Substation Grounding Design — Calculation Sheet

Ground grid safety assessment per IEEE Std 80-2000, simplified method (uniform soil)

Project	Sample Substation (IEEE 80 example)		
Location	—	**Document no.**	SAMPLE-GND-001
Prepared by	—	**Checked by**	—
Date	November 7, 2026	**Standard**	IEEE Std 80-2000 (simplified method)

1 Design summary

A safe design has been obtained and final details can now be added to the design.

Check	Status	Remark
Conductor size ≥ minimum	**PASS**	Adequate
GPR ≤ E_touch	**NEXT**	GPR is above the touch limit — the mesh and step voltages below decide
E_m ≤ E_touch	**PASS**	Pass
E_s ≤ E_step	**PASS**	Pass

Result	Symbol	Value	Unit	Limit / reference
Grid resistance	R_g	2.7698	Ω	
Maximum grid current	I_G	1,908.00	A	
Ground potential rise	GPR	5,284.70	V	$E_{touch} = 838.17$ V
Mesh (touch) voltage	E_m	837.81	V	$E_{touch70} = 838.17$ V
Step voltage	E_s	593.99	V	$E_{step70} = 2{,}686.58$ V
Minimum conductor size	A_{min}	7.98	mm²	Selected 78.5 mm²
Grid conductor length	L_C	1,540.0	m	78.5 mm² bare copper
Ground rods, total	n	12	pcs	12 corner/perimeter + 0 transformer + 0 arrester, 3.0 m each

Optimization check — conductor spacing and rods

Required margin 0%

OPTIMAL — Your layout is within 0.0% of the least-material layout that meets the limits — it is optimal.

Layout	Nx × Ny	Spacing D_x / D_y, m	Corner + perimeter rods	Conductor length, m	Total buried length, m	E_m, V (% limit)	E_s, V (% limit)
Your layout meets limits	11 × 11	7.00 / 7.00	12	1,540.0	1,576.0	838 99.9%	594 22.1%

Layout	Nx × Ny	Spacing D_x / D_y, m	Corner + perimeter rods	Conductor length, m	Total buried length, m	E_m, V (% limit)	E_s, V (% limit)
Least material that meets limits Corners + every 4th perimeter junction	11 × 11	7.00 / 7.00	12	1,540.0	1,576.0	838 99.9%	594 22.1%
Least material — no perimeter rods No corner / perimeter rods	14 × 14	5.38 / 5.38	none	1,960.0	1,960.0	825 98.3%	608 22.6%
Least material — corner rods only Corner rods only	12 × 12	6.36 / 6.36	4	1,680.0	1,692.0	796 94.9%	603 22.4%

- What changes: the number of parallel conductors in each direction (spacing) and the rods at the corners and along the perimeter. Everything else — grid area, depth, conductor size, rod length, soil and fault data — stays as entered.
- Material = total buried length = grid conductor length + total rod length (number of rods × rod length). Less is better; if two layouts tie, the one with fewer rods wins.
- No transformer-neutral or surge-arrester rods entered.
- Each layout uses evenly spaced conductors; where x and y spacings differ, the larger is used in Km and Ks. IEEE 80 validity limits are applied (spacing > 2.5 m, n ≤ 25), and perimeter rods are never closer together than their length.

2 Design input data

Symbol	Description	Value	Unit
ρ	Soil resistivity (uniform)	400	Ω·m
ρ_s	Surface layer resistivity (wet)	2500	Ω·m
h_s	Surface layer thickness	0.102	m
$3I_0$	Symmetrical ground fault current	3180	A
S_f	Current division (split) factor	0.6	—
t_s	Shock duration	0.5	s
t_c	Fault duration for conductor sizing	0.5	s
D_f	Decrement factor (entered)	1	—
L_x	Grid length	70	m
L_y	Grid width	70	m
N_x	Conductors parallel to x (incl. perimeter)	11	pcs
N_y	Conductors parallel to y (incl. perimeter)	11	pcs
h	Burial depth	0.5	m
A_c	Conductor cross-section (bare copper)	78.54	mm²
K_f	Conductor material constant	7	—
n_R	Ground rods at grid corners and along the perimeter	12	pcs
n_{TX}	Ground rods at power transformer neutrals (inside grid)	0	pcs

Symbol	Description	Value	Unit
n_{LA}	Ground rods at surge arresters (inside grid)	0	pcs
L_r	Length of each rod	3	m
—	Body weight criterion	70	kg

3 Detailed calculation

Each quantity is shown as: description → general formula → substituted values → result. Clause references are to IEEE Std 80-2000; the equations are unchanged in IEEE Std 80-2013.

Step 1 Field data and grid geometry

IEEE 80 Cl. 16.4, 16.5

The grid is modelled as a rectangle of length Lx and width Ly, with Nx conductors running parallel to the x-axis (each Lx long) and Ny conductors running parallel to the y-axis (each Ly long), perimeter conductors included. Soil is treated as uniform with resistivity ρ = 400.000 Ω·m.

1.1 Grid area — Area enclosed by the perimeter conductor.

$$A = L_x \, L_y$$
$$A = 70.00 \times 70.00$$
$$\boxed{A = 4{,}900.00 \ \mathrm{m}^2}$$

1.2 Peripheral length — Length of the outer conductor loop.

$$L_P = 2 \, (L_x + L_y)$$
$$L_P = 2 \, (70.00 + 70.00)$$
$$\boxed{L_P = 280.00 \ \mathrm{m}}$$

1.3 Total horizontal conductor length — Sum of all buried grid conductors in both directions.

$$L_C = L_x N_x + L_y N_y$$
$$L_C = 70.00 \times 11 + 70.00 \times 11$$
$$\boxed{L_C = 1{,}540.00 \ \mathrm{m}}$$

1.4 Total ground rod length — All rods count: corner/perimeter rods n_R, transformer-neutral rods n_TX and surge-arrester rods n_LA, each L_r long. Their exact position inside the grid does not enter the simplified equations.

$$L_R = (n_R + n_{TX} + n_{LA}) \, L_r$$
$$L_R = (12 + 0 + 0) \times 3.00$$
$$\boxed{L_R = 36.00 \ \mathrm{m}}$$

1.5 Total buried length — Used in the grid resistance equation.

$$L_T = L_C + L_R$$
$$L_T = 1{,}540.00 + 36.00$$
$$\boxed{L_T = 1{,}576.00 \ \mathrm{m}}$$

1.6 Maximum distance between grid points — The grid diagonal, used in the effective length L_M when rods are on the perimeter.

$$D_m = \sqrt{L_x^2 + L_y^2}$$
$$D_m = \sqrt{70.00^2 + 70.00^2}$$
$$\boxed{D_m = 98.995 \ \mathrm{m}}$$

1.7 Conductor diameter — Solid-equivalent diameter of a 78.5 mm² conductor (cross-section converted to metres).

$$d = \frac{1}{1000}\sqrt{\frac{4A_c}{\pi}}$$

$$d = \frac{1}{1000}\sqrt{\frac{4 \times 78.54}{\pi}}$$

$$\boxed{d = 0.01000\ \text{m}}$$

1.8 Conductor spacing in x — Spacing between the conductors that run parallel to y (they are spread along Lx).

$$D_x = \frac{L_x}{N_y - 1}$$

$$D_x = \frac{70.00}{10}$$

$$\boxed{D_x = 7.000\ \text{m}}$$

1.9 Conductor spacing in y — Spacing between the conductors that run parallel to x (they are spread along Ly).

$$D_y = \frac{L_y}{N_x - 1}$$

$$D_y = \frac{70.00}{10}$$

$$\boxed{D_y = 7.000\ \text{m}}$$

1.10 Design spacing — The simplified method assumes square meshes. The larger spacing is used, which gives the higher (conservative) mesh voltage.

$$D = \max(D_x,\ D_y)$$

$$D = \max(7.000,\ 7.000)$$

$$\boxed{D = 7.000\ \text{m}}$$

Step 2 Conductor size

IEEE 80 Cl. 11.3, Table 2

The grid conductor must carry the full fault current for the duration tc without exceeding its allowable temperature. With the material constant Kf (ambient 40 °C), the simplified sizing formula gives the minimum area in kcmil, converted to mm² by 1 kcmil = 0.5067 mm². The full fault current $3I_0$ is used (no split factor) for conservatism.

2.1 Minimum area (kcmil) — I in kA, tc in seconds.

$$A_{kcmil} = I\,K_f\sqrt{t_c}$$

$$A_{kcmil} = 3.180 \times 7.00 \times \sqrt{0.50}$$

$$\boxed{A_{kcmil} = 15.74\ \text{kcmil}}$$

2.2 Minimum area (mm²)

$$A_{min} = 0.5067\,A_{kcmil}$$

$$A_{min} = 0.5067 \times 15.74$$

$$\boxed{A_{min} = 7.98\ \text{mm}^2}$$

$$A_c = 78.5\ \text{mm}^2 \ \geq\ A_{min} = 7.98\ \text{mm}^2$$

The selected conductor is thermally adequate.

Step 3 Tolerable touch and step voltages

IEEE 80 Cl. 7.4, 8.3

The tolerable voltages follow from the body-current limit (Dalziel) for a 70 kg person exposed for ts = 0.50 s. The high-resistivity surface layer adds resistance under the feet; its effect is captured by the derating factor Cs, which depends on the reflection factor between the surface layer and the soil.

3.1 Reflection factor — A negative K means the surface layer is more resistive than the soil (beneficial).

$$K = \frac{\rho - \rho_s}{\rho + \rho_s}$$

$$K = \frac{400.000 - 2{,}500.0}{400.000 + 2{,}500.0}$$

$$\boxed{K = -0.7241}$$

3.2 Surface layer derating factor — Empirical expression for Cs; the value is rounded to two decimals before use.

$$C_s = 1 - \frac{0.09\left(1 - \dfrac{\rho}{\rho_s}\right)}{2h_s + 0.09}$$

$$C_s = 1 - \frac{0.09\left(1 - \dfrac{400.000}{2{,}500.0}\right)}{2 \times 0.102 + 0.09} = 0.7429$$

$$\boxed{C_s = 0.74}$$

3.3 Tolerable step voltage, 50 kg — Current flows foot-to-foot; the two feet act in series (6 Cs ρs).

$$E_{step50} = (1000 + 6\,C_s\,\rho_s)\,\frac{0.116}{\sqrt{t_s}}$$

$$E_{step50} = (1000 + 6 \times 0.74 \times 2{,}500.0)\,\frac{0.116}{\sqrt{0.500}}$$

$$\boxed{E_{step50} = 1{,}984.99\ \text{V}}$$

3.4 Tolerable step voltage, 70 kg

$$E_{step70} = (1000 + 6\,C_s\,\rho_s)\,\frac{0.157}{\sqrt{t_s}}$$

$$E_{step70} = (1000 + 6 \times 0.74 \times 2{,}500.0)\,\frac{0.157}{\sqrt{0.500}}$$

$$\boxed{E_{step70} = 2{,}686.58\ \text{V}}$$

3.5 Tolerable touch voltage, 50 kg — Current flows hand-to-feet; the two feet act in parallel (1.5 Cs ρs).

$$E_{touch50} = (1000 + 1.5\,C_s\,\rho_s)\,\frac{0.116}{\sqrt{t_s}}$$

$$E_{touch50} = (1000 + 1.5 \times 0.74 \times 2{,}500.0)\,\frac{0.116}{\sqrt{0.500}}$$

$$\boxed{E_{touch50} = 619.28\ \text{V}}$$

3.6 Tolerable touch voltage, 70 kg

$$E_{touch70} = (1000 + 1.5\,C_s\,\rho_s)\,\frac{0.157}{\sqrt{t_s}}$$

$$E_{touch70} = (1000 + 1.5 \times 0.74 \times 2{,}500.0)\,\frac{0.157}{\sqrt{0.500}}$$

$$\boxed{E_{touch70} = 838.17\ \text{V}}$$

$E_{touch} = 838.17\ \text{V}, \qquad E_{step} = 2{,}686.58\ \text{V}$

Design criterion: 70 kg body weight. These limits are used in Steps 7, 9 and 10.

Step 4 Initial design and validity of the simplified method

IEEE 80 Cl. 16.5

Trial layout: a 70.00 m × 70.00 m grid of 78.5 mm² bare copper buried at h = 0.50 m, with 11 × 11 parallel conductors (design spacing D = 7.00 m from Step 1), and 12 ground rods, each 3.00 m long, at the grid corners and along the perimeter. The simplified mesh and step equations are only valid within the limits below.

Parameter	Limit	Design value	Status
Geometric factor n	n ≤ 25	`11.00`	OK
Burial depth h	0.25 m ≤ h ≤ 2.5 m	`0.50 m`	OK
Conductor diameter d	d < 0.25 h = 0.1250 m	`0.01000 m`	OK
Conductor spacing D	D > 2.5 m	`7.00 m`	OK
Shock duration ts	0.03 s ≤ ts ≤ 3 s	`0.500 s`	OK

Step 5 Grid resistance

IEEE 80 Cl. 14.2 (Sverak)

Sverak's equation estimates the resistance of a horizontal grid in uniform soil, including the effect of burial depth h. The first term reflects total buried length; the second term reflects grid area.

5.1 Grid resistance

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

$$R_g = 400.000 \left[\frac{1}{1{,}576.00} + \frac{1}{\sqrt{20 \times 4{,}900.00}} \left(1 + \frac{1}{1 + 0.50\sqrt{20/4{,}900.00}} \right) \right]$$

$$\boxed{R_g = 2.7698\ \Omega}$$

Step 6 Maximum grid current

IEEE 80 Cl. 15, 15.10

The design current is the part of the ground fault current that flows between the grid and remote earth, increased by the decrement factor to cover DC offset.

6.1 Decrement factor — Entered directly by the designer (IEEE 80 Table 10).

$$\boxed{D_f = 1.0000}$$

6.2 Symmetrical grid current — Only the portion Sf of the fault current flows from the grid to remote earth; the rest returns through shield wires and neutrals.

$$I_g = S_f \cdot 3I_0$$

$$I_g = 0.600 \times 3{,}180.0$$

$$\boxed{I_g = 1{,}908.00\ \text{A}}$$

6.3 Maximum grid current

$$I_G = D_f \cdot I_g$$
$$I_G = 1.0000 \times 1{,}908.00$$
$$\boxed{I_G = 1{,}908.00\ \text{A}}$$

Step 7 Ground potential rise

IEEE 80 Cl. 16.4

GPR is the maximum voltage the grid reaches relative to remote earth. If it is below the tolerable touch voltage, no further analysis is needed — no touch or step voltage can exceed it.

7.1 Ground potential rise

$$GPR = I_G\, R_g$$
$$GPR = 1{,}908.00 \times 2.7698$$
$$\boxed{GPR = 5{,}284.70\ \text{V}}$$

$$GPR = 5{,}284.70\ \text{V} \ > \ E_{touch70} = 838.17\ \text{V}$$

GPR exceeds the tolerable touch voltage — mesh and step voltages must be checked (Step 8).

Step 8 Mesh voltage

IEEE 80 Cl. 16.5.1

The mesh voltage is the worst-case touch voltage inside the grid. It depends on the spacing factor Km (geometry of D, h, d and n), the irregularity factor Ki, and the effective buried length L_M.

8.1 Depth correction factor — Reference depth h_0 = 1 m.

$$K_h = \sqrt{1 + \frac{h}{h_0}}$$
$$K_h = \sqrt{1 + \frac{0.50}{1}}$$
$$\boxed{K_h = 1.2247}$$

8.2 Inner-conductor corrective factor — Rods at the corners and along the perimeter: the corner-mesh effect is removed.

$$K_{ii} = 1$$
$$\boxed{K_{ii} = 1}$$

8.3 Geometric factor — component n_a

$$n_a = \frac{2L_C}{L_P}$$
$$n_a = \frac{2 \times 1{,}540.00}{280.00}$$
$$\boxed{n_a = 11.0000}$$

8.4 Geometric factor — component n_b — For a square grid n_b = 1; for a rectangle it is slightly above 1. n_c = n_d = 1 for square and rectangular grids.

$$n_b = \sqrt{\frac{L_P}{4\sqrt{A}}}$$

$$n_b = \sqrt{\frac{280.00}{4\sqrt{4{,}900.00}}}$$

$$\boxed{n_b = 1.0000}$$

8.5 Effective number of parallel conductors

$$n = n_a\, n_b\, n_c\, n_d$$

$$n = 11.0000 \times 1.0000 \times 1 \times 1$$

$$\boxed{n = 11.0000}$$

8.6 Spacing factor for mesh voltage — Evaluated in two parts: the logarithmic spacing term and the inner-conductor term.

$$K_m = \frac{1}{2\pi}\left[\ln\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_{ii}}{K_h}\ln\frac{8}{\pi(2n-1)}\right]$$

$$\ln\left(\frac{7.000^2}{16 \times 0.50 \times 0.01000} + \frac{(7.000 + 2 \times 0.50)^2}{8 \times 7.000 \times 0.01000} - \frac{0.50}{4 \times 0.01000}\right) = \ln(714.285) = 6.5713$$

$$\frac{1.0000}{1.2247}\ln\frac{8}{\pi(2 \times 11.0000 - 1)} = -1.7227$$

$$K_m = \frac{1}{2\pi}\left[6.5713 - 1.7227\right]$$

$$\boxed{K_m = 0.7717}$$

8.7 Irregularity factor — Corrects for the non-uniform current density across the grid.

$$K_i = 0.644 + 0.148\, n$$

$$K_i = 0.644 + 0.148 \times 11.0000$$

$$\boxed{K_i = 2.2720}$$

8.8 Effective buried length for mesh voltage — With rods at the corners and along the perimeter, IEEE 80 weights the total rod length L_R (all rods, including those inside the grid), because rods reach deeper soil and relieve the corner mesh.

$$L_M = L_C + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] L_R$$

$$L_M = 1{,}540.00 + \left[1.55 + 1.22\left(\frac{3.00}{98.995}\right)\right] \times 36.00$$

$$\boxed{L_M = 1{,}597.13\ \text{m}}$$

8.9 Mesh voltage — The highest touch voltage within a mesh of the grid — normally in a corner mesh.

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

$$E_m = \frac{400.000 \times 0.7717 \times 2.2720 \times 1{,}908.00}{1{,}597.13}$$

$$\boxed{E_m = 837.81\ \text{V}}$$

Step 9 Mesh voltage vs. tolerable touch voltage

IEEE 80 Cl. 16.4

The calculated mesh voltage must not exceed the tolerable touch voltage from Step 3.

$$E_m = 837.81\ \text{V} \ \le\ E_{touch70} = 838.17\ \text{V}$$

Touch criterion satisfied (margin 0.0%).

Step 10 Step voltage

IEEE 80 Cl. 16.5.2

The step voltage is the potential difference across a 1 m step, highest just outside the perimeter conductor. It must not exceed the tolerable step voltage.

10.1 Spacing factor for step voltage

$$K_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{\,n-2}\right)\right]$$

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \times 0.50} + \frac{1}{7.000 + 0.50} + \frac{1}{7.000}\left(1 - 0.5^{\,11.0000-2}\right)\right]$$

$$\boxed{K_s = 0.4061}$$

10.2 Effective buried length for step voltage

$$L_S = 0.75\,L_C + 0.85\,L_R$$

$$L_S = 0.75 \times 1{,}540.00 + 0.85 \times 36.00$$

$$\boxed{L_S = 1{,}185.60\ \text{m}}$$

10.3 Step voltage

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

$$E_s = \frac{400.000 \times 0.4061 \times 2.2720 \times 1{,}908.00}{1{,}185.60}$$

$$\boxed{E_s = 593.99\ \text{V}}$$

$$E_s = 593.99\ \text{V} \ \le\ E_{step70} = 2{,}686.58\ \text{V}$$

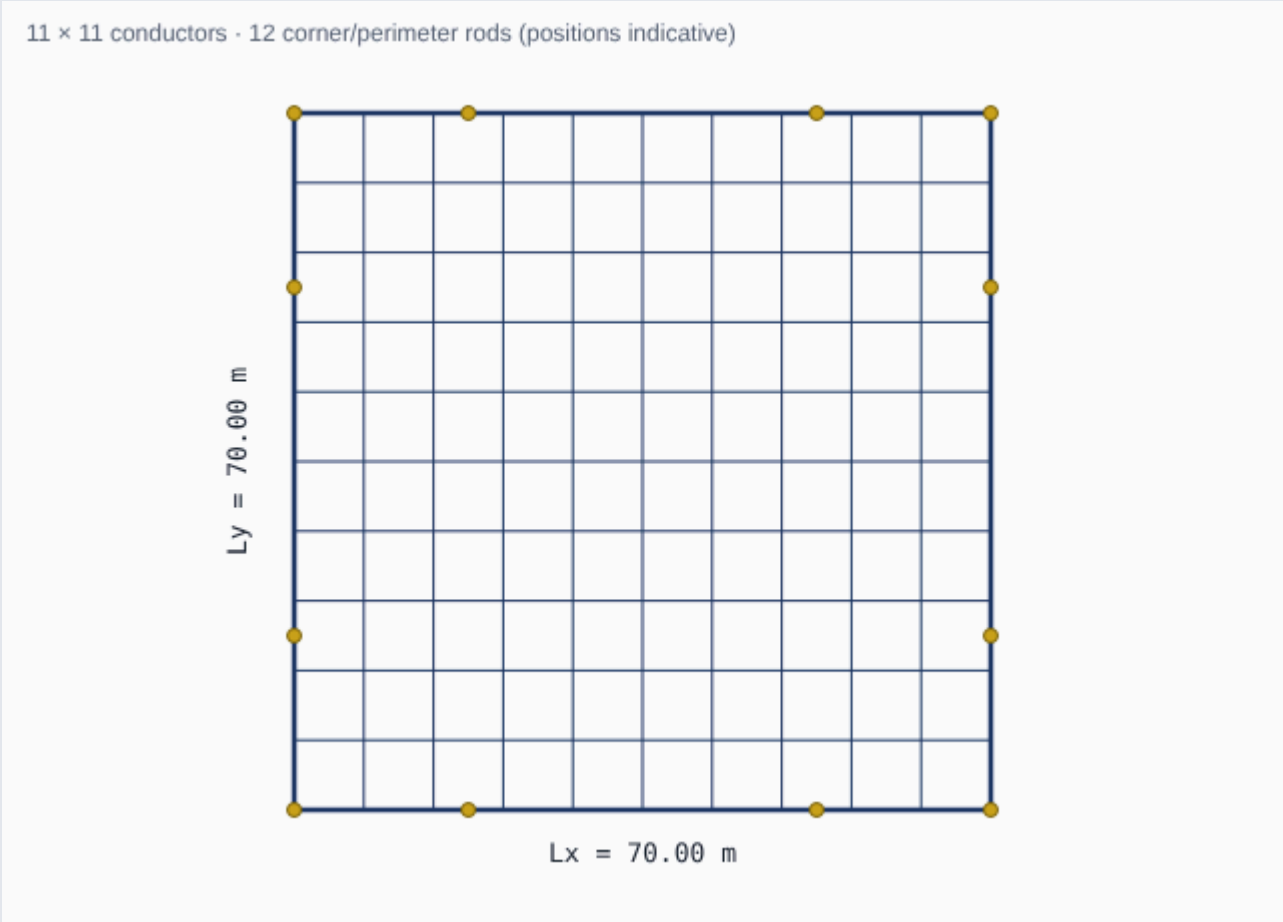
Step criterion satisfied (margin 77.9%).

Step 11–12 Conclusion and detailed design

IEEE 80 Cl. 16.4

Both the touch (mesh) and step criteria are met, so no modification of the layout is required. Proceed to the detailed design: connect equipment frames and structures to the grid with suitable pigtails, add rods at surge arresters and transformer neutrals, bond the fence, and review transferred-potential hazards (communication circuits, pipes, rails, and low-voltage neutrals leaving the site).

4 Grid plan (schematic)



Rod positions are indicative only.

5 Notes and assumptions

- Cs is rounded to 2 decimals before computing the tolerable voltages, as in the reference workbook.
- Conductor diameter d is the solid-equivalent diameter from the cross-section area (√(4A/π)), as in the reference workbook; actual stranded conductors are slightly larger.
- Conductor spacing is taken from the layout: Dx = 7.000 m, Dy = 7.000 m. The larger value (D = 7.000 m) is used in Km and Ks — conservative for mesh voltage, which normally governs. (The reference workbook used an entered D = 4.0 m.)
- Square and rectangular grids only (A = Lx × Ly, nc = nd = 1). L-shaped and irregular grids are outside this calculator's scope.
- Uniform soil model assumed (simplified method, IEEE Std 80-2000 Cl. 16.5; same equations in the 2013 edition).
- Df is entered directly (reference workbook uses Df = 1.0). Switch to "Compute from X/R" to calculate it per IEEE 80 Cl. 15.10.
- Conductor size check (Step 2) and the Df equation option are additions to the reference workbook, which takes the conductor area and Df as given.

6 References

1. IEEE Std 80-2000, *IEEE Guide for Safety in AC Substation Grounding*.

2. IEEE Std 80-2013, *IEEE Guide for Safety in AC Substation Grounding* (same simplified-method equations).

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