Direct stroke lightning protection calculation

Project	Client	Location	Revision	Date
Sample 230/34.5 kV pooling substation	Sample client	Sample site	0	4 Nov 2026

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230/34.5 kV pooling substation, 250 MW. Method: IEEE Std 998-2012 rolling sphere with the modified electrogeometric model (Mousa) for the 230 kV yard and the transformers. IEC 62305-3 lightning protection level I sphere for the 34.5 kV outdoor areas and the building.

1. Sphere radius per protected level

Level	Method	Protected height A (m)	Sphere radius S (m)
HV tubular bus	IEEE 998 (Mousa)	8.50	26.25
HV equipment	IEEE 998 (Mousa)	5.00	26.45
Transformer bushing tops	IEEE 998 (Mousa)	7.50	24.98
34.5 kV outdoor areas	IEC 62305 LPL I	5.00	20.00
Control building roof	IEC 62305 LPL I	6.00	20.00

2. Modified electrogeometric model (Mousa)

Quantity	Reference	Formula	Result
HV tubular bus: corona radius	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$	0.121 m (0.398 ft)
HV tubular bus: surge impedance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$	318.3 Ω
HV tubular bus: allowable stroke current	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$	6.22 kA
HV tubular bus: striking distance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$S = 8\,k\,I_s^{0.65}$	26.25 m (86.11 ft)
HV equipment: corona radius	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$	0.141 m (0.462 ft)
HV equipment: surge impedance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$	314.5 Ω
HV equipment: allowable stroke current	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$	6.30 kA
HV equipment: striking distance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$S = 8\,k\,I_s^{0.65}$	26.45 m (86.79 ft)
Transformer bushing tops: corona radius	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$	0.125 m (0.411 ft)
Transformer bushing tops: surge impedance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$	343.5 Ω

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Quantity	Reference	Formula	Result
Transformer bushing tops: allowable stroke current	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$	5.76 kA
Transformer bushing tops: striking distance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$S = 8\,k\,I_s^{0.65}$	24.98 m (81.96 ft)

IEC 62305-3 Table 2: rolling sphere radius 20 m for LPL I, used for 34.5 kV outdoor areas, control building roof. The Mousa sphere (IEEE 998-2012 §6.5) at BIL 170 kVp is approximately 7.8 m (25.6 ft). Masts at least that tall then stand no more than 11.0 m (36.2 ft) apart on a square grid (S·√2), against 28.3 m (92.8 ft) for the 20 m (65.6 ft) sphere.

Calculation trail

1 · Corona radius (HV tubular bus)

IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)

$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$

h 8.50 m (27.89 ft), BIL 900 kVp, E0 1500 kV/m → Rc = 0.121 m (0.398 ft)

2 · Surge impedance under corona

IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)

$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$

r 57.1 mm (2.25 in) → Zs = 318.3 Ω

3 · Allowable stroke current

IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)

$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$

BIL 900 kVp, Zs 318.3 Ω → Is = 6.22 kA

4 · Striking distance (sphere radius)

IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)

$S = 8\,k\,I_s^{0.65}$

k 1 → S = 26.25 m (86.11 ft) (other levels: HV equipment 26.5 m (86.8 ft), transformer bushing tops 25.0 m (82.0 ft), **34.5 kV outdoor areas 20.0 m (65.6 ft), Control building roof 20.0 m (65.6 ft))**

5 · Shield wires

Design rule

$h_{\mathrm{wire}} = h_{\mathrm{beam}} + 3\,\mathrm{m}$

8 towers → 4 wires at 19.0 m (62.3 ft)

6 · Lightning masts

Design rule

$\max_c N_{\mathrm{covered}}(c)$

mast height 25.0 m (82.0 ft) → 17 masts at 25.0 m (82.0 ft)

7 · Coverage check

IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)

$E(P) \geq A$

5 levels, least margin +1.77 m (+5.81 ft) → 5 of 5 levels protected

3. Shielding

Element	Count	Height (m)	Notes
Shield wires (column boundaries)	4	19.0	440 m (1444 ft) in total
Gantry peaks and shield-wire towers	8	19.0	wire ends
Lightning masts	17	25.0	added until the protected points are covered

Mast positions, x east and y north from the south-west corner of the fence. The last column is the fixed-angle (45°) protected radius at 5.5 m, for information (IEEE 998-2012, fixed-angle method):

$r = (h - 5.5)\tan 45^\circ$

Mast	x (m)	y (m)	Fixed-angle radius at 5.5 m (m)
LM-6	49.4	24.5	19.5
LM-8	68.6	36.1	19.5
LM-3	29.4	43.4	19.5

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Mast	x (m)	y (m)	Fixed-angle radius at 5.5 m (m)
LM-9	78.6	9.0	19.5
LM-11	101.9	23.0	19.5
LM-12	113.5	9.0	19.5
LM-15	136.7	23.0	19.5
LM-16	148.4	9.0	19.5
LM-17	156.1	16.0	19.5
LM-10	86.4	9.0	19.5
LM-13	121.2	9.0	19.5
LM-14	129.0	23.0	19.5
LM-7	67.0	9.0	19.5
LM-4	30.2	9.0	19.5
LM-1	1.0	19.0	19.5
LM-2	10.9	9.0	19.5
LM-5	37.9	9.0	19.5

4. Coverage check

A protected point P at height A is safe when the sphere cannot reach it: E(P) ≥ A. E is the lowest height the sphere reaches at P, rolled over the wires, towers and masts on a 1 m (3.28 ft) grid.

Level	Points	Protected	Least margin	Result
HV tubular bus	186	186	+8.52 m (+27.95 ft)	Pass
HV equipment	93	93	+12.04 m (+39.49 ft)	Pass
Transformer bushing tops	80	80	+10.03 m (+32.90 ft)	Pass
34.5 kV outdoor areas	264	264	+1.77 m (+5.81 ft)	Pass
Control building roof	196	196	+3.46 m (+11.37 ft)	Pass

5. Grounding

Each mast and shield-wire tower has 2 ground electrodes bonded to the ground grid (50 electrodes). The grounding calculation counts them.

6. Assumptions

1. The striking distance uses k = 1 for masts and shield wires. IEEE 998 allows k = 1.2 for a mast, which would protect a larger area, so the mast coverage shown is the smaller one.

2. Conductor radii: main bus 57.1 mm (2.25 in) (aluminum tube), equipment and 34.5 kV 15.9 mm (0.63 in) (ACSR Moose). Transformer bushing tops 7.5 m (24.6 ft), building roof 6.0 m (19.7 ft). Shield wires 19.0 m (62.3 ft) (gantry beam + 3 m (9.84 ft)), masts 25.0 m (82.0 ft). The design fixes these values.

3. The design assumes no shield-wire sag. Taking the attachment height along the whole span overstates the wire's height at mid-span, so the coverage under a span is smaller than drawn. Check mid-span coverage at detail design with the stringing sag. The BOM adds 3 % to the wire length for sag and jumpers.

4. The control building's roof air terminals and down conductors are the building's own design to IEC 62305-3.

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