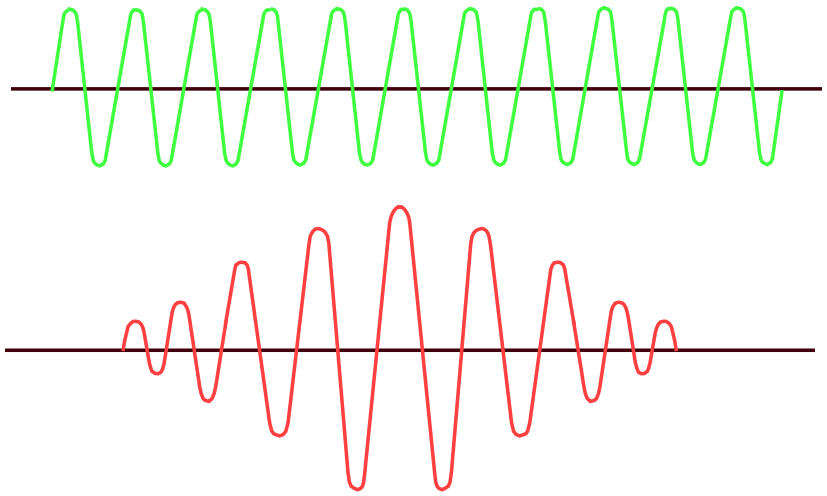
Sources of Voltage Surges

- Temporary Overvoltages
  - Capacitor Bank Switching
  - Ferroresonance
  - Ungrounded Wye-Delta Transformers
  - Voltage regulation problems
    - Ex. Solar Field
  - Harmonic voltages
  - Line to ground faults



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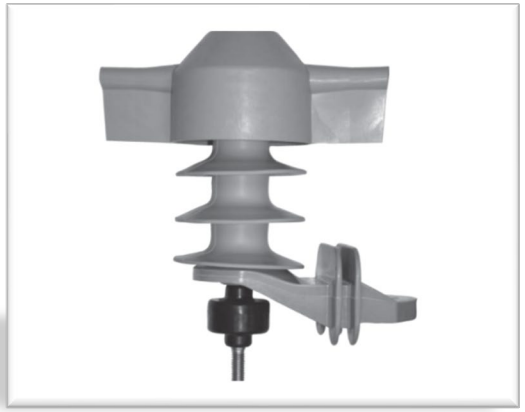
What Is An Arrester?

ARRESTER DOES NOT

- Absorb lightning
- Stop lightning



ARRESTER DOES

- Divert lightning
- Limits voltage
- Protects equipment installed in parallel

Arresters- “A protective device for limiting voltage on equipment by discharging or bypassing surge current…”

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Arrester Designs Must….

- Withstand the nominal line-to-ground voltage
- Withstand typical short time overvoltages
- Ease into conduction (“turn on”) during surges
- Reseal (“turn off”) after the surge passes
- Perform these functions repeatedly for 20 to 30 years

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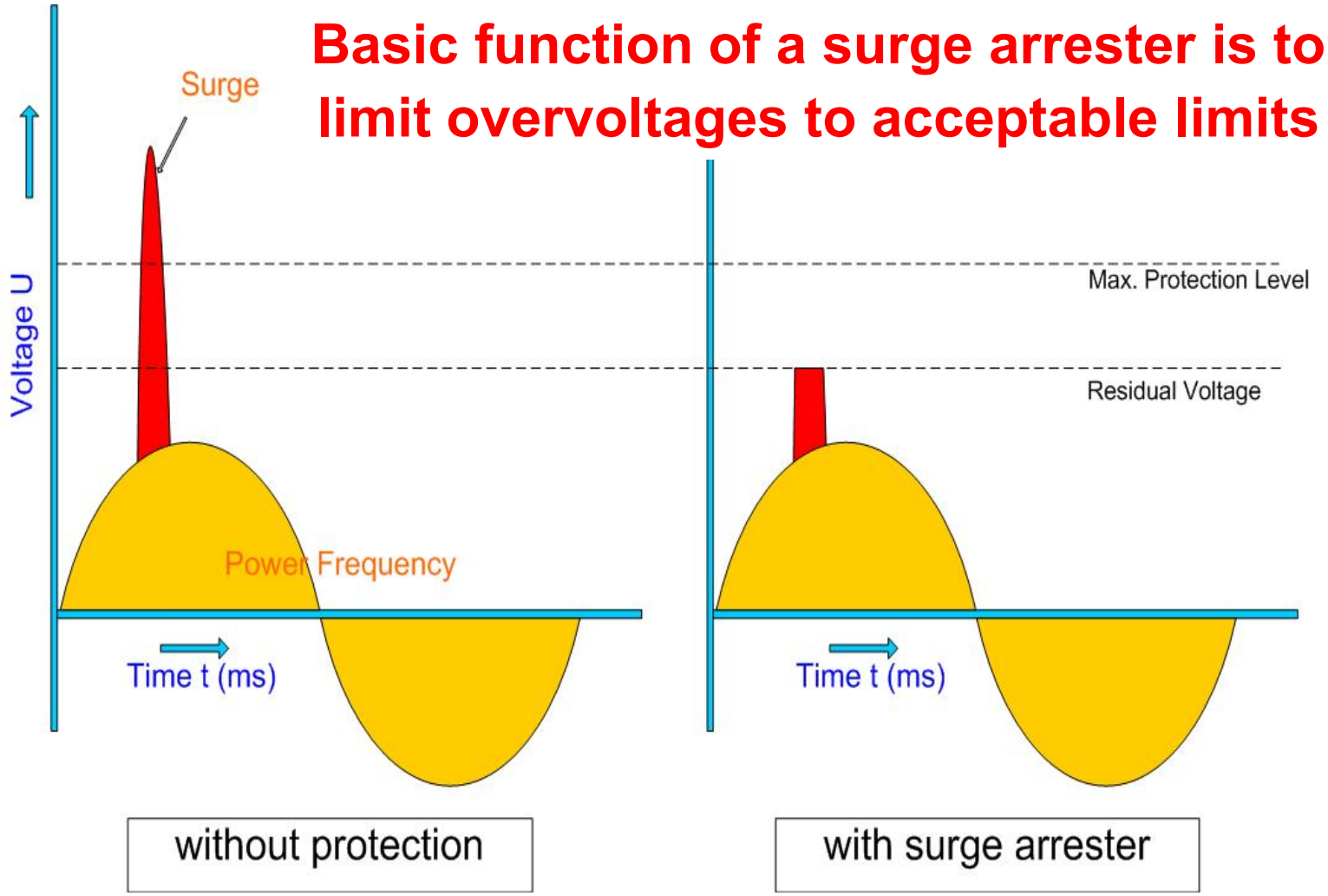
How MOV Arresters Work

Basic function of a surge arrester is to limit overvoltages to acceptable limits



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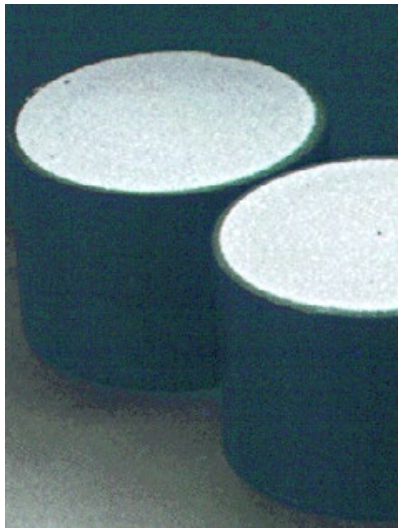
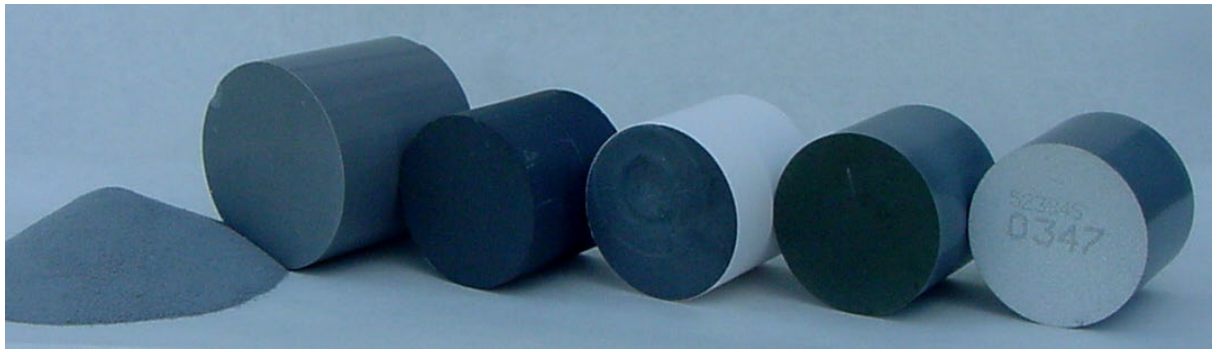
MOV Arresters

- Introduced in 1970's
- Highly non-linear MOV blocks
  - Much more non-linear than SiC
  - Material -- ZnO, bismuth, antimony, silver, Poly-vinyl-alcohol, …… 90% ZnO
  - Semiconductor device
- "Voltage controlled switch"
  - Act as an insulator with line voltage
  - Goes into conduction when voltage rises above V_{ref} (typically called the "turn on voltage")
  - Turns off after surge passes





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MOV Arrester Construction

3 MOV blocks stacked, aluminum electrodes on ends

9 or 10 kV

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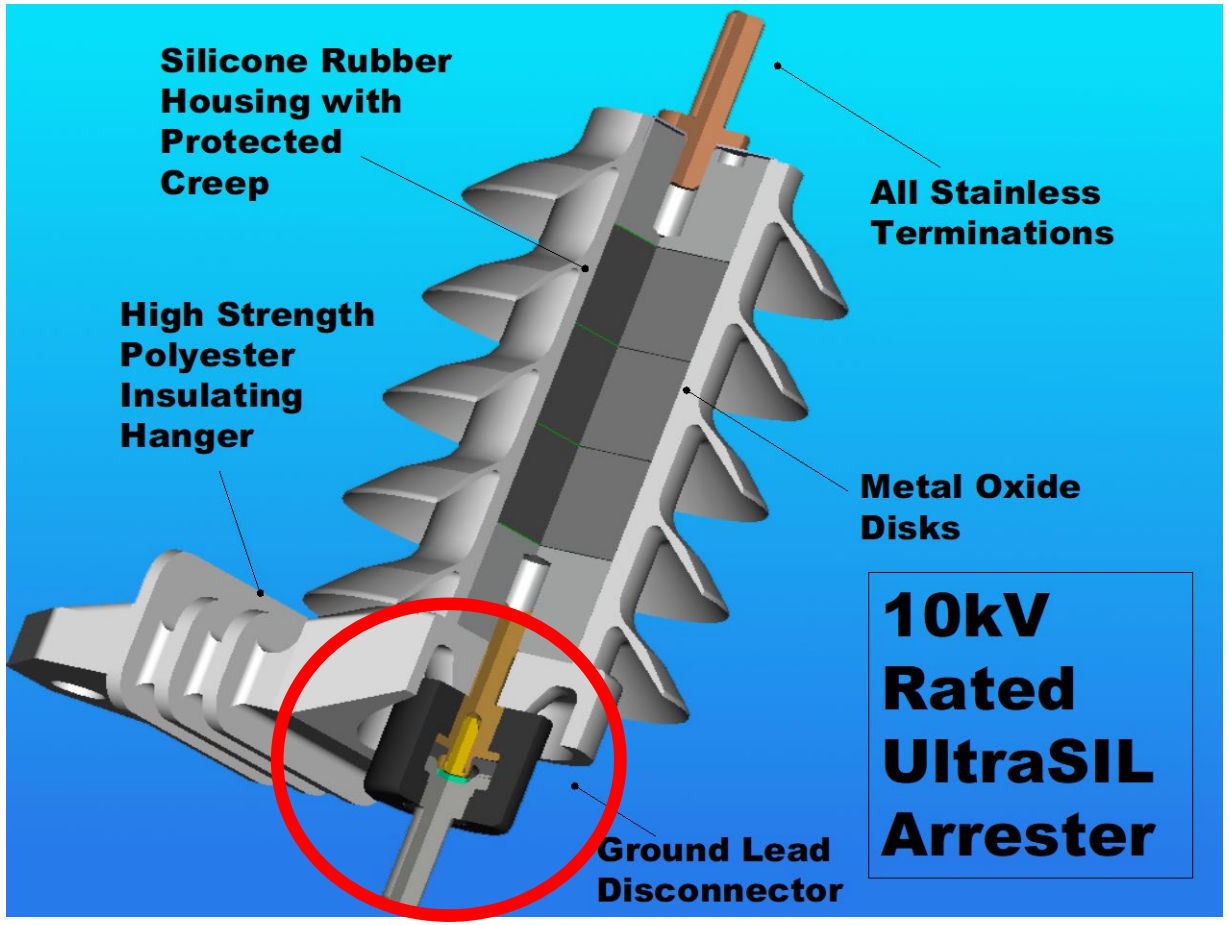
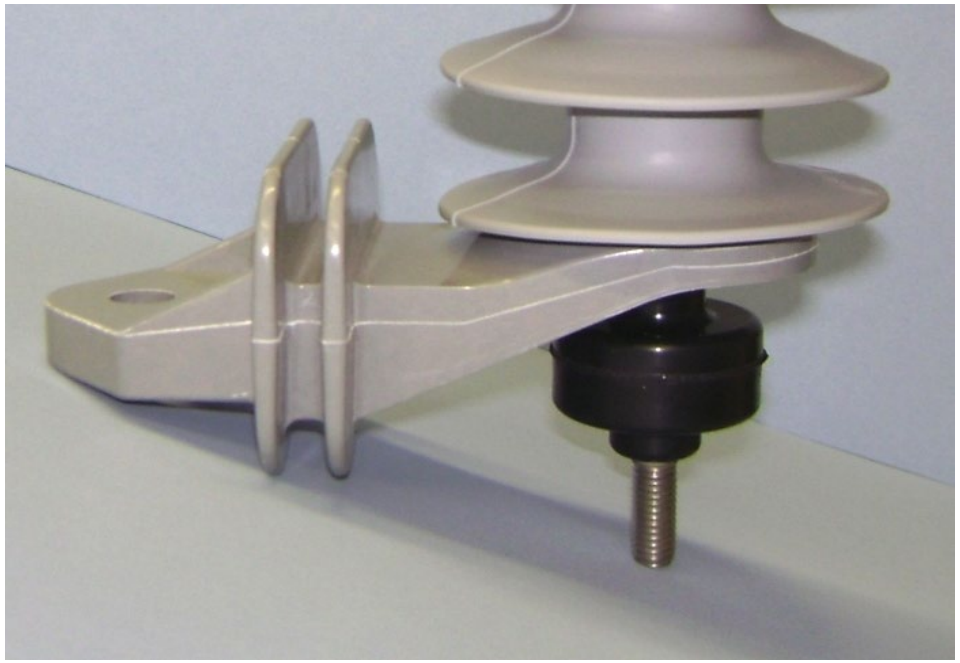
Isolator – Distribution Arresters





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UltraSIL Fire Protection (UFP) Arrester System

UFP Overview

- Fire prevention during end-of-life event
- Temporary CAL FIRE exemption to pole clearance requirements
- Compliance to IEEE C62.11
- 3 - 27kV rated overhead application

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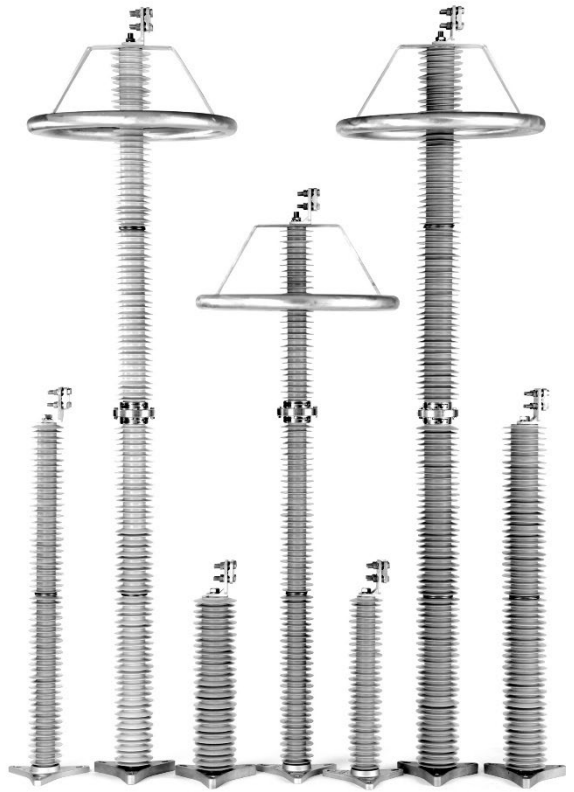
IEEE/ANSI Arrester Classifications

- Station Class - 3 to 684 kV
- Intermediate - 2 to 120 kV
- Distribution - 1 to 36 kV
  - Normal duty
  - Heavy duty
    - riser pole
- Secondary (<1000 V)



IEEE secondary arresters

Type S4

IEEE under-oil arresters

CLU (Light Duty)

AZU (Heavy Duty)

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Distribution Arrester Selection

- MCOV rating
- TOV magnitude
  - arrester usually based on maximum phase-to-ground voltage on unfaulted phase during single line-to-ground fault
- Insulation coordination
  - Maximum discharge voltage
  - Margin of Protection
  - Lead length considerations

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Maximum Continuous Operating Voltage

- MCOV is the maximum RMS voltage that can be applied between the terminals of the arrester before conducting (Uc)
- MCOV is approximately 84% of the arrester rated voltage For example:
  - 10 kV ➔ 8.4 kV MCOV
  - 18 kV ➔ 15.3 kV MCOV
  - 27kV ➔ 22.1 kV MCOV

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Duty Cycle Rating

Duty Cycle Rating = Arrester Rating

- Maximum allowable voltage applied to an arrester without changing operating characteristics
- Now used as a test value; Max voltage at which it can pass a specified test. (20 lightning impulses while energized at Duty Cycle Rating)
- Arrester rated voltage
    - (9kV, 10kV, 18kV, 27kV, etc.)

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IEEE C62.11 – 2020 Changes

Page 17

duty-cycle voltage rating: Historically the designated maximum permissible voltage between its terminals at which an arrester is designed to perform its duty cycle. The duty-cycle rating of arresters was more appropriate to the previous generation of arresters and is being phased out of this standard.

Page 24

5. Standard MCOV rating of an arrester and previously used duty-cycle rating

The relevant arrester voltage rating for MOSA type arresters is MCOV. The duty-cycle rating of arresters was more appropriate to the previous generation of arresters and is being phased out of this and future editions of this standard. Table 1 is a cross reference for common MCOV ratings of MOSA type arresters as well as the previously used duty-cycle rating associated with that specific MCOV rating.

NOTE—The duty-cycle rating is an obsolete term that is used here for historical reference only.

Table 1—Arrester ratings

MCOV (kV rms)	Duty-cycle voltage (kV rms)	MCOV (kV rms)	Duty-cycle voltage (kV rms)
2.55	3	115	144
5.1	6	131	168
7.65	9	140	172
8.4	10	144	180
10.2	12	152	192
12.7	15	180	228
15.3	18	190	240
17	21	209	258
19.5	24	212	264
22	27	220	276
24.4	30	230	288
29	36	235	294
31.5	39	245	312
36.5	45	318	396
39	48	335	420
42	54	353	444
48	60	372	468
57	72	392	492
70	90	428	540
76	96	448	564
84	108	462	576
98	120	470	588
106	132	485	612

Change applicable to all arrester classifications:

- Distribution
- Intermediate
- Station

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So, What Does This Mean?

Arrester Rating (kV rms)	MCOV (kV rms)	Front-of-wave Protective Level (kV crest)	Maximum Discharge Voltage (kV crest) 8/20 µs Current Wave						Switching Surge kV Crest)
			1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA	500 A
3	2.55	20.0	8.1	8.7	9.3	10.2	11.6	13.5	7.6
6	5.10	23.0	16.1	17.4	18.6	20.3	23.3	27.0	15.2
9	7.65	32.4	18.9	20.3	21.8	23.8	27.3	31.6	17.8
10	8.40	32.4	20.1	21.6	23.2	25.4	29.0	33.7	19.0
12	10.2	52.4	25.2	27.2	29.1	31.8	36.4	42.2	23.8
15	12.7	55.4	30.5	32.8	35.2	38.5	44.0	51.1	28.8
18	15.3	64.8	37.8	40.8	43.7	47.8	54.6	63.4	35.7
21	17.0	64.8	40.1	43.2	46.3	50.6	57.9	67.2	37.8
24	19.5	87.8	46.4	50.0	53.6	58.6	67.0	78	43.8
27	22.0	97.2	53.9	58.0	62.2	68.0	78	90	50.8
30	24.4	117.2	58.6	63.2	67.7	74	85	98	55.3
33	27.0	120.2	66.6	71.7	77	84	96	112	62.8
36	29.0	129.6	70.4	76	81	89	102	118	66.4

OBSOLETE per C62.11 – 2020

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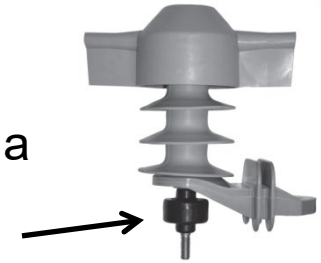
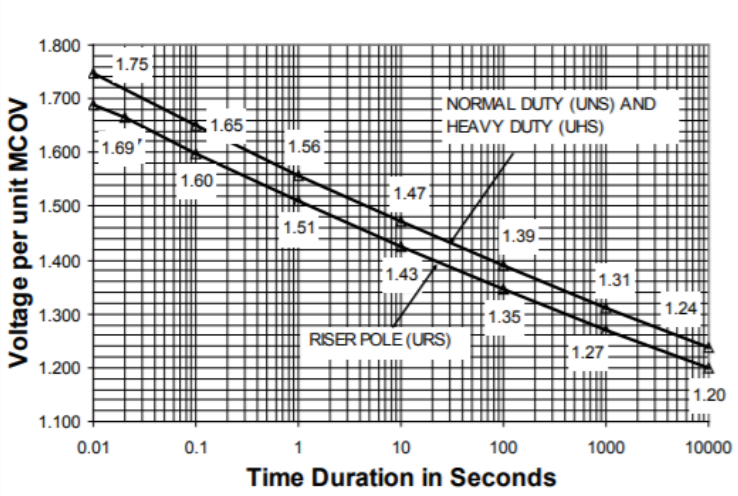
TOV Capability

Temporary overvoltage capability shows the allowable overvoltage and duration that an arrester can withstand without damage

- Exceeding voltage as defined by the TOV curve can result in damaging or destroying the arrester
- Once the arrester experiences a voltage exceeding TOV, the disconnector will operate





TOV curve for UHS and URS arresters

Before

After

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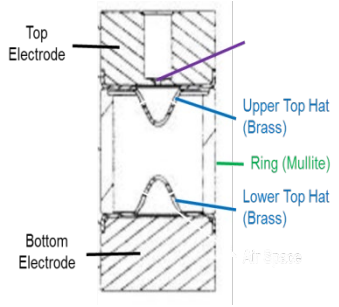
Evolution Gapped Arrester

- Resistively grading silicon carbide rings have been replaced by a proprietary isolating ceramic ring assembly.
  - Similar insulating characteristics to porcelain
  - Resistant to moisture ingress
- During steady-state conditions the ceramic ring assembly withstands system voltage:
  - Resistant to 60HZ disturbances
    - TOV generated L-G/L-N Faults
  - Increased Survivability
  - Less stress on MOV blocks

Module prior to composite wrap



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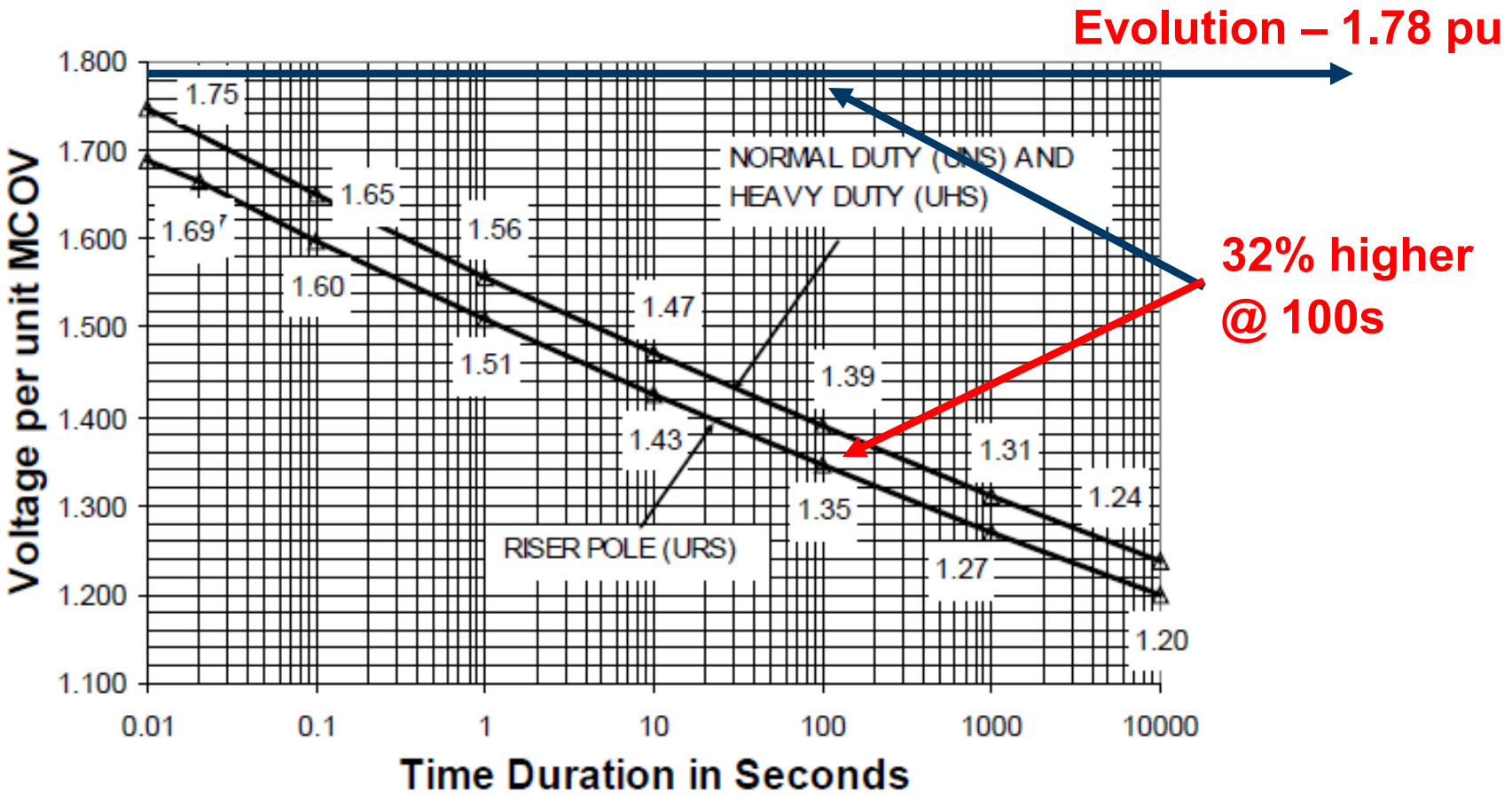
TOV – Evolution Gapped Arrester



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Distribution Arrester Selection

Selecting a Distribution Arrester

- Catalog Sheets assist with Selection
- Choose arrester where MCOV is greater than single phase line to ground voltage
- Factor in any regulation voltage
- Rule of thumb MCOV should be min. 5% above nominal line to ground voltage

Table 1. Commonly Applied Voltage Ratings of VariSTAR Arresters

System Voltage (kV rms)		Recommended Arrester Rating per IEEE Std C62.22™ standard (kV rms)		
Nominal	Maximum	Four-Wire Wye Multi-Grounded Neutral	Three-Wire Wye Solidly Grounded Neutral	Delta and Ungrounded Wye
2.4	2.54	—	—	3
4.16Y/2.4	4.4Y/2.54	3	6	6
4.16	4.4	—	—	6
4.8	5.08	—	—	6
6.9	7.26	—	—	9
8.32Y/4.8	8.8Y/5.08	6	9	—
12.0Y/6.93	12.7Y/7.33	9	12	—
12.47Y/7.2	13.2Y/7.62	9	15	—
13.2Y/7.62	13.97Y/8.07	10	15	—
13.8Y/7.97	14.52Y/8.38	10	15	—
13.8	14.52	—	—	18
20.78Y/12.0	22Y/12.7	15	21	—
22.86Y/13.2	24.2Y/13.87	18	24	—
23	24.34	—	—	30
24.94Y/14.4	26.4Y/15.24	18	27	—
27.6Y/15.93	29.3Y/16.89	21	30	—
34.5Y/19.92	36.5Y/21.08	27	36	—
46Y/26.6	48.3Y/28	36	—	—

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Arrester Selection Example

Select an arrester for an overhead distribution application.
The system is grounded-wye, 12470V_{LL} or 7200V_{LN}.

Solution: Determine arrester rating based on MCOV

$$V_{MAX(L\text{-}G)} = (V_{LN})(\text{Positive regulation error})$$

Regulation error = 5%

$$V_{MAX(L\text{-}G)} = 7200 \times 1.05 = 7560V$$

Need an MCOV rating of 7560V or above.

A 9 kV arrester has an MCOV rating of 7650V. Acceptable!!

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MCOV

Table 6. Protective Characteristics – VariSTAR Normal-Duty (UNS) Arrester

Arrester Rating (kV rms)	MCOV (kV rms)	Equivalent Front-of-wave Protective Level* (kV crest)	Maximum Discharge Voltage (kV crest) 8/20 µs Current Wave					
			1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA
3	2.55	11	9	9.7	10.4	11.4	13	15.1
6	5.1	22	18.0	19.4	20.8	22.7	26	30.2
9	7.65	31.7	26.0	28	30	32.8	37.4	43.5
10	8.4	33	27.0	29.1	31.2	34.1	38.9	45.3
12	10.2	41.5	33.9	36.6	39.2	42.9	48.9	56.9
15	12.7	51.8	42.4	45.7	49	53.6	61.1	71.1
18	15.3	62.2	50.9	54.9	58.8	64.3	73.4	85.3
21	17	66	54.0	58.2	62.4	68.2	77.9	90.6
24	19.5	77	63.0	67.9	72.8	79.6	90.8	106
27	22	87.2	71.4	76.9	82.4	90.1	103	120
30	24.4	97.1	79.5	85.7	91.8	100	115	133
33	27	108	87.8	95.1	102	112	127	148
36	29	116	95.3	103	110	120	137	160

* Based on 5 kA current impulse that results in a discharge voltage cresting in 0.5 µs.

Table 7. Protective Characteristics – VariSTAR Heavy-Duty (UHS) Arrester

Arrester Rating (kV rms)	MCOV (kV rms)	Equivalent Front-of-wave Protective Level* (kV crest)	Maximum Discharge Voltage (kV crest) 8/20 µs Current Wave					
			1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA
3	2.55	11	8.2	8.7	9.1	9.9	10.9	12.3
6	5.1	21.9	16.3	17.4	18.2	19.8	21.9	24.7
9	7.65	33	24.6	26.1	27.3	29.8	33	37.1
10	8.4	35	26	27.7	29	31.6	34.9	39.4
12	10.2	43.9	32.7	34.8	36.4	39.7	43.9	49.5
15	12.7	53.1	39.6	42.1	44	48	53.1	59.8
18	15.3	66	49.1	52.3	54.7	59.6	65.9	74.2
21	17	70	52.1	55.4	58	63.2	69.9	78.7
24	19.5	80.9	60.2	64.1	67	73.1	80.8	91.1
27	22	94	70	74.5	77.9	84.9	93.9	106
30	24.4	102	76.1	81	84.7	92.4	102	115
33	27	116	86.5	92.1	96.3	105	116	131
36	29	123	91.5	97.3	102	111	123	138

* Based on 10 kA current impulse that results in a discharge voltage cresting in 0.5 µs.

L-G Fault TOV --unfaulted phase

TABLE 5-2
Single Line-to-ground Voltage Rises (TOV) on Unfaulted Phases for Different System Configurations

System Type	Per Unit Overvoltage
Four Wire Multi-grounded Wye	1.25 - 1.35
Spacer Cable (4 wire Wye)	1.50
Three Wire Low Impedance Grounded	1.40
Three Wire High Impedance Grounded	1.73
Delta	1.73

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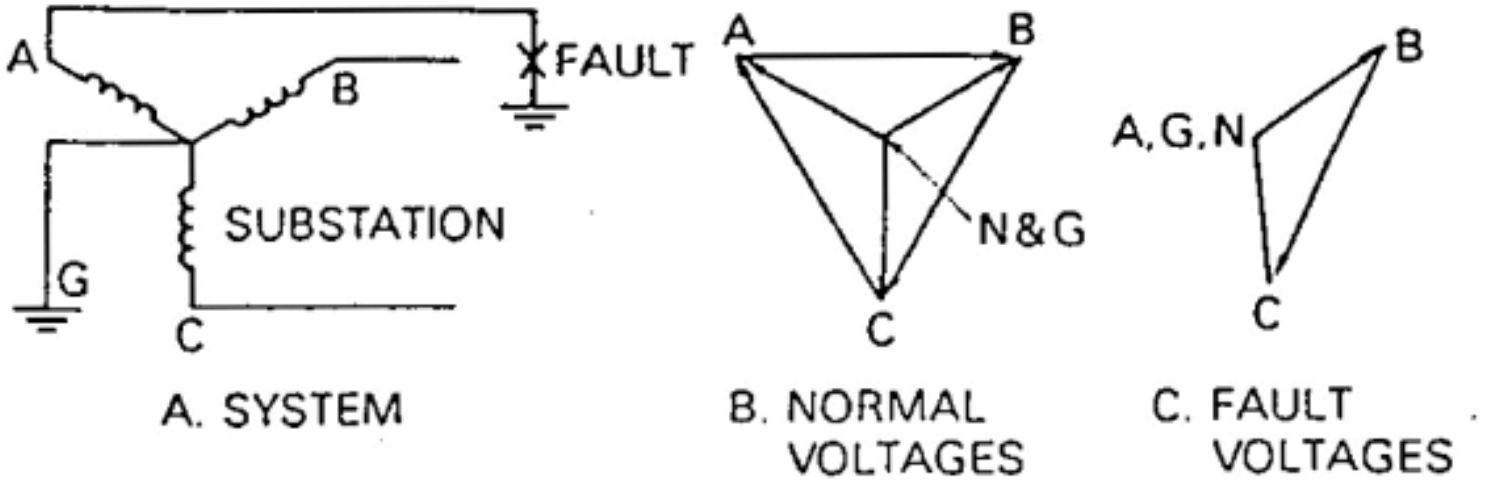
TOV Caused By SLG Faults
Wye System with No Ground Resistance



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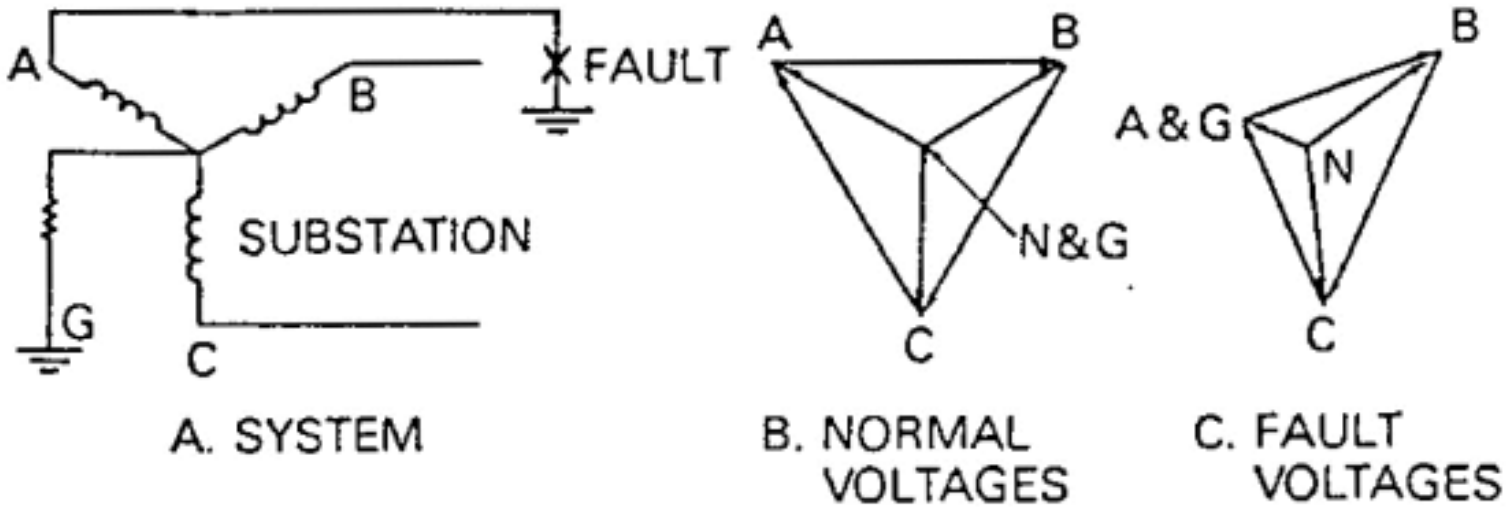
TOV Caused By SLG Faults
Wye System with Ground Resistance



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Arrester Selection Example

Select an arrester for an overhead distribution application. The system is grounded-wye, impedance grounded (neutral grounding resistor) 13200V_{LL} or 7620V_{LN}.

Solution: Determine arrester rating based on MCOV

$V_{MAX(L-G)}$ = (V_{LN})(Positive regulation error)
Regulation error = 5%
$V_{MAX(L-G)}$ = 7620 x 1.05 = 8001V

Preliminary calculations point to an arrester with an MCOV of 8001V or above.

A 10kV arrester has an MCOV rating of 8400V. Is this rating acceptable?

Answer: No
Impedance grounded circuits may experience L-L voltage on the unfaulted phases during a L-G fault. An arrester with an MCOV above L-L voltage is the first choice.

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Distribution Arrester Selection

Selecting a Distribution Arrester

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- Factor in any regulation voltage
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4.16Y/2.4	4.4Y/2.54	3	6	6
4.16	4.4	—	—	6
4.8	5.08	—	—	6
6.9	7.26	—	—	9
8.32Y/4.8	8.8Y/5.08	6	9	—
12.0Y/6.93	12.7Y/7.33	9	12	—
12.47Y/7.2	13.2Y/7.62	9	15	—
13.2Y/7.62	13.97Y/8.07	10	15	—
13.8Y/7.97	14.52Y/8.38	10	15	—
13.8	14.52	—	—	18
20.78Y/12.0	22Y/12.7	15	21	—
22.86Y/13.2	24.2Y/13.87	18	24	—
23	24.34	—	—	30
24.94Y/14.4	26.4Y/15.24	18	27	—
27.6Y/15.93	29.3Y/16.89	21	30	—
34.5Y/19.92	36.5Y/21.08	27	36	—
46Y/26.6	48.3Y/28	36	—	—

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Margin of Protection (Insulation Coordination)

- Margin of Protection represents how well the system is protected from voltage surges
- IEEE C62.22.1-1996 recommends margin of protection greater than or equal to 20%. While there is some debate over increasing the minimum value, there is no consensus as to what value might be appropriate."
- Some utilities recommend a protective margin of up to 40 - 60% to compensate for factors they do not consider directly.

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Arrester Impulse Rating

- Front of Wave Protective Level
  - Discharge voltage from fast rise-time impulses: 1/10 µs wave shape
- Lightning Protective Level
  - Discharge voltage from nominal rise-time impulses: 8/20 µs wave shape
- Switching Surge Protective Level
  - The discharge voltage at slower rising surges: 45/90µs

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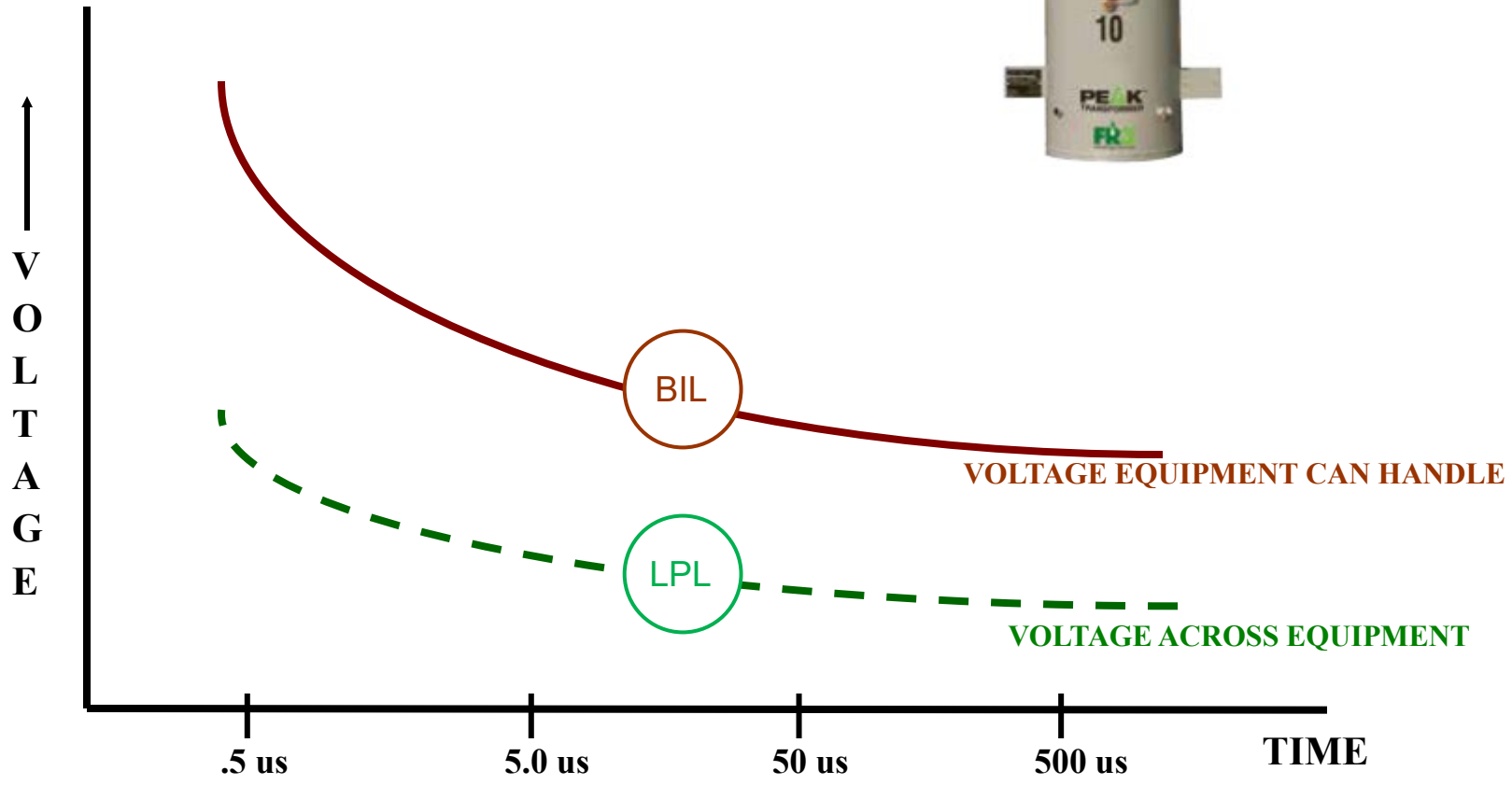
Margin of Protection : Example

$$MOP_2 = \left[\frac{BIL}{LPL} - 1\right] \times 100\%$$



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Arrester Data Sheets

FOW: Front of Wave Prot. Level

LPL: Lightning Protective Level

SPL: Switching Protective Level

Arrester Rating (kV rms)	MCOV (kV rms)	Front-of-wave Protective Level (kV crest)	Maximum Discharge Voltage (kV crest) 8/20 µs Current Wave						Switching Surge kV Crest)
			1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA	500 A
3	2.55	20.0	8.1	8.7	9.3	10.2	11.6	13.5	7.6
6	5.10	23.0	16.1	17.4	18.6	20.3	23.3	27.0	15.2
9	7.65	32.4	18.9	20.3	21.8	23.8	27.3	31.6	17.8
10	8.40	32.4	20.1	21.6	23.2	25.4	29.0	33.7	19.0
12	10.2	52.4	25.2	27.2	29.1	31.8	36.4	42.2	23.8
15	12.7	55.4	30.5	32.8	35.2	38.5	44.0	51.1	28.8
18	15.3	64.8	37.8	40.8	43.7	47.8	54.6	63.4	35.7
21	17.0	64.8	40.1	43.2	46.3	50.6	57.9	67.2	37.8
24	19.5	87.8	46.4	50.0	53.6	58.6	67.0	78	43.8
27	22.0	97.2	53.9	58.0	62.2	68.0	78	90	50.8
30	24.4	117.2	58.6	63.2	67.7	74	85	98	55.3
33	27.0	120.2	66.6	71.7	77	84	96	112	62.8
36	29.0	129.6	70.4	76	81	89	102	118	66.4

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Margin of Protection

$$PML2 = \left[\left(\frac{BIL}{LPL + L\frac{di}{dt}} \right) - 1 \right] \times 100$$

- Comparison of the equipment BIL to the arrester discharge voltage plus lead length contribution
- LPL is the discharge voltage of arrester, found in manufacturer's bulletin

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Lead Length - A Bit of Calculus

- Length of lead connecting arrester line and ground terminals
- Portion that is electrically in parallel with equipment being protected, and in path of surge current
- The part of an arrester installation that you have some control over
- L is the inductance of the conductor lead
- di/dt is the rate of change of current
- L = 0.4 µH/ft is typical
- di/dt = 4 kA/µs is typical
- Ldi/dt = 1.6 to 8 kV/ft

$$L\frac{di}{dt}$$

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Why is Lead Length Important?

- Surge current flowing through leads create a large inductive voltage drop
- This voltage drop can exceed arrester discharge voltage if leads are too long
- Coiled wire can make matters much worse
- Keep lead lengths short!!!

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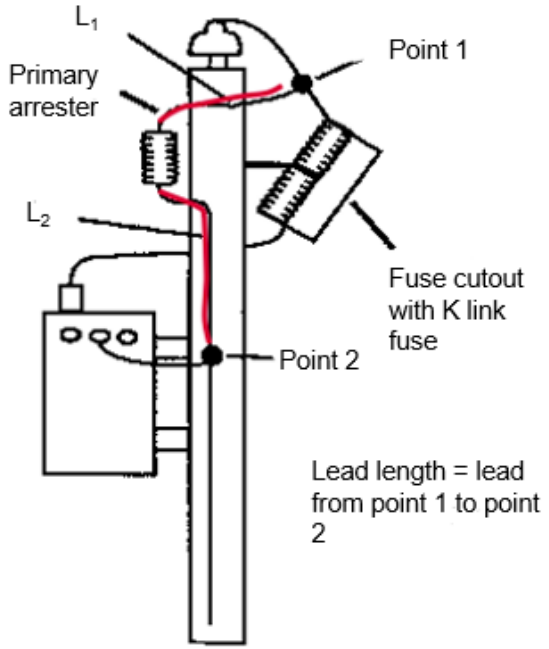
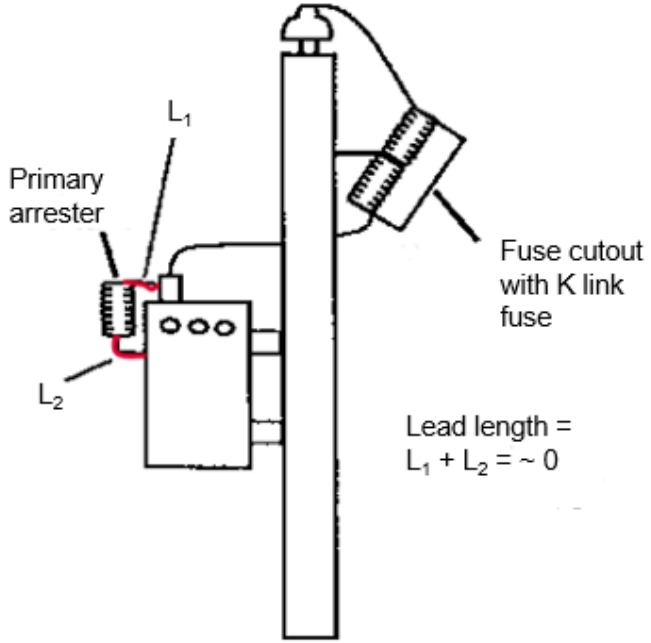
Reducing Lead Length

- Mount arrester on transformer tank
- Ground lead does matter



Typical conventional transformer installation with remote mounted arrester



Typical transformer installation with tank mounted arrester

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Margin of Protection Example

- Transformer BIL: 95 kV
- Arrester: 10 kV MOV, HD
- Lead length: 10 ft.
- Lightning surge: 20 kA, 8/20 us wave
- Arrester discharge voltage: 34.9 kV
- L di/dt: (0.4uH/ft)(10ft)(20kA)/8us = 10 kV

$$PM_{L2} = \left[\left(\frac{BIL}{LPL + L\frac{di}{dt}}\right) - 1\right] \times 100 = \left[\left(\frac{95}{34.9 + 10}\right) - 1\right] \times 100 = 112\%$$

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Table 6. Protective Characteristics – VariSTAR Normal-Duty (UNS) Arrester

Arrester Rating (kV rms)	MCOV (kV rms)	Equivalent Front-of-wave Protective Level* (kV crest)	Maximum Discharge Voltage (kV crest) 8/20 µs Current Wave					
			1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA
3	2.55	11	9	9.7	10.4	11.4	13	15.1
6	5.1	22	18.0	19.4	20.8	22.7	26	30.2
9	7.65	31.7	26.0	28	30	32.8	37.4	43.5
10	8.4	33	27.0	29.1	31.2	34.1	38.9	45.3
12	10.2	41.5	33.9	36.6	39.2	42.9	48.9	56.9
15	12.7	51.8	42.4	45.7	49	53.6	61.1	71.1
18	15.3	62.2	50.9	54.9	58.8	64.3	73.4	85.3
21	17	66	54.0	58.2	62.4	68.2	77.9	90.6
24	19.5	77	63.0	67.9	72.8	79.6	90.8	106
27	22	87.2	71.4	76.9	82.4	90.1	103	120
30	24.4	97.1	79.5	85.7	91.8	100	115	133
33	27	108	87.8	95.1	102	112	127	148
36	29	116	95.3	103	110	120	137	160

* Based on 5 kA current impulse that results in a discharge voltage cresting in 0.5 µs.

Table 7. Protective Characteristics – VariSTAR Heavy-Duty (UHS) Arrester

Arrester Rating (kV rms)	MCOV (kV rms)	Equivalent Front-of-wave Protective Level* (kV crest)	Maximum Discharge Voltage (kV crest) 8/20 µs Current Wave					
			1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA
3	2.55	11	8.2	8.7	9.1	9.9	10.9	12.3
6	5.1	21.9	16.3	17.4	18.2	19.8	21.9	24.7
9	7.65	33	24.6	26.1	27.3	29.8	33	37.1
10	8.4	35	26	27.7	29	31.6	34.9	39.4
12	10.2	43.9	32.7	34.8	36.4	39.7	43.8	49.5
15	12.7	53.1	39.6	42.1	44	48	53.1	59.8
18	15.3	66	49.1	52.3	54.7	59.6	65.9	74.2
21	17	70	52.1	55.4	58	63.2	69.9	78.7
24	19.5	80.9	60.2	64.1	67	73.1	80.8	91.1
27	22	94	70	74.5	77.9	84.9	93.9	106
30	24.4	102	76.1	81	84.7	92.4	102	115
33	27	116	86.5	92.1	96.3	105	116	131
36	29	123	91.5	97.3	102	111	123	138

* Based on 10 kA current impulse that results in a discharge voltage cresting in 0.5 µs.

Margin of Protection Example: Aged Transformer

- Transformer BIL: 75 kV
- Arrester: 10 kV MOV, HD
- Lead length: 10 ft.
- Lightning surge: 20 kA, 8/20 us wave
- Arrester discharge voltage: 34.9 kV
- L di/dt: (0.4uH/ft)(10ft)(20kA)/8us = 10 kV

$$PM_{L2} = \left[\left(\frac{BIL}{LPL + L\frac{di}{dt}}\right) - 1\right] \times 100 = \left[\left(\frac{75}{34.9 + 10}\right) - 1\right] \times 100 = 67\%$$

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Aged Transformer, Fast Rise Time Reduced Lead Length

- Transformer BIL: 75 kV
- Arrester: 10 kV MOV, HD
- Lead length: 1 ft.
- Lightning surge: 20 kA, 8/20 us wave
- L di/dt: (0.4uH/ft)(1ft)(20kA)/8us = 1 kV
- Arrester discharge voltage: 34.9 kV

$$PM_2 = \left[\left(\frac{BIL}{LPL + L\frac{di}{dt}}\right) - 1\right] \times 100 = \left[\left(\frac{75}{34.9 + 1}\right) - 1\right] \times 100 = 109\%$$

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Margin of Protection Example: Aged Transformer

- Transformer BIL: 75 kV
- Arrester: 10 kV, Evolution (gapped) Arrester
- Lead length: 10 ft.
- Lightning surge: 20 kA, 8/20 us wave
- Arrester discharge voltage: 29 kV
- L di/dt: (0.4uH/ft)(10ft)(20kA)/8us = 10 kV

$$PML2 = \left[\left(\frac{BIL}{LPL+L\frac{di}{dt}}\right) - 1\right] X\ 100 = \left[\left(\frac{75}{29+10}\right) - 1\right]\ X\ 100 = 92.3\%$$

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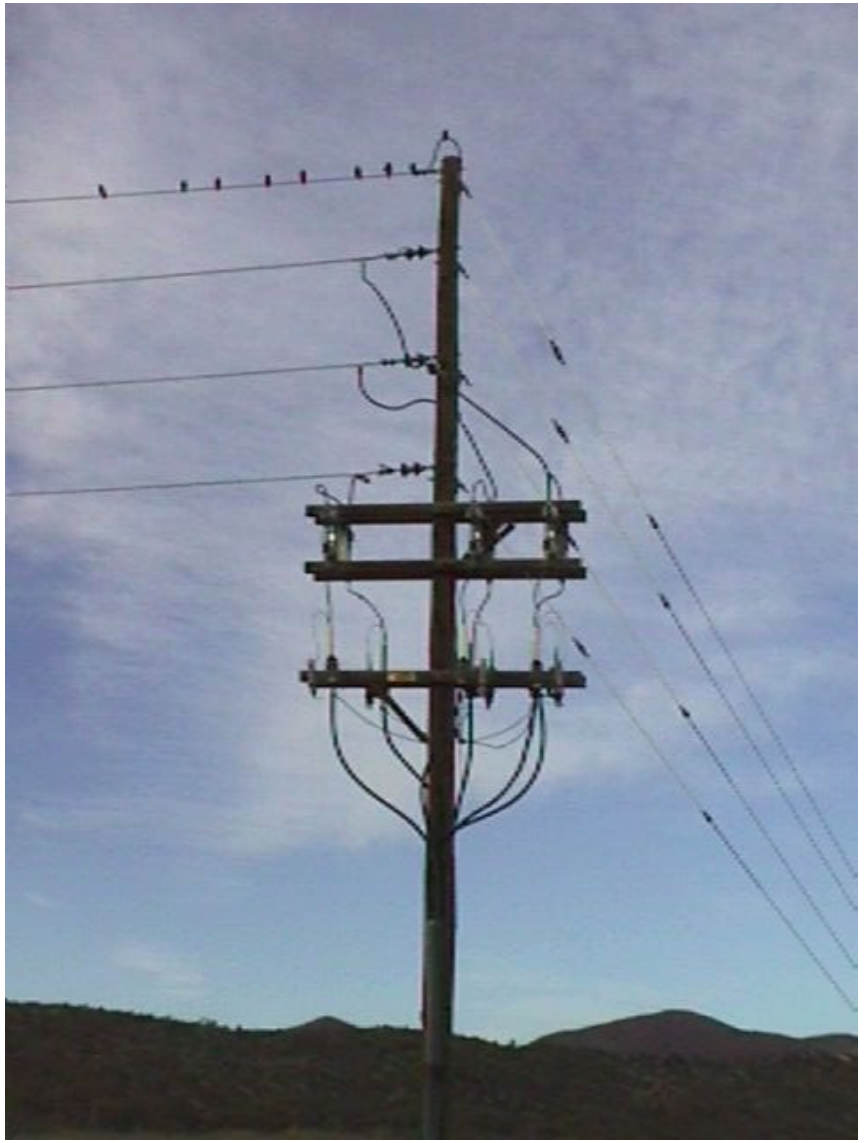
Underground Protection

- Underground cable insulation is not self-restoring
- Factors affecting protection margin
  - Cable BIL deterioration
  - Riser pole arrester discharge voltage
  - Lead lengths
  - Rate of rise of surge current
  - Traveling waves
  - Open point protection for URD



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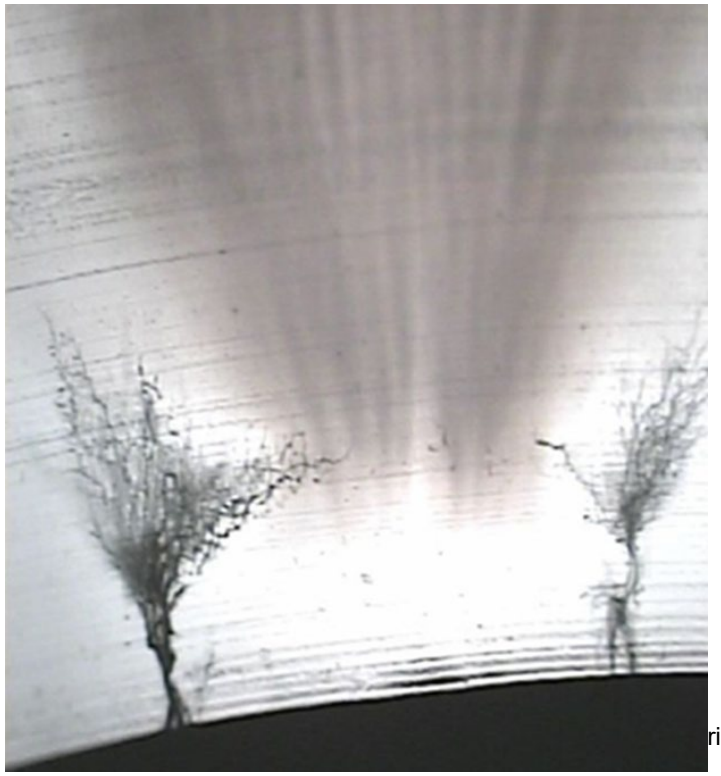
Underground Cable

- Cable fails through a breakdown of the insulation
  - water trees
  - voltage trees
- Older HMWPE and XLPE cable insulation can deteriorate rapidly
  - aged cable BIL might be 50% of new cable



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Riser Pole Type Arrester

- Provides better protection due to lower discharge voltages
- RP falls under Heavy Duty distribution class
  - However, lower TOV capability than HD
  - More expensive than HD
- Better or bigger MOV blocks used
- Lead lengths are more critical
- For URD circuits, riser pole arrester by itself usually not sufficient to protect cable

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URD and Voltage Doubling

- Surge diverted by a riser pole arrester will generate a traveling voltage wave down the cable
- Voltage wave is reflected and doubles upon itself at the open point(s)
- Incident wave voltage magnitude = 2x (LPL + Ldi/dt)

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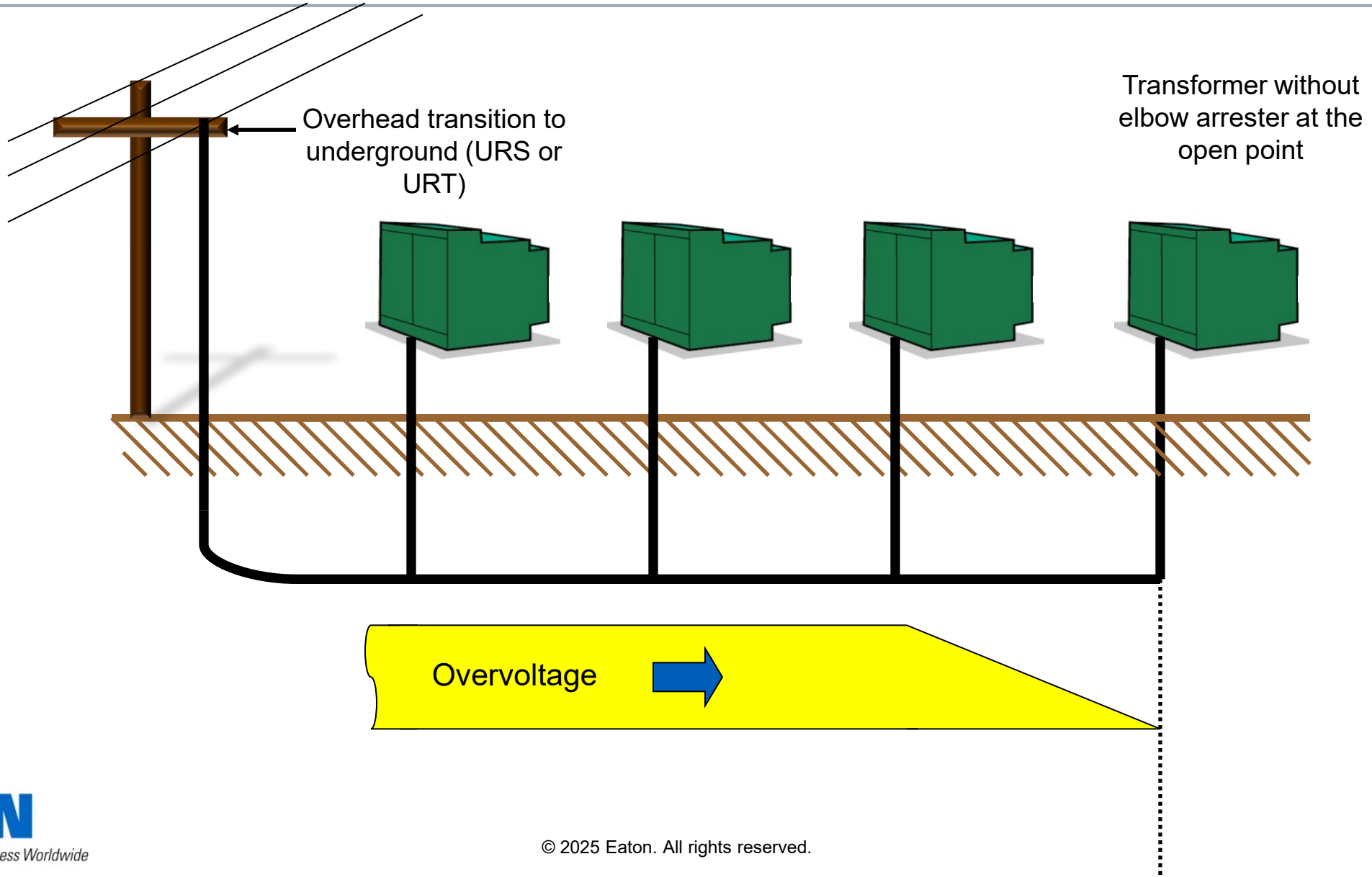
Overvoltages in Underground Distribution



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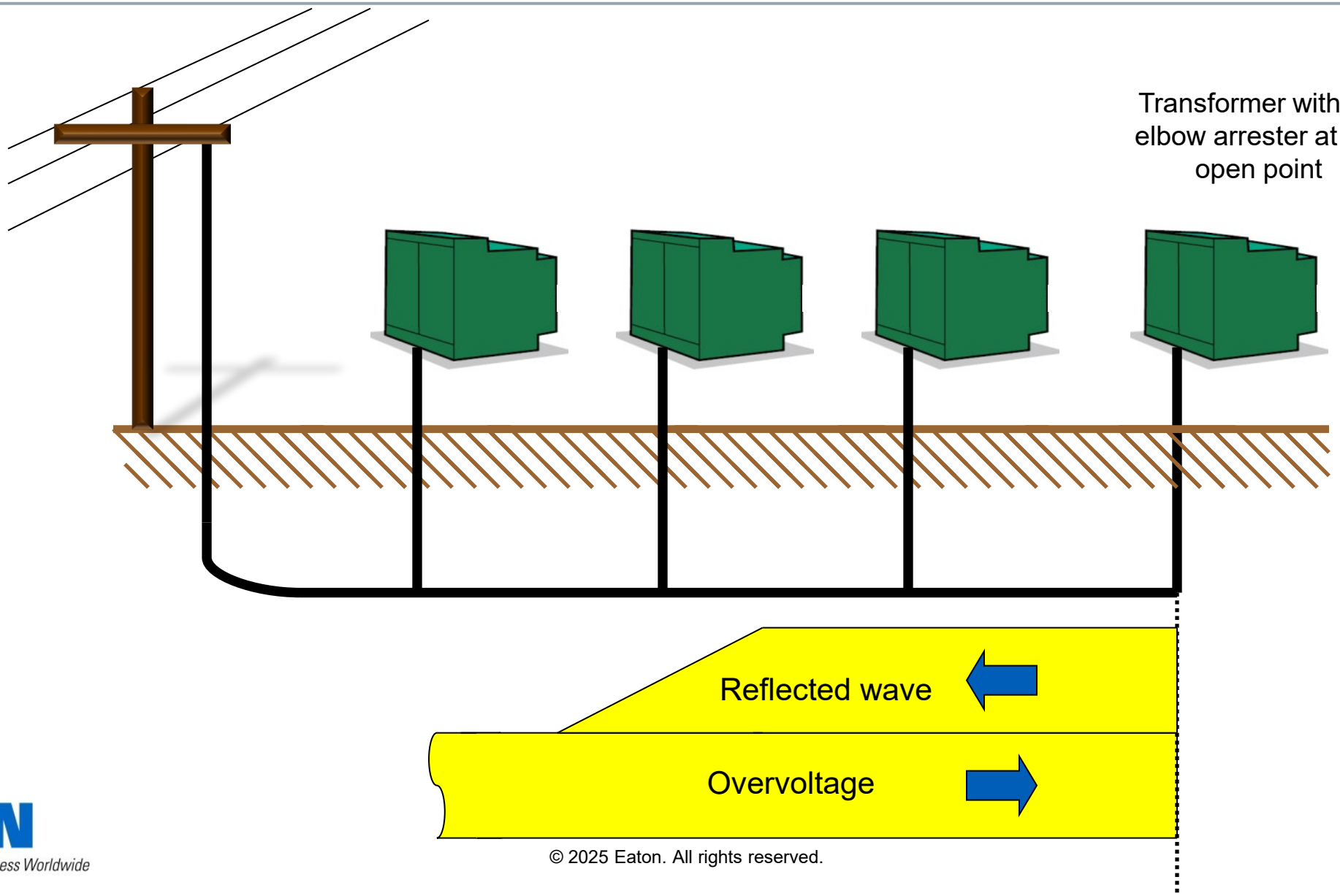
Overvoltages in Underground Distribution



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IEEE MOP Estimate Equations for the Major Protection Schemes

- IEEE 62.22.1 Outlines 3 Arrester Protection Schemes:
  - Riser pole arrester with no open point arrester
  - Riser pole arrester and open point arrester
  - Riser pole, open point, and midpoint arrester
- Equations for Margin of Protection are provided for each scheme in the standard.

- **Arrester at Riser Pole Only**

$$PM_{RP} = \left[\left(\frac{BIL}{2(RP_{DV} + L_{RP}\frac{di}{dt})} \right) - 1 \right] \times 100$$

- **Arresters at Riser Pole and Open Point**

$$PM_{RP,OP} = \left[\left(\frac{BIL}{(RP_{DV} + L_{RP}\frac{di}{dt}) + 0.5(OP_{DV} + L_{OP}\frac{di}{dt})} \right) - 1 \right] \times 100$$

- **Arresters at Riser Pole, Open Point, and Midpoint**

$$PM_{RP,OP,MP} = \left[\left(\frac{BIL}{(RP_{DV} + L_{RP}\frac{di}{dt})} \right) - 1 \right] \times 100$$

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Protection Margin for 20 kA, 8/20 Surge, Voltage Doubling Effect

- 12.47 kV gndY system, 10 kV MOV arrester
- Aged cable BIL=75 kV
- About 10’ of lead length
- HD RP Arrester, DV=31 kV

$$PM2 = \left[\left(\frac{BIL}{2(LPL + L\frac{di}{dt})}\right) - 1\right] \times 100 = \left[\left(\frac{75}{2\times\left[(31) + 10(0.4)(\frac{20}{8})\right]}\right) - 1\right] \times 100 = 9.75\%$$

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Margin of Protection With Open Point Arrester

$$PM_{RP,OP} = \left[\left(\frac{BIL}{(RP_{DV} + L_{RP}\frac{di}{dt}) + 0.5(OP_{DV} + L_{OP}\frac{di}{dt})} \right) - 1 \right] \times 100$$

- OP is the discharge voltage at the open point arrester
- Reflected voltage is clamped to a lower level than without an arrester, but still adds to the RP arrester discharge voltage and Ldi/dt contribution of leads

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Protection Margin for 20 kA, 8/20 Surge, Voltage Doubling Effect

- 12.47 kV gndY system, 10 kV MOV arrester
- Aged cable BIL=75 kV
- About 10’ of lead length
- HD RP Arrester, DV=31 kV
- Elbow Arrester, DV=38.9 kV, 3’ lead length

$$PM_{RP,\,OP} = \left[\left(\frac{BIL}{(RP_{DV} + L_{RP}\frac{di}{dt}) + 0.5(OP_{DV} + L_{OP}\frac{di}{dt})}\right) - 1\right] \times 100$$

$$PM2 = \left[\left(\frac{75}{\left[(31) + 10(0.4)(\frac{20}{8})\right] + .5\left[(38.9) + 3(0.4)(\frac{20}{8})\right]}\right) - 1\right] \times 100 = 76.5\%$$

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Elbow Arrester Applications - URD Open Point Protection

- Elbow or parking-stand arrester
- Extends the life of cable by limiting overvoltages on URD
- Designed for 200 A load break bushings and elbows
- Commonly used at all kV classes
- Best arrester at RP alone may not be enough to protect cable
- More economical than an under-oil arrester in every URD padmount transformer

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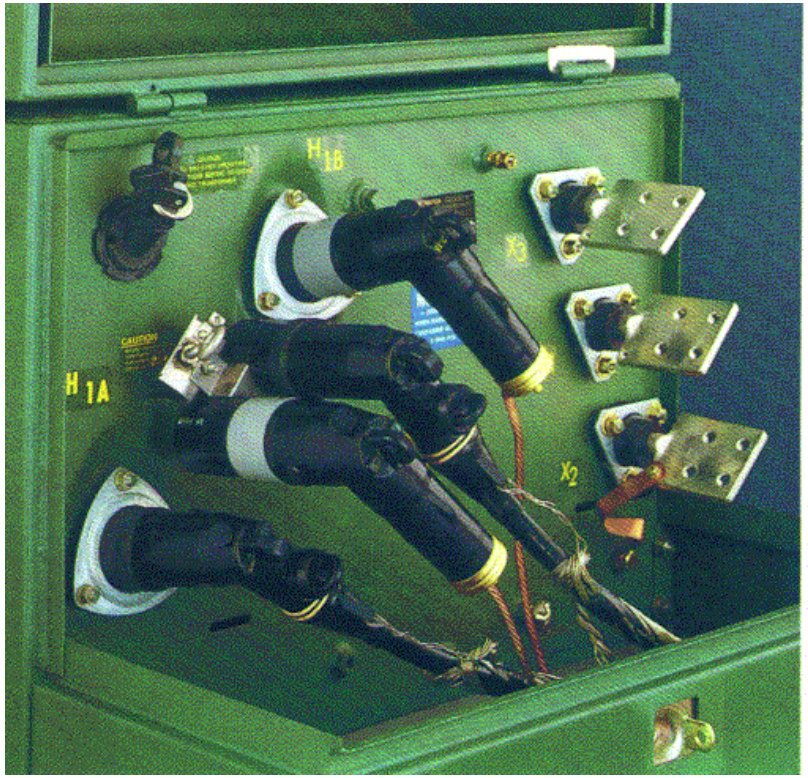
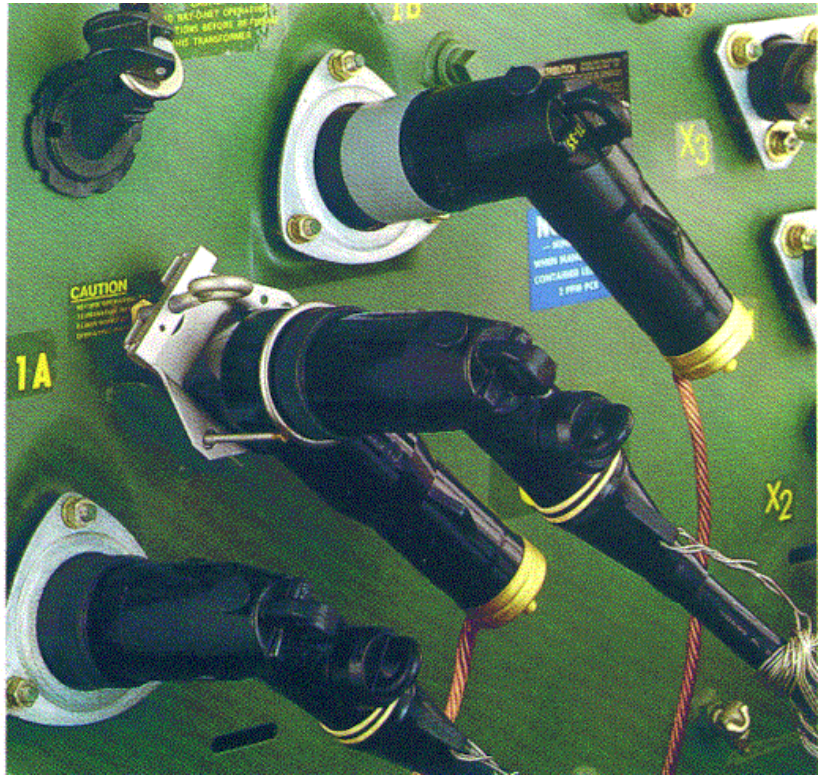
Installation of Open Point Arresters





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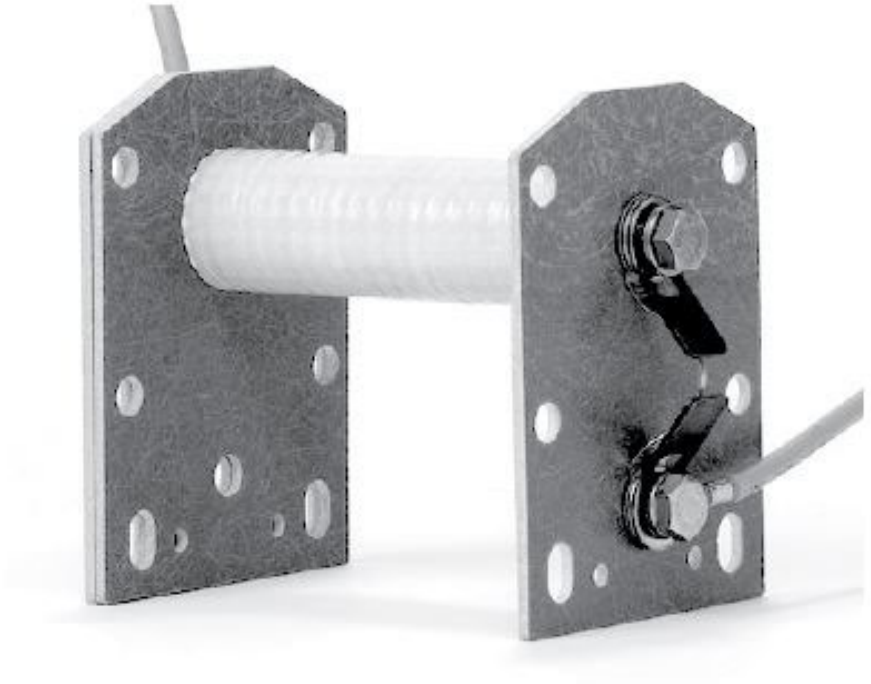
Transformer Under Oil Arrester



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Questions??

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