Surge Arrester Separation Distance Considerations for High-Voltage Substation Circuit Breakers

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Station Equipment Standards

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Agenda

- Introduction
- Separation Distance Calculations
- Separation Distance Applications
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Surge Protection to Circuit Breakers

- Most utilities sufficiently protect power transformers using transformer-mounted arresters next to bushings.
- Conversely, surge protection for circuit breakers lacks the attention of industry if:
  - The number of circuit breakers per a substation is typically large.
  - The cost of repairing or replacing a circuit breaker is relatively low.
  - The risk of damaging a circuit breaker from a lightning surge is not clear.
- However, the above judgements are in comparison to a power transformer. The likelihood and negative impact of failing or degrading an opened or closed circuit breaker due to a lightning surge are generally underestimated.
- Negative impacts may include required breaker replacement and harm to substation personnel due to breaker misoperations.

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IEEE-C62.22 Equation

$$D_{\mathrm{B}} = \frac{c}{2S}\left(\frac{1.15\,\delta\,BIL}{1.05} - V_{sa}\right)$$

The equipment in air-insulated substations may have a useful life in the range of 30 years to 75 years. Therefore, a MTBF of 50 years to 150 years could be used for air-insulated substations. The flashover rate of all lines connected to the substation is obtained or assumed, i.e., flashovers per 100 km per year. This establishes the surge exposure of the substation. The steepness of the design surge entering the substation is derived from this and other parameters, as is described later. The steepness of this entering surge is the major factor in determining the permissible separation distance between the arrester and the protected equipment.

$$S = (S') \times 3/(N+2)$$

$$S' = \frac{K_c}{d_m}$$

$$d_m = \frac{1}{n(\mathrm{MTBF})(\mathrm{FOR}/100)}$$

Table C.1—Estimated Values for K_c (IEC 60071-2-1997)

Type of line construction	K_c (kV-km/µs)
Distribution lines (phase-phase flashovers)[a]	
with grounded crossarms (flashover to ground at low voltage)	150
wood-pole lines (flashover to ground at high voltage)	400
Transmission lines (single-phase flashover to earth)	
single conductor	700
2-conductor bundle	1000
3 or 4 conductor bundle	1700
6 or 8 conductor bundle	2500

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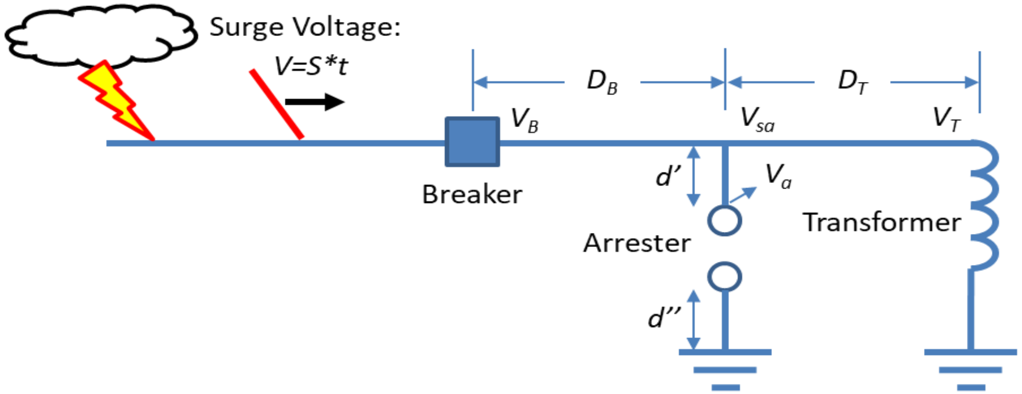
IEEE-C62.22 Equation



$$D_B = \frac{c}{2S}\left(\frac{1.15 \cdot \delta \cdot BIL}{1.05} - V_{sa}\right) \quad (1)$$

where:

c: Velocity of light, 300 m/µs

S: Steepness or rate of rise of the incoming surge, $S = \frac{K_c}{d_m}$

K_c: Corona constant that determines steepness of incoming surge (kV – km/µs)

d_m: Distance from a lightning stroke occurrence on a line to a substation, in km, $d_m = \frac{100}{MTBF \cdot FOR}$

MTBF: Mean time between failures (years)

FOR: Flashover rate of lines (flashovers/100 km-year)

δ: Altitude adjustment factor, $\delta = e^{-\frac{A}{8.6}}$

A: Altitude, in km

BIL: Basic lightning impulse insulation level

V_{sa}: Voltage across the surge arrester, from junction *J* to ground (kV), $V_{sa} = V_a + 1.3\mu H/m * (d' + d'') * (2 * S/Z)$

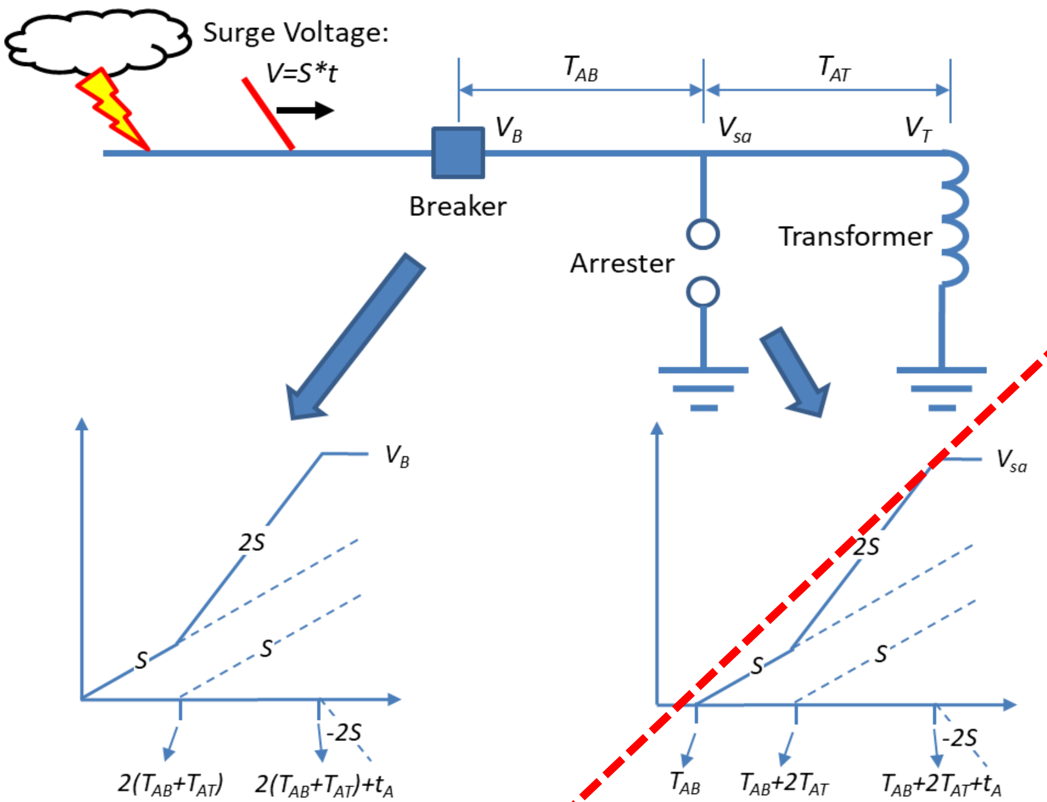
V_a: Surge arrester FOW protective level at 0.5 µs (kV)

d': Conductor length between arrester-bus junction and arrester terminal (m)

d'': Conductor length between ground and arrester grounding terminal (m)

Z: Line surge impedance (Ω)

Typical Layout



$$V_B = S \cdot 2(T_{AB} + T_{AT}) + 2S \cdot t_A$$
$$= V_{sa} + 2S \cdot T_{AB}$$

$$V_{sa} = S \cdot 2T_{AT} + 2S \cdot t_A$$

$$V_B = V_{sa} + 2S \cdot \frac{D_B}{c}$$

$$V_B = \frac{1.15 \cdot \delta \cdot BIL}{1.05}$$

$$D_B = \frac{c}{2S}\left(\frac{1.15 \cdot \delta \cdot BIL}{1.05} - V_{sa}\right)$$

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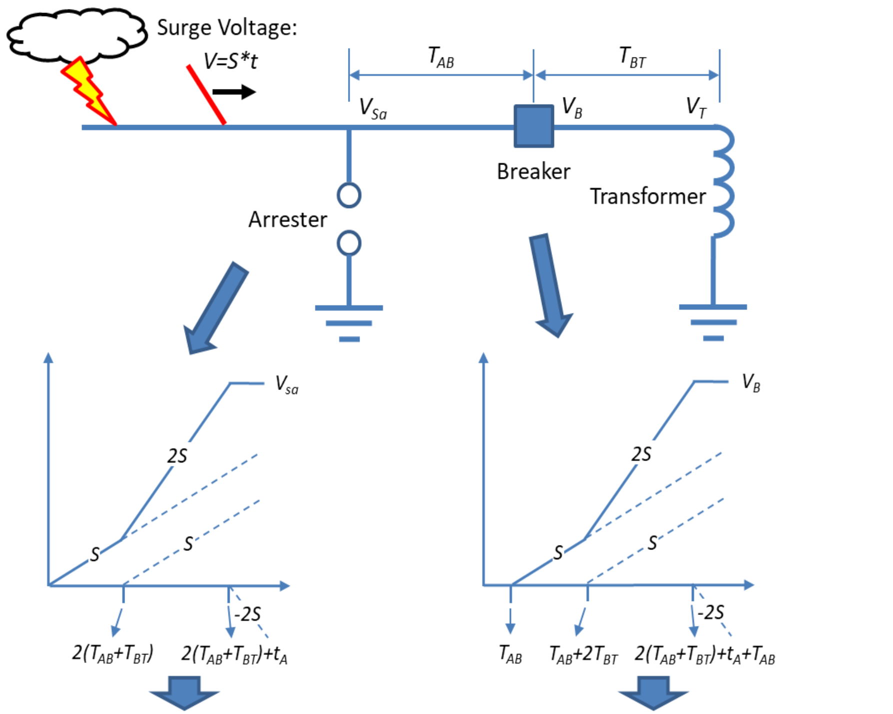
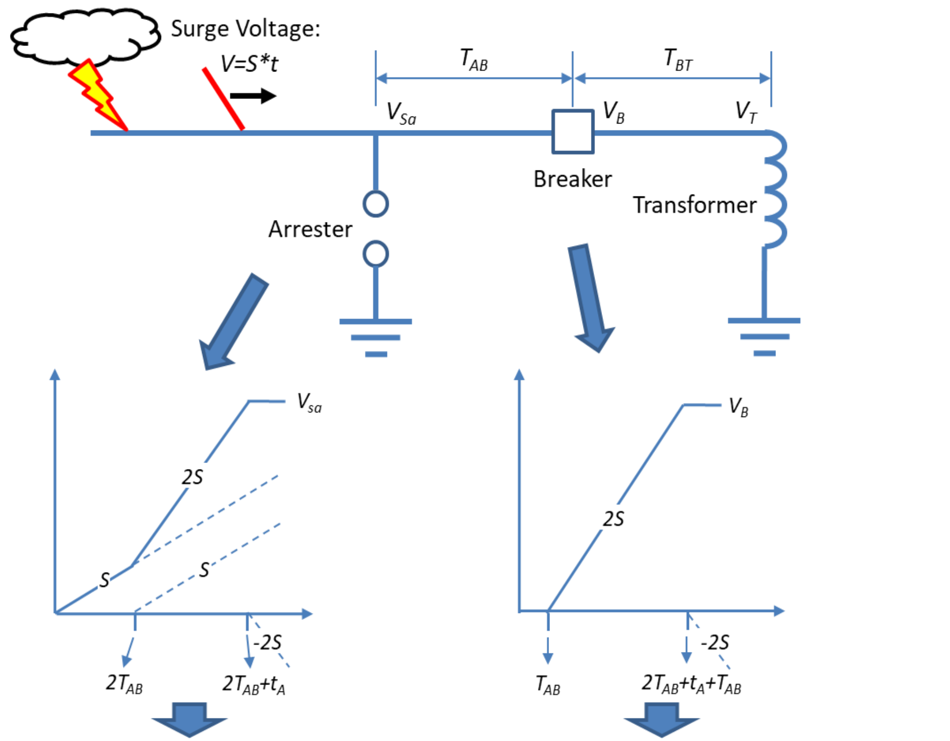
Other Layouts



$$V_{sa} = S \cdot 2(T_{AB} + T_{BT}) + 2S \cdot t_A$$

$$V_B = S \cdot 2T_{BT} + 2S \cdot (t_A + T_{AB}) + 2S \cdot T_{AB} = V_{sa} + 2S \cdot T_{AB}$$



$$V_{sa} = S \cdot 2T_{AB} + 2S \cdot t_A$$

$$V_B = 2S \cdot (t_A + 2T_{AB}) = V_{sa} + 2S \cdot T_{AB}$$

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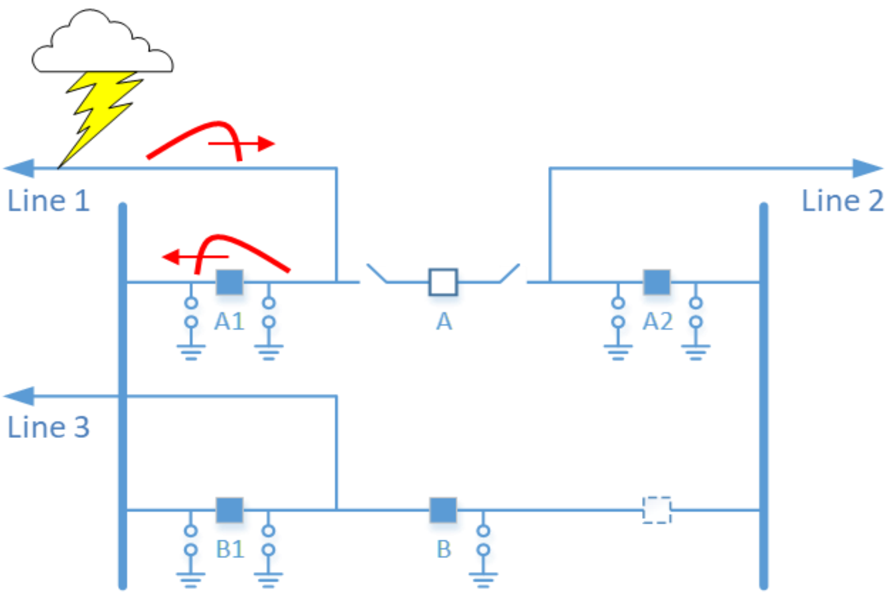
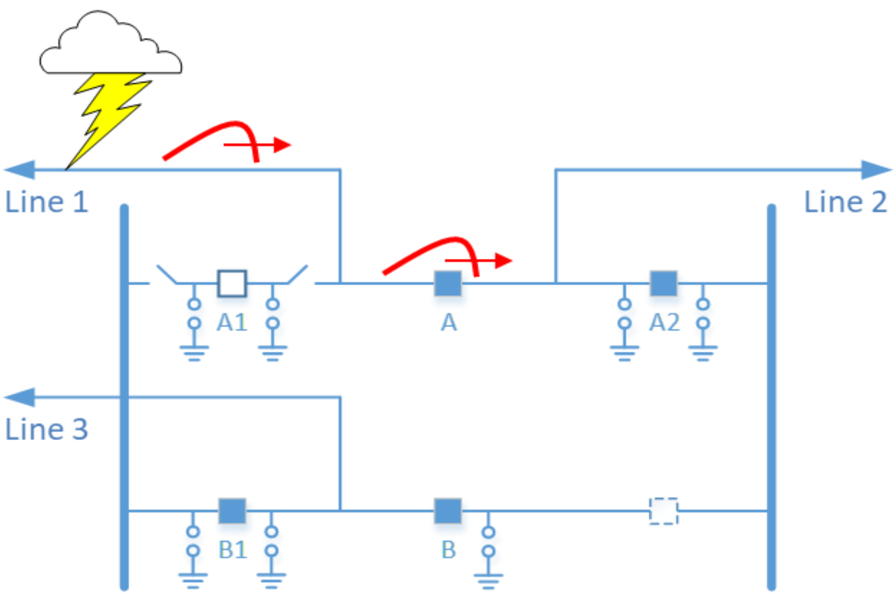
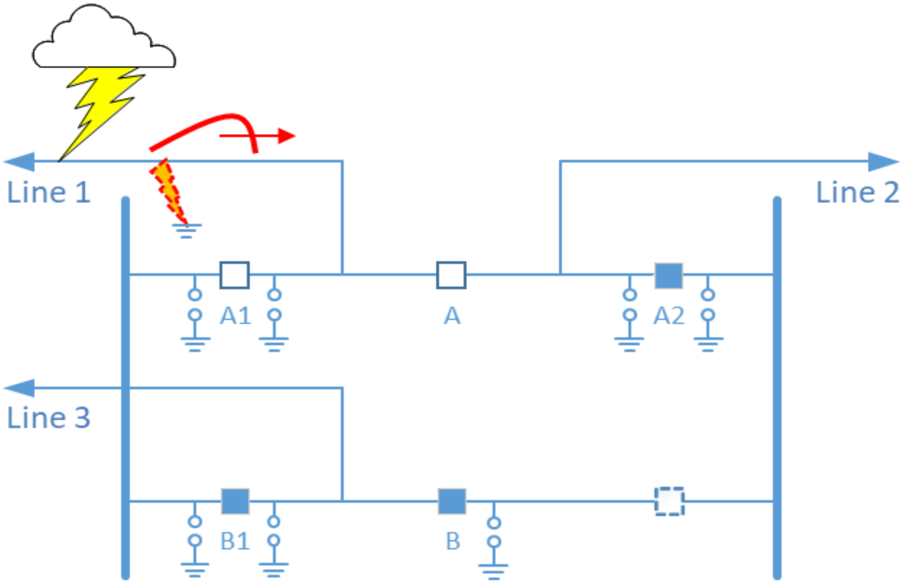
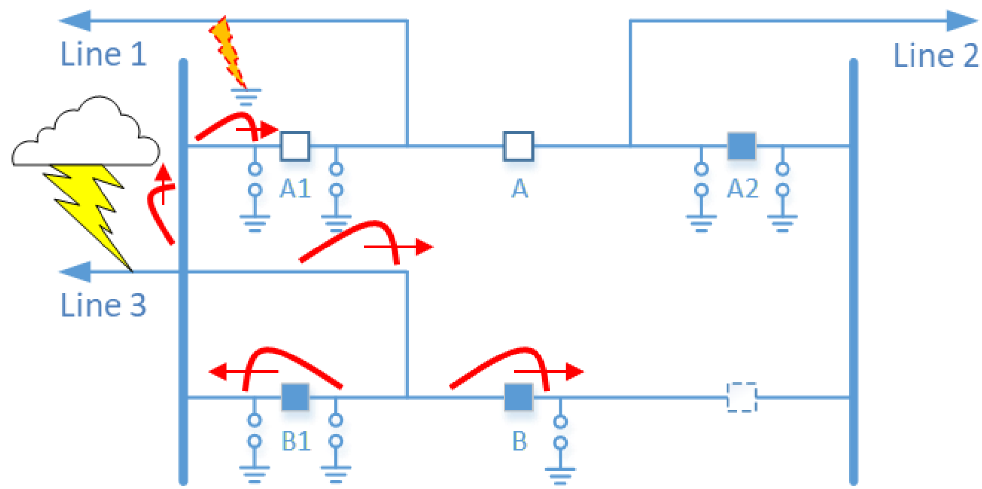
Breaker Maintenance Scenarios





Breaker Tripping Scenarios





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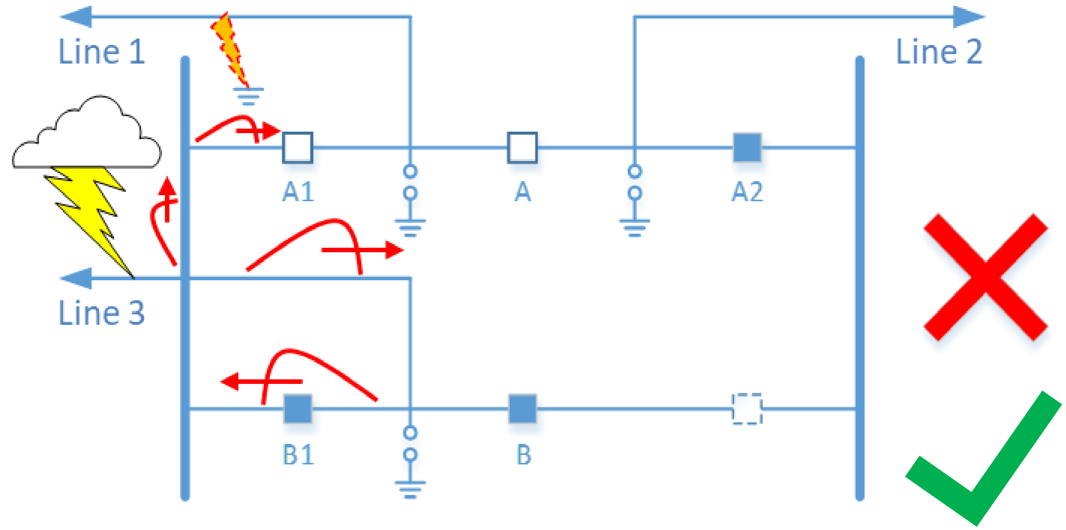
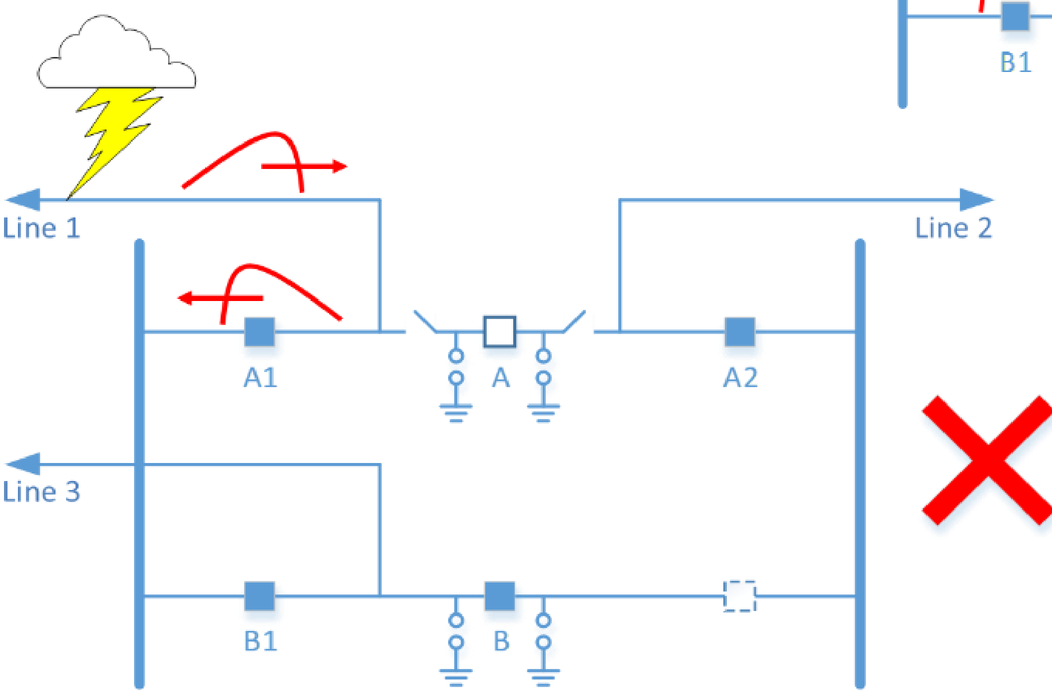
Other Arrester Placements





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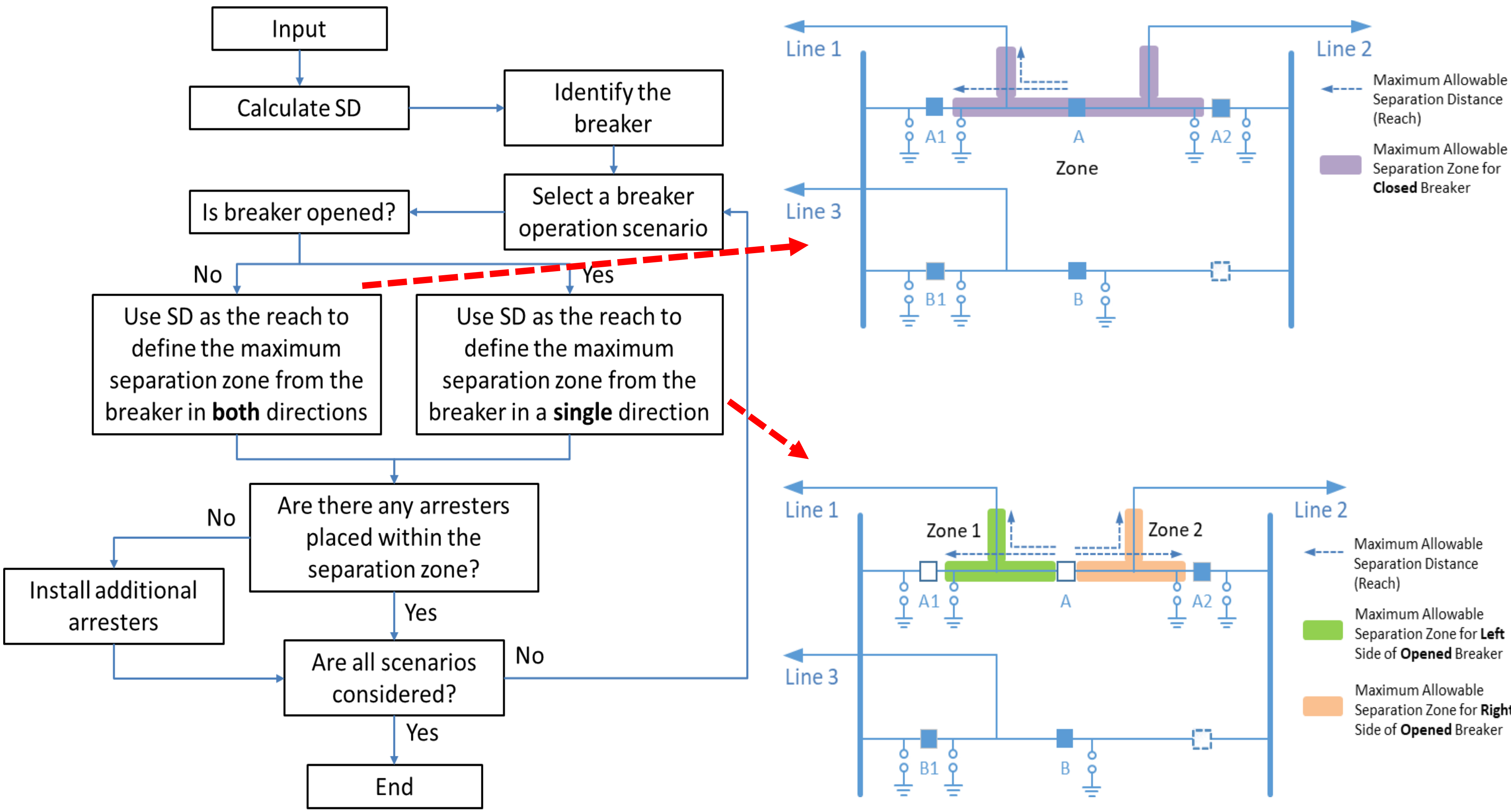
Procedure for Determining Surge Arrester Placements



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- We proved and verified that the equation is valid for calculating the maximum allowable separation distance for substation circuit breakers recommended by IEEE-C62.22 for various breaker-arrester positions and breaker closed/opened statuses.
- This exercise also helps explain the fundamentals of separation effects and the importance of installing arresters as close as possible to the equipment they are intended to protect.
- In addition, we explore various breaker operation scenarios including removing a breaker due to scheduled maintenance or a fault, which may influence the placement of surge arresters.
- Furthermore, we propose an optimal surge arrester placement solution for a typical 138-kV breaker-and-a-half station bus.
- Lastly, a procedure for determining arrester placements for lightning surge protection of circuit breakers is recommended.

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Reference

- IEEE Std. C62.22, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems, 2009 Edition.
- Andrew R. Hileman, “Insulation Coordination for Power Systems,” CRC Press, Boca Raton, FL, 1999.


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kia ora
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matondo
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