Short-circuit calculation

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

Document no.	Prepared	Checked	Approved
SSL-C-SCC-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: IEC 60909-0:2016, equivalent voltage source at the fault location. Equation numbers refer to IEC 60909-0:2016.

1. Inputs

Parameter	Value	Source
Grid 3-phase fault level at the remote 220 kV bus	40 kA	Level default
Grid 1-phase fault level at the remote 220 kV bus	40 kA	Level default
Grid X/R	15	Typical
220 kV line	1 × 10 km Twin ACSR Moose	Typical
Line constants R1, X1, R0, X0 (Ω/km)	0.028, 0.31, 0.2, 1	Typical
ICTs	2 × 160 MVA YNyn0 + d, uk 12.5 %, X/R 40, Z0 = 0.9 × Z1	From the SLD
33 kV neutral earthing	NGR 1000 A per LV winding (19.05 Ω)	Typical
Plant infeed (full-size converters)	k = 1.2 × Ir, plant 263 MVA	Typical
Voltage factor	cmax 1.1, cmin 1.0	IEC 60909-0 Table 1

2. Sequence impedances

Element	Reference	Formula	Value
Grid feeder Z1	IEC 60909-0 §6.2 Eq. 4	$Z_Q = \frac{c U_n}{\sqrt{3}\, I''_{kQ}}, \quad R_Q = \frac{X_Q}{X/R}$	0.232 + j3.485 Ω
Grid feeder Z0	IEC 60909-0 §7.5 Eq. 52	$\lvert Z_0\rvert = \frac{\sqrt{3}\, c U_n}{I''_{k1}} - 2\lvert Z_1\rvert$	0.232 + j3.485 Ω
Line Z1	IEC 60909-0 §6.4	$Z_{L1} = (R_1 + jX_1)\frac{l}{n}$	0.280 + j3.100 Ω
Line Z0	IEC 60909-0 §6.4	$Z_{L0} = (R_0 + jX_0)\frac{l}{n}$	2.000 + j10.000 Ω
ICT ZT (at 220 kV, full rating)	IEC 60909-0 §6.3.1 Eq. 7	$Z_T = \frac{u_{kr}}{100}\frac{U_{rT}^2}{S_{rT}}$	0.945 + j37.801 Ω
Correction KT	IEC 60909-0 §6.3.3 Eq. 12a	$K_T = \frac{0.95\, c_{max}}{1 + 0.6\, x_T}$	0.9721
ICT Z1 = KT·ZT	IEC 60909-0 §6.3.3	$Z_{T1} = K_T Z_T$	0.919 + j36.747 Ω
ICT Z0 (HV side, delta tertiary closed)	IEC 60909-0 §6.3.3	$Z_{T0} = k_0 K_T Z_T$	0.827 + j33.072 Ω
NGR	Ohm's law	$R_{NGR} = \frac{U_n/\sqrt{3}}{I_{NGR}}$	19.053 Ω

220 kV bus, with the ICT zero sequence in parallel:

$$Z_1 = Z_{Q1} + Z_{L1}, \quad Z_0 = (Z_{Q0} + Z_{L0}) \parallel \frac{Z_{T0}}{n}$$

33 kV section, bus-section CBs normally open, one ICT per section, referred by t = 33/220. Z2 = Z1: the negative-sequence impedance equals the positive-sequence one, as for a network far from a generator.

$$Z_{1,\mathrm{MV}} = (Z_{Q1} + Z_{L1})t^2 + Z_{T1}t^2, \quad Z_{0,\mathrm{MV}} = 3R_{\mathrm{NGR}} + Z_{T0}t^2, \quad t = U_{n,\mathrm{MV}}/U_{n,\mathrm{HV}}$$

Calculation trail

Sample document for a sample project, generated by SubstationLayout. Not for construction. © SolarLayout.

1 · Network feeder impedance

IEC 60909-0:2016 §6.2 Eq. 4–5

$Z_Q = \frac{c\,U_n}{\sqrt{3}\,I''_{kQ}}, \quad R_Q = \frac{X_Q}{X/R}$

I″kQ 40 kA, grid X/R 15, cmax 1.1 → ZQ1 = 0.232 + j3.485 Ω

2 · Line impedance

IEC 60909-0:2016 §6.4

$Z_{L1} = (R_1 + jX_1)\frac{l}{n}$

1 × 10 km Twin ACSR Moose → ZL1 = 0.280 + j3.100 Ω

3 · Transformer impedance with correction

IEC 60909-0:2016 §6.3.1 Eq. 7, §6.3.3 Eq. 12a

$Z_T = \frac{u_{kr}}{100}\frac{U_{rT}^2}{S_{rT}}, \quad K_T = \frac{0.95\,c_{\max}}{1 + 0.6\,x_T}$

2 × 160 MVA, uk 12.5 %, X/R 40 → KT = 0.9721, ZT1 = 0.919 + j36.747 Ω

4 · Plant infeed

IEC 60909-0:2016 §6.9

$I_{\text{plant}} = k\,I_r$

k 1.2, plant 263 MVA → 829 A at 220 kV

5 · Initial symmetrical current

IEC 60909-0:2016 §7.2 Eq. 29

$I''_{k3} = \frac{c\,U_n}{\sqrt{3}\,|Z_1|} + I_{\text{plant}}$

220 kV Z1 0.512 + j6.585 Ω, 33 kV Z1 0.032 + j0.975 Ω → 220 kV 21.98 kA, 33 kV 24.25 kA (per section)

6 · Peak current

IEC 60909-0:2016 §8.1.1 Eq. 54, §8.1.2 (κ, method B)

$i_p = \kappa\sqrt{2}\,I''_k, \quad \kappa = 1.15\,(1.02 + 0.98\,e^{-3R/X}) \le 2.0$

κ 2.000 (220 kV), 2.000 (33 kV) → 220 kV 62.17 kA, 33 kV 68.58 kA

7 · Thermal equivalent current

IEC 60909-0:2016 §10 Eq. 100

$I_{\text{th}} = I''_k\sqrt{m+n}, \; n = 1$

tk 1.00 s (220 kV), 3.00 s (33 kV), m 0.044 (220 kV), 0.034 (33 kV) → 220 kV 22.46 kA, 33 kV 24.66 kA

8 · Equipment rating checks

IEC 62271-100:2008 §4.101, §4.103

$I_b \le I_{\text{rated}}, \quad i_p \le k_{\text{make}}\,I_{\text{rated}}, \quad I_{\text{th}} \le I_{\text{rated}}$

220 kV 50 kA, 33 kV 31.5 kA, kmake 2.5 at 50 Hz → 7 of 7 checks pass

3. Maximum short-circuit currents (c = 1.10, with plant infeed)

Quantity	Reference	Formula	Result
220 kV Z1, Z0			0.512 + j6.585 Ω, 0.758 + j7.464 Ω
220 kV 3-phase I″k max	IEC 60909-0 §7.2 Eq. 29	$I''_{k3} = \frac{c\,U_n}{\sqrt{3}\,\lvert Z_1\rvert} + I_{\text{plant}}$	21.98 kA (plant 0.83)
220 kV 2-phase I″k2 max	IEC 60909-0 §7.3 Eq. 49	$I''_{k2} = \frac{c\,U_n}{\lvert Z_1 + Z_2\rvert}$	18.32 kA
220 kV 2-phase-to-earth max	IEC 60909-0 §7.4 Eq. 50–51	$I''_{k2E},\; 3I''_0$	20.87 kA, earth 19.40 kA
220 kV 1-phase-to-earth I″k1 max	IEC 60909-0 §7.5 Eq. 52	$I''_{k1} = \frac{\sqrt{3}\,c\,U_n}{\lvert Z_1 + Z_2 + Z_0\rvert}$	20.24 kA
220 kV κ (method B)	IEC 60909-0 §8.1.2	$\kappa = 1.15\,(1.02 + 0.98\,e^{-3R/X}) \le 2.0$	2.000 *
220 kV peak ip max	IEC 60909-0 §8.1.1 Eq. 54	$i_p = \kappa\sqrt{2}\,I''_k$	62.17 kA
220 kV Ith max (1.00 s, m = 0.044)	IEC 60909-0 §10 Eq. 100	$I_{\text{th}} = I''_k\sqrt{m+n},\; n = 1$	22.46 kA
33 kV Z1, Z0			0.032 + j0.975 Ω, 57.176 + j0.744 Ω
33 kV 3-phase I″k max	IEC 60909-0 §7.2 Eq. 29	$I''_{k3} = \frac{c\,U_n}{\sqrt{3}\,\lvert Z_1\rvert} + I_{\text{plant}}$	24.25 kA (plant 2.76)
33 kV 2-phase I″k2 max	IEC 60909-0 §7.3 Eq. 49	$I''_{k2} = \frac{c\,U_n}{\lvert Z_1 + Z_2\rvert}$	18.61 kA
33 kV 2-phase-to-earth max	IEC 60909-0 §7.4 Eq. 50–51	$I''_{k2E},\; 3I''_0$	18.88 kA, earth 0.55 kA

SAMPLE

Sample document for a sample project, generated by SubstationLayout. Not for construction. © SolarLayout.

Quantity	Reference	Formula	Result
33 kV 1-phase-to-earth I″k1 max	IEC 60909-0 §7.5 Eq. 52	$I''_{k1} = \frac{\sqrt{3}\, c\, U_n}{\lvert Z_1 + Z_2 + Z_0 \rvert}$	1.10 kA
33 kV κ (method B)	IEC 60909-0 §8.1.2	$\kappa = 1.15\,(1.02 + 0.98\, e^{-3R/X}) \le 2.0$	2.000 *
33 kV peak ip max	IEC 60909-0 §8.1.1 Eq. 54	$i_p = \kappa \sqrt{2}\, I''_k$	68.58 kA
33 kV Ith max (3.00 s, m = 0.034)	IEC 60909-0 §10 Eq. 100	$I_{th} = I''_k \sqrt{m + n},\ n = 1$	24.66 kA

* κ, the peak factor (IEC 60909-0 §8.1.2): 1.15 times κb, the factor from the bus X/R, capped at 2.0.

4. Minimum short-circuit currents (c = 1.00, no plant infeed)

Quantity	Reference	Formula	Result
220 kV Z1, Z0			0.512 + j6.585 Ω, 0.758 + j7.464 Ω
220 kV 3-phase I″k min	IEC 60909-0 §7.2 Eq. 29	$I''_{k3} = \frac{c\, U_n}{\sqrt{3}\, \lvert Z_1 \rvert}$	19.23 kA
220 kV 2-phase I″k2 min	IEC 60909-0 §7.3 Eq. 49	$I''_{k2} = \frac{c\, U_n}{\lvert Z_1 + Z_2 \rvert}$	16.65 kA
220 kV 2-phase-to-earth min	IEC 60909-0 §7.4 Eq. 50–51	$I''_{k2E},\ 3I''_0$	18.97 kA, earth 17.63 kA
220 kV 1-phase-to-earth I″k1 min	IEC 60909-0 §7.5 Eq. 52	$I''_{k1} = \frac{\sqrt{3}\, c\, U_n}{\lvert Z_1 + Z_2 + Z_0 \rvert}$	18.40 kA
220 kV κ (method B)	IEC 60909-0 §8.1.2	$\kappa = 1.15\,(1.02 + 0.98\, e^{-3R/X}) \le 2.0$	2.000 *
220 kV peak ip min	IEC 60909-0 §8.1.1 Eq. 54	$i_p = \kappa \sqrt{2}\, I''_k$	54.39 kA
220 kV Ith min (1.00 s, m = 0.044)	IEC 60909-0 §10 Eq. 100	$I_{th} = I''_k \sqrt{m + n},\ n = 1$	19.65 kA
33 kV Z1, Z0			0.032 + j0.975 Ω, 57.176 + j0.744 Ω
33 kV 3-phase I″k min	IEC 60909-0 §7.2 Eq. 29	$I''_{k3} = \frac{c\, U_n}{\sqrt{3}\, \lvert Z_1 \rvert}$	19.53 kA
33 kV 2-phase I″k2 min	IEC 60909-0 §7.3 Eq. 49	$I''_{k2} = \frac{c\, U_n}{\lvert Z_1 + Z_2 \rvert}$	16.91 kA
33 kV 2-phase-to-earth min	IEC 60909-0 §7.4 Eq. 50–51	$I''_{k2E},\ 3I''_0$	17.16 kA, earth 0.50 kA
33 kV 1-phase-to-earth I″k1 min	IEC 60909-0 §7.5 Eq. 52	$I''_{k1} = \frac{\sqrt{3}\, c\, U_n}{\lvert Z_1 + Z_2 + Z_0 \rvert}$	1.00 kA
33 kV κ (method B)	IEC 60909-0 §8.1.2	$\kappa = 1.15\,(1.02 + 0.98\, e^{-3R/X}) \le 2.0$	2.000 *
33 kV peak ip min	IEC 60909-0 §8.1.1 Eq. 54	$i_p = \kappa \sqrt{2}\, I''_k$	55.24 kA
33 kV Ith min (3.00 s, m = 0.034)	IEC 60909-0 §10 Eq. 100	$I_{th} = I''_k \sqrt{m + n},\ n = 1$	19.86 kA

* κ, the peak factor (IEC 60909-0 §8.1.2): 1.15 times κb, the factor from the bus X/R, capped at 2.0.

5. Plant infeed

Converter current k·Ir = 1.2 × 4604 A = 5525 A at 33 kV for the whole plant (829 A referred to 220 kV). A 33 kV section fault sees the share of its own feeders (50 %). The infeed is added to the 3-phase result (positive sequence only).

6. Equipment rating checks

Check	Calculated (kA)	Rating (kA)	Result
220 kV CB breaking current (Ib = I″k)	21.98	50.00	Pass
220 kV CB making current (ip)	62.17	125.00	Pass
220 kV short-time current Ith (1 s)	22.46	50.00	Pass
33 kV CB breaking current (Ib = I″k)	24.25	31.50	Pass

Sample document for a sample project, generated by SubstationLayout. Not for construction. © SolarLayout.

Check	Calculated (kA)	Rating (kA)	Result
33 kV CB making current (ip)	68.58	78.75	Pass
33 kV short-time current Ith (3 s)	24.66	31.50	Pass
Earth-mat design current ≥ 220 kV earth fault	20.24	50.00	Pass

Ratings from the SLD: 220 kV 50 kA 1 s, 33 kV 31.5 kA 3 s. Making current = 2.5 × breaking current at 50 Hz (IEC 62271-100:2008 §4.103). Breaking current Ib = I″k (far from generator, IEC 60909-0 §9.1).

SAMPLE

Sample document for a sample project, generated by SubstationLayout. Not for construction. © SolarLayout.