Earthing design calculation

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

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SSL-C-EAR-001	Sample engineer	Sample engineer	Sample engineer

Rev	Date	Description	By
0	2 Nov 2026	Issued	Sample engineer

220/33 kV pooling substation, 250 MW. Method: IEEE Std 80-2013, uniform soil, rectangular grid with electrodes.

1. Inputs

Parameter	Symbol	Value	Source
Design fault current (220 kV, 3I0)	3I0	50 kA (rating), 20.24 kA calculated	Level default
Fault duration for conductor sizing	tc	1.00 s	Typical
Shock duration	ts = tf	0.50 s	Typical
Current split factor	Sf	0.6	Typical
X/R for the decrement factor Df (IEEE 80 Eq. 79)	X/R	20	Typical
Grid X/R used by the short-circuit study	X/R	15 (HV bus, calculated: 12.9)	Typical
Frequency	f	50 Hz	Typical
Soil resistivity (entered)	ρ0	100 Ω·m	Typical
Season factor	k	1.5	Typical
Design soil resistivity	ρ	150 Ω·m	ρ0 × season factor
Surface layer (gravel)	ρs, hs	3000 Ω·m, 0.10 m	Typical
Body weight		50 kg (the lighter body: the lower tolerable voltages)	IEEE 80 §8.3
Grid burial depth	h	0.60 m	Typical
Ambient temperature	Ta	50 °C	Typical
Maximum conductor temperature (welded joints)	Tm	500 °C	Design limit, below the weld fusing temperature (IEEE 80 Table 1)
Electrodes	Lr	40 mm × 3 m MS rod	Typical

Calculation trail

1 · Soil resistivity

IEEE 80 §13.4.2 (uniform soil)

$\rho = \rho_0 \times k_{\text{season}}$

ρ0 100 Ω·m (entered), season factor 1.5 → ρ = 150 Ω·m

2 · Surface derating

IEEE 80 §7.4 Eq. 27

$C_s = 1 - \frac{0.09\,(1-\rho/\rho_s)}{2h_s + 0.09}$

ρs 3000 Ω·m, hs 0.10 m → Cs = 0.705

3 · Tolerable touch and step voltages (50 kg)

IEEE 80 §8.3 Eq. 32, Eq. 29

$E_{\text{touch},50} = (1000 + 1.5\,C_s\rho_s)\frac{0.116}{\sqrt{t_s}}, \quad E_{\text{step},50} = (1000 + 6\,C_s\rho_s)\frac{0.116}{\sqrt{t_s}}$

ts 0.50 s → Etouch = 684.6 V, Estep = 2246.3 V

4 · Conductor size

IEEE 80 §11.3.1 Eq. 37

$A = \frac{I}{\sqrt{\frac{\text{TCAP}\cdot 10^{-4}}{t_c \alpha_r \rho_r}\ln\frac{K_0 + T_m}{K_0 + T_a}}}$

Steel 1020, I 50 kA (rating), 20.24 kA calculated, tc 1.00 s, Tm 500 °C, Ta 50 °C (ambient) → A = 608.9 mm² → Ø 40 mm

MS rod (+6 mm corrosion)

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5 · Grid current

IEEE 80 §15.10 Eq. 79, §15.1 Eq. 63–64

$D_f = \sqrt{1 + \frac{\tau}{t_f}(1 - e^{-2t_f/\tau})}, \quad \tau = \frac{X}{\omega R}, \quad I_G = D_f S_f 3I_0$

X/R for Df 20, tf 0.50 s, Sf 0.6, 3I0 50 kA → Df = 1.062, IG = 31.85 kA

6 · Grid resistance (Sverak)

IEEE 80 §14.2 Eq. 52

$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$

A 20 677 m², LT 11 193 m, h 0.60 m → Rg = 0.476 Ω

7 · Ground potential rise

IEEE 80 §16, design procedure, step 6

$\mathrm{GPR} = I_G R_g$

IG 31.85 kA, Rg 0.476 Ω → GPR = 15.15 kV The rise of earth potential is above the tolerable touch voltage, so the mesh **and step check follows.**

8 · Mesh voltage

IEEE 80 §16.5.1 Eq. 80–91

$E_m = \frac{\rho K_m K_i I_G}{L_M}$

n 37.37, Km 0.224, Ki 6.174, LM 11 438 m → Em = 577.6 V ≤ 684.6 V

9 · Step voltage

IEEE 80 §16.5.2 Eq. 92–94

$E_s = \frac{\rho K_s K_i I_G}{L_S}$

Ks 0.415, Ki 6.174, LS 8438 m → Es = 1450.6 V ≤ 2246.3 V

10 · Spacing search

Design rule

$D = \frac{L_x}{n_x - 1}, \quad n_x = \lceil L_x / S \rceil + 1$

start 10 m, step 0.5 m, minimum 3 m → trial S = 4.00 m → 40 × 35 conductors, D = 3.97 m, 144 electrodes

2. Tolerable touch and step voltages

Quantity	Reference	Formula	Result
Surface derating factor	IEEE 80 §7.4 Eq. 27	$C_s = 1 - \frac{0.09\,(1 - \rho/\rho_s)}{2h_s + 0.09}$	0.705
Touch, 50 kg	IEEE 80 §8.3 Eq. 32	$E_{\text{touch, 50}} = (1000 + 1.5\,C_s\rho_s)\frac{0.116}{\sqrt{t_s}}$	684.6 V
Step, 50 kg	IEEE 80 §8.3 Eq. 29	$E_{\text{step, 50}} = (1000 + 6\,C_s\rho_s)\frac{0.116}{\sqrt{t_s}}$	2246.3 V
Touch, 70 kg (for information)	IEEE 80 §8.3 Eq. 33	$E_{\text{touch, 70}} = (1000 + 1.5\,C_s\rho_s)\frac{0.157}{\sqrt{t_s}}$	926.6 V
Step, 70 kg (for information)	IEEE 80 §8.3 Eq. 30	$E_{\text{step, 70}} = (1000 + 6\,C_s\rho_s)\frac{0.157}{\sqrt{t_s}}$	3040.3 V

3. Conductor size

Quantity	Reference	Formula	Result
Material constants	IEEE 80 Table 1	Steel 1020: αr 0.0016 1/°C, K0 605 °C, ρr 15.9 µΩ·cm, TCAP 3.28 J/(cm³·°C)	
Minimum area	IEEE 80 §11.3.1 Eq. 37	$A = \frac{I}{\sqrt{\frac{\mathrm{TCAP}\cdot 10^{-4}}{t_c \alpha_r \rho_r}\ln\frac{K_0 + T_m}{K_0 + T_a}}}$	608.9 mm²
Diameter from area	Geometry	$d = \sqrt{4A/\pi}$	27.84 mm
Corrosion allowance	Design rule	$c = 2\,v_{\text{corr}}\,t_{\text{life}}$	6 mm
Selected MS rod	Design rule	$d_{\text{rod}} \geq d + c$	40 mm

4. Grid current

Quantity	Reference	Formula	Result
Decrement factor	IEEE 80 §15.10 Eq. 79	$D_f = \sqrt{1 + \frac{\tau}{t_f}(1 - e^{-2t_f/\tau})}, \quad \tau = \frac{X}{\omega R}$	1.062
Grid current	IEEE 80 §15.1 Eq. 63–64	$I_G = D_f S_f 3I_0$	31.85 kA

5. Grid geometry and resistance

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Quantity	Reference	Formula	Result
Grid size	Design rule	$L_x = W + 2 \times 1.5, \quad L_y = H + 2 \times 1.5$	155.0 m × 133.4 m
Conductors	Design method	$n_x = \lceil L_x/D \rceil + 1, \quad n_y = \lceil L_y/D \rceil + 1$	40 × 35, D = 3.97 m
Grid conductor length	Geometry	$L_C = n_y L_x + n_x L_y$	10 761 m
Electrodes	Design rule	$L_R = N_{\text{rod}} L_r$	144 nos, LR = 432 m
Grid resistance	IEEE 80 §14.2 Eq. 52	$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$	0.476 Ω
Cross-check, Laurent–Niemann	IEEE 80 Eq. 51, IS 3043	$R_g = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} + \frac{\rho}{L_T}$	0.476 Ω
Ground potential rise	IEEE 80 §16, design procedure, step 6	$\text{GPR} = I_G R_g$	15.15 kV

6. Mesh (touch) and step voltage

Quantity	Reference	Formula	Result
Geometry factor	IEEE 80 §16.5.1 Eq. 84–88	$n = n_a n_b$	37.37
Depth factor	IEEE 80 §16.5.1 Eq. 83	$K_h = \sqrt{1 + h/h_0}$	1.265
Inner-mesh correction	IEEE 80 §16.5.1	$K_{ii} = 1$	1.000
Spacing factor (mesh)	IEEE 80 §16.5.1 Eq. 81	$K_m = \frac{1}{2\pi}\left[\ln\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_{ii}}{K_h}\ln\frac{8}{\pi(2n-1)}\right]$	0.224
Irregularity factor	IEEE 80 §16.5.1 Eq. 89	$K_i = 0.644 + 0.148n$	6.174
Effective length (mesh)	IEEE 80 §16.5.1 Eq. 91	$L_M = L_C + \left[1.55 + 1.22\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right]L_R$	11 438 m
Mesh voltage	IEEE 80 §16.5.1 Eq. 80	$E_m = \frac{\rho K_m K_i I_G}{L_M}$	577.6 V
Spacing factor (step)	IEEE 80 §16.5.2 Eq. 94	$K_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}(1 - 0.5^{n-2})\right]$	0.415
Effective length (step)	IEEE 80 §16.5.2 Eq. 93	$L_S = 0.75 L_C + 0.85 L_R$	8438 m
Step voltage	IEEE 80 §16.5.2 Eq. 92	$E_s = \frac{\rho K_s K_i I_G}{L_S}$	1450.6 V

7. Results

Check	Calculated	Limit	Result
Touch: Em ≤ Etouch (50 kg)	577.6 V	684.6 V	Pass
Step: Es ≤ Estep (50 kg)	1450.6 V	2246.3 V	Pass
Grid resistance Rg	0.476 Ω	1 Ω (CBIP, IEEE 80 §14.1)	Pass

The earth mat's verdict is the touch and step check. The grid resistance row is the CBIP guideline (Manual on Earthing of AC Power Systems, Publication 311, §6.1; IEEE 80 §14.1) and does not change the verdict. Above 1 Ω, lower it with more electrodes or a larger mat at detail design.

8. Quantities

Item	Quantity	Unit
MS rod 40 mm dia, earth mat at 0.6 m	10 761	m
MS rod electrode 40 mm × 3 m	144	nos
GS flat 75 × 12 mm risers (≈2 × 3 m per structure)	546	m
Gravel 20 677 m² × 0.10 m	2068	m³

9. Notes

The earth mat's geometry factor n is 37 (IEEE 80-2013 Eq. 84), for 40 × 35 conductors. Earlier editions of IEEE 80 stated the mesh and step voltage equations for n up to 25. The 2013 edition (§16.7) reports them checked for up

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to 40 meshes per side. This mat has 39 × 34 meshes of 3.97 m. No change is needed.

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