Grounding design 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 80-2013, uniform soil, rectangular grid with electrodes.

1. Inputs

Parameter	Symbol	Value	Source
Design fault current (230 kV, 3I0)	3I0	50 kA (rating), 20.41 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: 12.8)	Typical
Frequency	f	60 Hz	Your input
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 (0.33 ft)	Typical
Body weight		70 kg (the verdict), 50 kg for information	IEEE 80 §8.3, RUS 1724E-300 §9.7.1
Grid burial depth	h	0.46 m (1.50 ft)	RUS 1724E-300 §9.10.3
Ambient temperature	Ta	50 °C (122 °F)	Typical
Maximum conductor temperature (exothermic connections)	Tm	1083 °C (1980 °F)	Fusing temperature of annealed copper (RUS 1724E-300 Table 9-2, from IEEE 80; §9.6.6)
Electrodes	Lr	19.05 mm (0.75 in) × 3.048 m (10 ft) copper-clad steel rod	Design value

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 (0.33 ft) → Cs = 0.705

3 · Tolerable touch and step voltages (70 kg)

IEEE 80 §8.3 Eq. 33, Eq. 30

$$E_{\text{touch},\,70} = (1000 + 1.5\,C_s\rho_s)\frac{0.157}{\sqrt{t_s}}, \quad E_{\text{step},\,70} = (1000 + 6\,C_s\rho_s)\frac{0.157}{\sqrt{t_s}}$$

ts 0.50 s → Etouch = 926.6 V, Estep = 3040.3 V

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4 · Conductor size

IEEE 80 §11.3.1 Eq. 37

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

Copper, annealed soft-drawn, I 50 kA (rating), 20.41 kA calculated, tc 1.00 s, Tm 1083 °C (1980 °F), Ta 50 °C (122 °F) **(ambient) → A = 179.5 mm² → 400 kcmil bare copper (202.7 mm²)**

5 · Grid current

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

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

X/R for Df 20, tf 0.50 s, Sf 0.6, 3I0 50 kA → Df = 1.052, IG = 31.55 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 29 263 m² (314 984 ft²), LT 14 667 m (48 120 ft), h 0.46 m (1.50 ft) → Rg = 0.400 Ω

7 · Ground potential rise

IEEE 80 §16, design procedure, step 6

$$\mathrm{GPR} = I_G R_g$$

IG 31.55 kA, Rg 0.400 Ω → GPR = 12.62 kV The rise of ground 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 41.49, Km 0.382, Ki 6.785, LM 14 932 m (48 990 ft) → Em = 820.5 V ≤ 926.6 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 0.491, Ki 6.785, LS 11 047 m (36 244 ft) → Es = 1426.6 V ≤ 3040.3 V

10 · Spacing search

Design rule

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

start 12.192 m (40 ft), step 0.6096 m (2 ft), minimum 3.048 m (10 ft) → trial S = 4.27 m (14.00 ft) → 41 × 42 **conductors, D = 4.25 m (13.93 ft), 154 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, 70 kg	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	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
Touch, 50 kg (for information)	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 (for information)	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

3. Conductor size

Quantity	Reference	Formula	Result
Material constants	RUS 1724E-300 Table 9-2 (from IEEE 80)	Copper, annealed soft-drawn: αr 0.00393 1/°C, K0 234 °C, ρr 1.72 μΩ·cm, TCAP 3.42 J/(cm³·°C)	
Minimum area	IEEE 80 §11.3.1 Eq. 37	$A = \frac{I}{\sqrt{\frac{TCAP \cdot 10^{-4}}{t_c \alpha_r \rho_r} \ln \frac{K_0 + T_m}{K_0 + T_a}}}$	179.5 mm²
Selected conductor	Design rule	next standard size ≥ A, from 4/0 AWG (RUS 1724E-300 §9.10.2: 2/0 AWG to 500 kcmil)	400 kcmil (202.7 mm²)
Equivalent diameter of the selected size	Geometry	$d = \sqrt{4A/\pi}$	16.06 mm (0.632 in)

4. Grid current

Quantity	Reference	Formula	Result

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Quantity	Reference	Formula	Result
Decrement factor	IEEE 80 §15.10 Eq. 79	$D_f = \sqrt{1 + \frac{\tau}{t_f}(1 - e^{-2t_f/\tau})}, \quad \tau = \frac{X}{\omega R}$	1.052
Grid current	IEEE 80 §15.1 Eq. 63–64	$I_G = D_f S_f 3I_0$	31.55 kA

5. Grid geometry and resistance

Quantity	Reference	Formula	Result
Grid size	Design rule	$L_x = W + 2 \times 1.5, \quad L_y = H + 2 \times 1.5$	168.1 m (551.6 ft) × 174.1 m (571.1 ft)
Conductors	Design method	$n_x = \lceil L_x/D \rceil + 1, \quad n_y = \lceil L_y/D \rceil + 1$	41 × 42, D = 4.25 m (13.93 ft)
Grid conductor length	Geometry	$L_C = n_y L_x + n_x L_y$	14 198 m (46 580 ft)
Electrodes	Design rule	$L_R = N_{\text{rod}} L_r$	154 ea, LR = 469 m (1540 ft)
Grid resistance	IEEE 80 §14.2 Eq. 52	$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$	0.400 Ω
Ground potential rise	IEEE 80 §16, design procedure, step 6	$\text{GPR} = I_G R_g$	12.62 kV

6. Mesh (touch) and step voltage

Quantity	Reference	Formula	Result
Geometry factor	IEEE 80 §16.5.1 Eq. 84–88	$n = n_a n_b$	41.49
Depth factor	IEEE 80 §16.5.1 Eq. 83	$K_h = \sqrt{1 + h/h_0}$	1.207
Inner-mesh correction	IEEE 80 §16.5.1	$K_{ii} = 1$	1.000
Spacing factor (mesh)	IEEE 80 §16.5.1 Eq. 81	$K_m = \frac{1}{2\pi}\left[\ln\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_{ii}}{K_h}\ln\frac{8}{\pi(2n-1)}\right]$	0.382
Irregularity factor	IEEE 80 §16.5.1 Eq. 89	$K_i = 0.644 + 0.148n$	6.785
Effective length (mesh)	IEEE 80 §16.5.1 Eq. 91	$L_M = L_C + \left[1.55 + 1.22\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right]L_R$	14 932 m (48 990 ft)
Mesh voltage	IEEE 80 §16.5.1 Eq. 80	$E_m = \frac{\rho K_m K_i I_G}{L_M}$	820.5 V
Spacing factor (step)	IEEE 80 §16.5.2 Eq. 94	$K_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}(1 - 0.5^{n-2})\right]$	0.491
Effective length (step)	IEEE 80 §16.5.2 Eq. 93	$L_S = 0.75L_C + 0.85L_R$	11 047 m (36 244 ft)
Step voltage	IEEE 80 §16.5.2 Eq. 92	$E_s = \frac{\rho K_s K_i I_G}{L_S}$	1426.6 V

7. Results

Check	Calculated	Limit	Result
Touch: Em ≤ Etouch (70 kg)	820.5 V	926.6 V	Pass
Step: Es ≤ Estep (70 kg)	1426.6 V	3040.3 V	Pass

The ground grid's verdict is the touch and step check (70 kg). The grid resistance is 0.400 Ω.

8. Quantities

Item	Quantity	Unit
Bare copper 400 kcmil, ground grid at 1.5 ft	46 580	ft
Copper-clad steel ground rod 0.75 in × 10 ft	154	ea
Bare copper 400 kcmil risers (≈2 × 10 ft per structure)	1940	ft
Gravel 314 984 ft² × 0.33 ft	3827	yd³

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