Direct stroke lightning protection calculation

Project	Client	Location	Revision	Date
Sample 220/33 kV pooling substation	Sample client	Sample site	0	2 Nov 2026

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220/33 kV pooling substation, 250 MW. Method: IEEE Std 998-2012 rolling sphere with the modified electrogeometric model (Mousa) for the 220 kV yard and the ICTs. IEC 62305-3 lightning protection level I sphere for the 33 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)	9.00	29.15
HV equipment	IEEE 998 (Mousa)	5.90	28.97
ICT bushing tops	IEEE 998 (Mousa)	7.50	27.99
33 kV outdoor areas	IEC 62305 LPL I	5.50	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)	$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$	0.145 m
HV tubular bus: surge impedance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$	315.9 Ω
HV tubular bus: allowable stroke current	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$	7.31 kA
HV tubular bus: striking distance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$S = 8\,k\,I_s^{0.65}$	29.15 m
HV equipment: corona radius	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$	0.164 m
HV equipment: surge impedance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$	319.1 Ω
HV equipment: allowable stroke current	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$	7.24 kA
HV equipment: striking distance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$S = 8\,k\,I_s^{0.65}$	28.97 m
ICT bushing tops: corona radius	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$R_c \ln\frac{2h}{R_c} = \frac{\mathrm{BIL}}{E_0}$	0.153 m
ICT bushing tops: surge impedance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$Z_s = 60\sqrt{\ln\frac{2h}{R_c}\ln\frac{2h}{r}}$	336.4 Ω
ICT bushing tops: allowable stroke current	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$I_s = \frac{2.2\,\mathrm{BIL}}{Z_s}$	6.87 kA

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Quantity	Reference	Formula	Result
ICT bushing tops: striking distance	IEEE 998-2012 §6.5, §6.6 (rolling sphere, Mousa)	$S = 8\,k\,I_s^{0.65}$	27.99 m

IEC 62305-3 Table 2: rolling sphere radius 20 m for LPL I, used for 33 kV outdoor areas, control building roof. The Mousa sphere (IEEE 998-2012 §6.5) at BIL 170 kVp is approximately 7.8 m. Masts at least that tall then stand no more than 11.0 m apart on a square grid (S·√2), against 28.3 m for the 20 m 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 9.00 m, BIL 1050 kVp, E0 1500 kV/m → Rc = 0.145 m

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 → Zs = 315.9 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 1050 kVp, Zs 315.9 Ω → Is = 7.31 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 = 29.15 m (other levels: HV equipment 29.0 m, ICT bushing tops 28.0 m, 33 kV outdoor areas 20.0 m, Control **building roof 20.0 m)**

5 · Shield wires

Design rule

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

10 towers → 5 wires at 18.5 m

6 · Lightning masts

Design rule

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

mast height 25.0 m → 14 masts at 25.0 m

7 · Coverage check

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

$E(P) \geq A$

5 levels, least margin +0.22 m → 5 of 5 levels protected

3. Shielding

Element	Count	Height (m)	Notes
Shield wires (column boundaries)	5	18.5	348 m in total
Gantry peaks and shield-wire towers	10	18.5	wire ends
Lightning masts	14	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	52.5	24.5	19.5
LM-9	81.5	36.1	19.5
LM-3	26.5	43.3	19.5
LM-8	79.0	9.0	19.5
LM-10	103.0	9.0	19.5
LM-12	119.0	23.0	19.5

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Mast	x (m)	y (m)	Fixed-angle radius at 5.5 m (m)
LM-13	135.0	9.0	19.5
LM-14	143.0	16.0	19.5
LM-11	111.0	23.0	19.5
LM-7	67.0	9.0	19.5
LM-4	30.2	9.0	19.5
LM-1	1.0	17.0	19.5
LM-5	37.9	9.0	19.5
LM-2	10.9	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 grid.

Level	Points	Protected	Least margin	Result
HV tubular bus	222	222	+8.09 m	Pass
HV equipment	81	81	+11.17 m	Pass
ICT bushing tops	70	70	+9.82 m	Pass
33 kV outdoor areas	222	222	+0.22 m	Pass
Control building roof	196	196	+3.46 m	Pass

5. Earthing

Each mast and shield-wire tower has 2 earth electrodes bonded to the earth mat (48 electrodes). The earthing 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 (aluminium tube), equipment and 33 kV 15.9 mm (ACSR Moose). ICT bushing tops 7.5 m, building roof 6.0 m. Shield wires 18.5 m (gantry beam + 3 m), masts 25.0 m. 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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