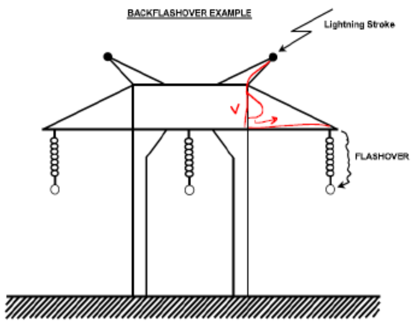
Note Title

4/12/2014

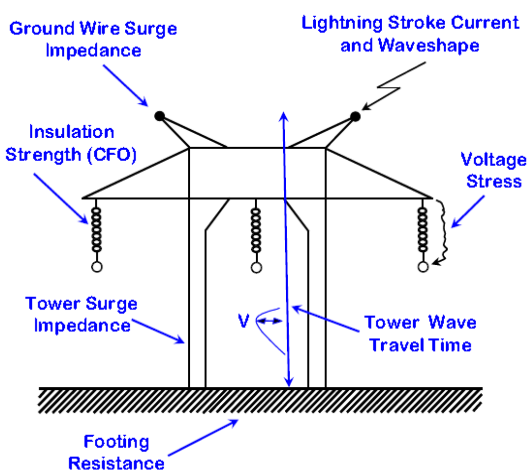
Lighting Impacts - Backflashover and Shielding Failures

① Backflashover

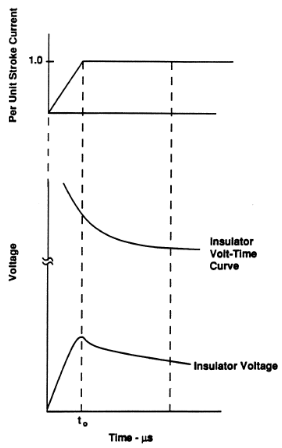


× Elements of backflashovers:

- Tower surge impedance
- Footing resistance
- Ground wire surge impedance
- Line insulation strength (CFO)
- Lightning stroke current magnitude and waveshape
- Traveling voltage waves caused by lightning stroke (magnitude and travel time)
- Phase coupling and power frequency voltages



* Backflashover Calculation - Simplified 2-point Method:



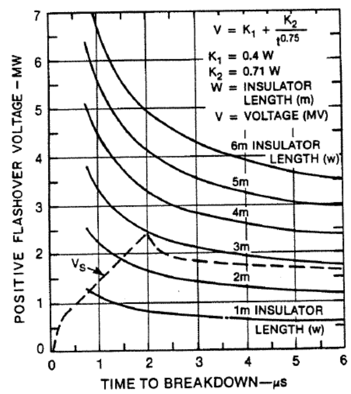
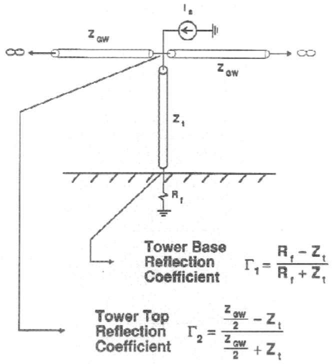
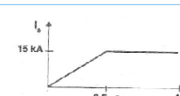


Figure 8. Volt-Time Curves for Line Insulators Plotted with One Insulator Voltage Wave V_S

Ex:



$$Z_{eq} \ (\text{@ Tower Top}) = \frac{\left(\frac{Z_{gw}}{2}\right)(Z_t)}{\left(\frac{Z_{gw}}{2}\right) + (Z_t)}$$



$Z_{gw} = 350\ \Omega$

$Z_t = 150\ \Omega$

Tower is 30m high
Travel Time = 0.1 µs

$R_f = 20\ \Omega$

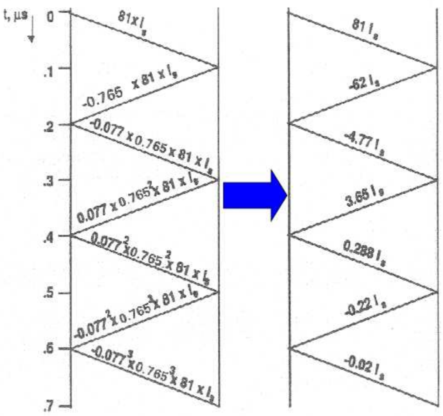
@ Tower Base

$$\Gamma_1 = \frac{20 - 150}{20 + 150} = -0.765$$

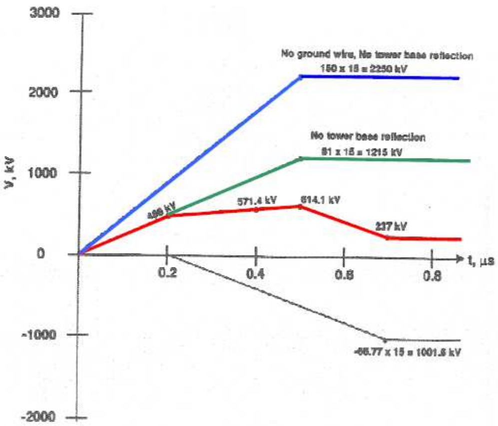
@ Tower Top

$$\Gamma_2 = \frac{\frac{350}{2} - 150}{\frac{350}{2} + 150} = 0.077$$

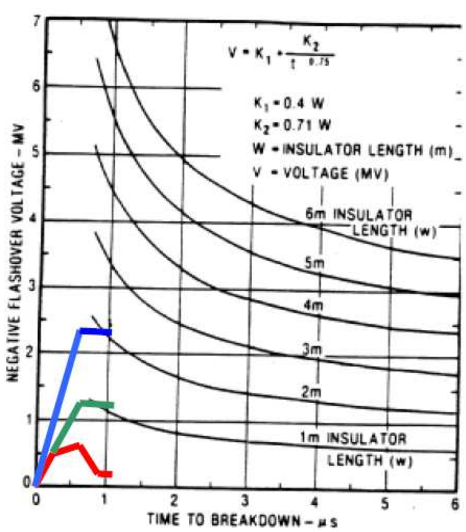
$$Z_{eg} = \frac{\frac{350}{2}(150)}{\frac{350}{2} + 150} = 81\Omega$$



t, μs
0
.1
.2
.3
.4
.5
.6
.7
81 x I_s
-0.765 x 81 x I_s
-0.077 x 0.765 x 81 x I_s
0.077 x 0.765^2 x 81 x I_s
0.077^2 x 0.765^2 x 81 x I_s
-0.077^2 x 0.765^3 x 81 x I_s
-0.077^3 x 0.765^3 x 81 x I_s
81 I_s
-62 I_s
-4.77 I_s
3.65 I_s
0.288 I_s
-0.22 I_s
-0.02 I_s

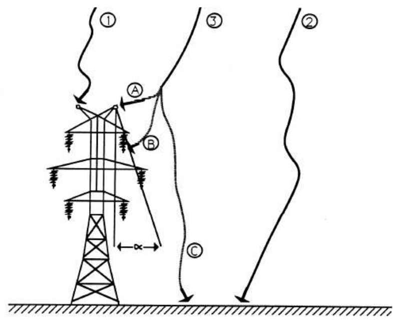


V, kV
3000
2000
1000
0
-1000
-2000
0.2
0.4
0.6
0.8
t, μs
No ground wire, No tower base reflection
150 x 15 = 2250 kV
No tower base reflection
81 x 15 = 1215 kV
571.4 kV
614.1 kV
237 kV
-66.77 x 15 = 1001.6 kV



$V = K_1 + \frac{K_2}{t^{0.75}}$
K_1 = 0.4 W
K_2 = 0.71 W
W = INSULATOR LENGTH (m)
V = VOLTAGE (MV)
6m INSULATOR LENGTH (w)
5m
4m
3m
2m
1m INSULATOR LENGTH (w)
NEGATIVE FLASHOVER VOLTAGE – MV
TIME TO BREAKDOWN – μs
0
1
2
3
4
5
6
7

* Shielding:



1) Lightning stroke in region (1) results in strike to ground wire or tower [desirable]
2) Lightning stroke in regions (2) results in strike to earth/ground [desirable]
3) Lightning stroke in regions (3) results in unknown strike to ground wire or tower, or phase conductor, or earth/ground [undesirable]

① Finding the # of insulators

TABLE 17-2 Number of Standard Insulator Units (5.75 in × 10 in) (146 mm × 254 mm)[3]

System Voltage	Number of Standard Units Required for Contamination Severity I-Strings/V-Strings			
	Very Light	(Light)	Moderate	Heavy
138	6/6	8/7	9/7	11/8
161	7/7	10/8	11/9	13/10
230	11/10	14/12	16/13	19/15
345	16/15	21/17	24/19	29/22
500	25/22	32/27	37/29	44/33
765	36/22	47/39	53/42	64/48

Leakage distance = 11.5 in (292 mm) for the standard insulator unit

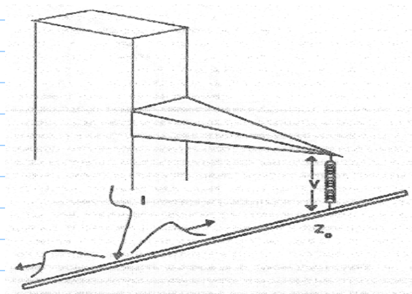
② Find the Line insulation strenght – Critical Flashover Overvoltage (CFO)

Number of Insulators (10" x 5 1/4")	Critical-Impulse Average Flashover Negative / kV	Critical-Impulse Average Flashover Positive / kV
1	130	125
2	255	255
3	345	355
4	415	440
5	485	525
6	585	610
7	670	695
8	760	760
9	845	860
10	930	940
11	1015	1025
12	1105	1105
13	1190	1185
14	1275	1285
15	1360	1345
16	1440	1425
17	1530	1505
18	1615	1585
19	1700	1685
20	1785	1745
21	1870	1825
22	1955	1905
23	2040	1985
24	2125	2065
25	2210	2145
26	2295	2225
27	2380	2305
28	2465	2385
29	2550	2465
30	2635	2545
31	2720	2625
32	2805	2705
33	2890	2785
34	2975	2865
35	3060	2945

Critical Flashover Voltage (CFO)

Source: Suspension Insulators NGK Insulators, LTD. Cat. No. 14B

③ Calulate $I_{critical}$ or I_{min}



$$V = \frac{1}{2} I Z_o$$

$$I_{critical} \text{ or } I_{min} = 2\frac{CFO}{Z_o}$$

④ Calculating Keraunic Level (N_g):

① $N_g = 0.04T^{1.25}$

or

② $N_g = 0.14T$

Where:

- Ng = ground flash density in units of # flashes per km² per year
- T = thunderstorm days per year (Keraunic Level)

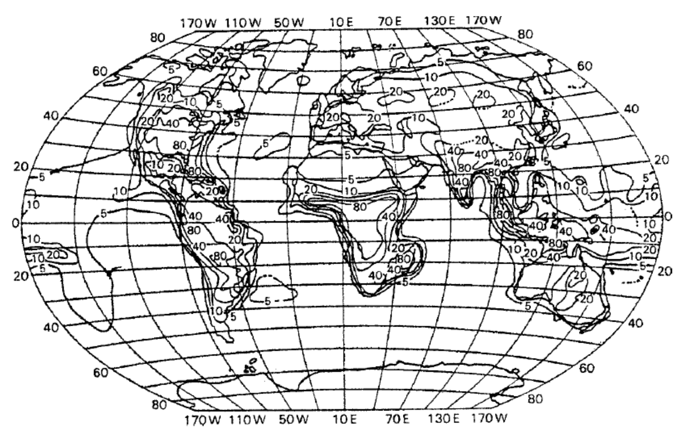


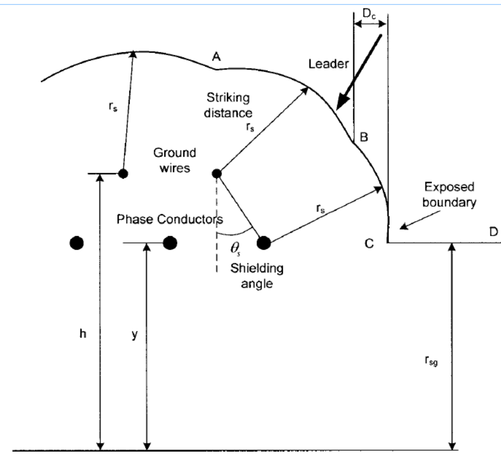
FIGURE 5-14 Isokeraunic map of the world.

(5) Calculating the striking distance (r_s) :

TABLE 5-3 Expressions for the Striking Distance in Meters

Author/Researcher	Striking Distance Expression, r_s to Phase Conductors and Ground Wire (in meters)	Striking Distance Expression, r_g to Earth or Ground Wires (in meters)
Darveniza, 1979	$2I_s + 30(1 - e^{-0.147I})$	—
Love, 1973	$10I_s^{0.65}$	$10I_s^{0.65}$
Brown-Whitehead, 1977	$7.1I_s^{0.75}$	$6.4I_s^{0.75}$
Suzuki, 1981	$3.3I_s^{0.78}$	—
Erickson, 1982	$0.67h^{0.6}I_s^{0.74}$	$0.67h^{0.6}I_s^{0.74}$
IEEE-1995 Subcommittee	$8h^{0.6}I_s^{0.65}$	$8h^{0.6}I_s^{0.65}$

I_s, the first return stroke current.



(6) Calculinging D_c :

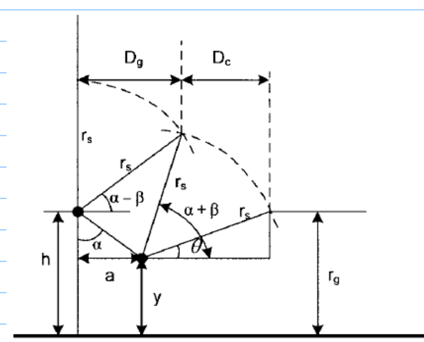
$$D_c = r_s[\cos\theta - \cos(\alpha+\beta)]$$
$$D_g = r_s\cos(\alpha-\beta) \qquad (5\text{-}56)$$

where:

$$\beta = \frac{1}{2}\sin^{-1}\frac{(h-y)\sqrt{1+\tan^2\alpha}}{2r_s}$$
$$\theta = \sin^{-1}\frac{r_g - y}{r_s} \qquad \alpha = \tan^{-1}\frac{a}{h-y} \qquad (5\text{-}57)$$

For I_m, where all striking distances coincide at a single point:

$$a = \sqrt{r_s^2 - (r_g - h)^2} - \sqrt{r_s^2 - (r_g - y)^2}$$
$$r_{gm} = \frac{(h+y)/2}{1 - (r_s/r_g)\sin\alpha} \qquad (5\text{-}58)$$
$$I_m = \left[\frac{r_{gm}}{A}\right]^{1/b} \quad (r_g = AI_s^b)\ \text{(Table 5-3)}$$ where $A=8$, $b=0.65$



* To find Sheilding Failure Rate (SFR):

$$\text{SFR} = 2N_g D_c l$$

where l is the length of the line.

* To find Sheilding Failure Flashover Rate (SFFOR):

$$\text{SFFOR} = 2N_g l \int_{Ic}^{I_m} D_c f(I)\,dI = N_g l D_c P(I_m \geq I \geq I_c) = N_g l D_c [Q(I_c) - Q(I_m)]$$

where: $Q(I) = 1 - F(I)$

$$z = \frac{\ln I - \ln M_1}{\beta_1}$$

TABLE 5-6 CIGRE Cumulative Distribution Approximations

Range of Current I (kA)	Approximate Equation of Q
3–20	$1 - 0.31e^{-z/1.6}$
20–60	$0.50 – 0.35Z$
60–200	$0.278e^{-z/1.7}$

TABLE 5-7 Median and Log Standard Deviations for CIGRE Distribution

Current Range (kA)	Median M_1	Beta β_1
3–20	61.1	1.33
>20	33.3	0.605

Example 5-4 Calculate the SFFOR for a transmission line with two shield wires, located at 30 m, conductor height = 25 m, shielding angle = 30°, I_c = 15 kA, N_g = 4.

Sol.

Let us use IEEE equations for r_s and r_g, from Table 5-3. These give $r_s = r_g = 46.5$ m, $r_c/r_g = 1$

$$r_{gm} = \frac{(30+25)/2}{1-\sin 30°} = 55\ \text{m}$$

$$I_m = (55/8)^{1/0.65} = 19.4\ \text{kA} \qquad \beta = 3.56° \qquad \theta = 27.5°$$

This gives $D_c = 2.51$ m.

and then the values of Q:

$$z_c = \frac{\ln(15/61.1)}{1.33} = -1.05$$

$$Q_c = 1 - 0.31e^{-1.1025/1.6} = 0.844$$

$$z_m = \frac{\ln(19.4/61.1)}{1.33} = -0.863$$

$$Q_m = 1 - 0.31e^{-0.863/1.6} = 0.819$$

Therefore:

$$\text{SFFOR} = 4 \times 100 \times 2.51 \times 0.025 \times 10^{-3} = 0.0251/100\ \text{km} - \text{years}.$$

* The perfect shielding angle:

$$\alpha_p = \sin^{-1}\frac{r_g-(h+y)/2}{r_s} \approx \frac{r_g}{r_s}-\frac{1}{r_s}\left(\frac{h+y}{2}\right)$$

TABLE 5-8 Required Shielding Angle for SFFOR of 0.05/100 km-yr.[26]

Ground Flash Density (flashes km² year)	Ground Wire Height (m)	Phase Conductor Height (m)	Shielding Angle IEEE (deg.)	Shielding Angle CIGRE, (deg.)
0.5	30	22	38	42
	45	37	12	28
3.0	30	22	33.5	36
	45	37		19
5.0	30	33	32	35
	45	37	4	17