Short-circuit calculation

Project	Client	Location	Revision	Date
Sample 230/34.5 kV pooling substation	Sample client	Sample site	0	4 Nov 2026

Document no.	Prepared	Checked	Approved
SSL-C-SCC-001	Sample engineer	Sample engineer	Sample engineer

Rev	Date	Description	By
0	4 Nov 2026	Issued	Sample engineer

230/34.5 kV pooling substation, 250 MW. Method: IEEE C37.010-2016, the E/X method with adjustment for ac and dc decrements (§5.2.3), with E/Z for E/X (§5.2.1); breaker capability per IEEE C37.04-2018. Equation numbers refer to IEEE C37.010-2016.

1. Inputs

Parameter	Value	Source
Grid 3-phase fault level at the remote 230 kV bus	40 kA	Level default
Grid 1-phase fault level at the remote 230 kV bus	40 kA	Level default
Grid X/R	15	Typical
230 kV line	1 × 10 km (6.21 mi) Twin ACSR Moose	Typical
Line constants R1, X1, R0, X0 (Ω/km)	0.028, 0.31, 0.2, 1	Typical
Transformers	2 × 168 MVA YNyn0 + d, uk 12.5 %, X/R 40, Z0 = 0.9 × Z1	From the SLD
34.5 kV neutral grounding	NGR 1000 A per LV winding (19.92 Ω)	Typical
Plant infeed (full-size converters)	k = 1.2 × Ir, plant 263 MVA	Typical
Pre-fault voltage E at the maximum system voltage	230 kV 1.052 pu, 34.5 kV 1.058 pu	IEEE C37.010-2016 §5.1.2

2. Sequence impedances

Element	Reference	Formula	Value
Grid feeder Z1	Design rule	$Z_Q = \frac{U_n}{\sqrt{3}\, I_{kQ}}, \quad R_Q = \frac{X_Q}{X/R}$	0.221 + j3.312 Ω
Grid feeder Z0	IEEE C37.010-2016 §5.2.2	$\lvert Z_0\rvert = \frac{\sqrt{3}\, U_n}{I_{k1}} - 2\lvert Z_1\rvert$	0.221 + j3.312 Ω
Line Z1	IEEE C37.010-2016 Table 22	$Z_{L1} = (R_1 + jX_1)\frac{l}{n}$	0.280 + j3.100 Ω
Line Z0	IEEE C37.010-2016 Table 22	$Z_{L0} = (R_0 + jX_0)\frac{l}{n}$	2.000 + j10.000 Ω
Transformer ZT (at 230 kV, full rating)	IEEE C37.010-2016 Table 22	$Z_T = \frac{u_k}{100}\frac{U_{rT}^2}{S_{rT}}$	0.984 + j39.348 Ω
Transformer Z0	Rated impedance	$Z_{T0} = k_0 Z_T$	0.885 + j35.413 Ω
NGR	Ohm's law	$R_{NGR} = \frac{U_n/\sqrt{3}}{I_{NGR}}$	19.919 Ω

The bus networks are those of the phasor calculation: the grid behind its lines, the transformers, and one 34.5 kV section per LV winding with its NGR. Z2 = Z1. The X/R of a bus is the reduction of the reactances alone (R = 0) over the reduction of the resistances alone (X = 0), IEEE C37.010-2016 §5.2.3.

Calculation trail

1 · Network feeder impedance

Design rule

$$Z_Q = \frac{U_n}{\sqrt{3}\, I_{kQ}}, \quad R_Q = \frac{X_Q}{X/R}$$

IkQ 40 kA, grid X/R 15 → ZQ1 = 0.221 + j3.312 Ω

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2 · Line impedance

IEEE C37.010-2016 §5.3.2 Table 22

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

1 × 10 km (6.21 mi) Twin ACSR Moose → ZL1 = 0.280 + j3.100 Ω

3 · Transformer impedance

IEEE C37.010-2016 §5.3.2 Table 22

$Z_T = \frac{u_k}{100}\frac{U_{rT}^2}{S_{rT}}$

2 × 168 MVA, uk 12.5 %, X/R 40 → ZT = 0.984 + j39.348 Ω

4 · Plant infeed

Design rule

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

k 1.2, plant 263 MVA → 793 A at 230 kV

5 · Symmetrical current

IEEE C37.010-2016 §5.1.2, §5.2.1, §5.2.2

$I_3 = \frac{E}{|Z_1|} + I_{\text{plant}}$

E 1.052 pu (230 kV), 1.058 pu (34.5 kV) → 230 kV 22.52 kA, 34.5 kV 23.10 kA (per section)

6 · X/R by separate reductions

IEEE C37.010-2016 §5.2.3

$\frac{X}{R} = \frac{X_1}{R_1}, \quad \frac{X}{R} = \frac{2X_1 + X_0}{2R_1 + R_0}$

X with R = 0, R with X = 0 → 230 kV 12.8 and 14.9, 34.5 kV 30.8 and 0.048

7 · Duty factor

IEEE C37.010-2016 §5.2.2, Eq. 39 to 42, IEEE C37.04-2018 §5.6.2.2 Eq. 1

$MF = \frac{\sqrt{1 + 2e^{-2t/\tau}}}{\sqrt{1 + 2e^{-2t/0.045}}} \geq 1, \quad \tau = \frac{X/R}{2\pi f}$

230 kV 2-cycle (1.5 cycles), 3-cycle (2 cycles), 34.5 kV 3-cycle (2 cycles), 5-cycle (3 cycles) → 230 kV 1.000 and 1.000, **34.5 kV 1.143 and 1.000**

8 · Closing and latching current

IEEE C37.010-2016 Eq. 43, IEEE C37.04-2018 §5.6.2.3

$I_{\text{CL}} = \max(2.6,\ \sqrt{2}\,(1 + e^{-\pi/(X/R)}))\,(I - I_{\text{plant}}) + \sqrt{2}\,I_{\text{plant}}$

f 60 Hz → 230 kV 57.60 kA, 34.5 kV 58.79 kA

9 · Equipment rating checks

IEEE C37.04-2018 §5.6.2.3, Table 12, Table 16

$MF\,I \leq I_{sc}, \quad I_{\text{CL}} \leq 2.6\,I_{sc}, \quad I \leq I_{sc}\ (Y), \quad \tau \leq 120\,\text{ms}$

230 kV 50 kA, 34.5 kV 40 kA → 11 of 11 checks pass

3. Maximum short-circuit currents (maximum E, with plant infeed)

Quantity	Reference	Formula	Result
230 kV Z1, Z0			0.501 + j6.412 Ω, 0.802 + j7.636 Ω
230 kV 3-phase I max	IEEE C37.010-2016 §5.2.2	$I_3 = \frac{E}{\lvert Z_1\rvert} + I_{\text{plant}}$	22.52 kA (plant 0.79)
230 kV 2-phase max	Phasor network at E	$I_2 = \frac{\sqrt{3}\,E}{\lvert Z_1 + Z_2\rvert}$	18.81 kA
230 kV 2-phase-to-ground max	Phasor network at E	$I_{2E},\ 3I_0$	21.29 kA, ground 19.24 kA
230 kV line-to-ground I max	IEEE C37.010-2016 §5.2.2	$I_1 = \frac{3E}{\lvert Z_1 + Z_2 + Z_0\rvert}$	20.41 kA
230 kV X/R, three-phase and line to ground	IEEE C37.010-2016 §5.2.3	$\frac{X}{R} = \frac{X_1}{R_1},\ \frac{X}{R} = \frac{2X_1 + X_0}{2R_1 + R_0}$	12.8, 14.9
230 kV closing and latching current max	IEEE C37.010-2016 Eq. 43	$I_{\text{CL}} = \max(2.6,\ \sqrt{2}\,(1 + e^{-\pi/(X/R)}))\,I$	57.60 kA
34.5 kV Z1, Z0			0.033 + j1.030 Ω, 59.776 + j0.797 Ω
34.5 kV 3-phase I max	IEEE C37.010-2016 §5.2.2	$I_3 = \frac{E}{\lvert Z_1\rvert} + I_{\text{plant}}$	23.10 kA (plant 2.64)
34.5 kV 2-phase max	Phasor network at E	$I_2 = \frac{\sqrt{3}\,E}{\lvert Z_1 + Z_2\rvert}$	17.72 kA
34.5 kV 2-phase-to-ground max	Phasor network at E	$I_{2E},\ 3I_0$	17.98 kA, ground 0.53 kA
34.5 kV line-to-ground I max	IEEE C37.010-2016 §5.2.2	$I_1 = \frac{3E}{\lvert Z_1 + Z_2 + Z_0\rvert}$	1.06 kA

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Quantity	Reference	Formula	Result
34.5 kV X/R, three-phase and line to ground	IEEE C37.010-2016 §5.2.3	$\frac{X}{R} = \frac{X_1}{R_1},\ \frac{X}{R} = \frac{2X_1 + X_0}{2R_1 + R_0}$	30.8, 0.048
34.5 kV closing and latching current max	IEEE C37.010-2016 Eq. 43	$I_{CL} = \max(2.6,\ \sqrt{2}\,(1 + e^{-\pi/(X/R)}))\,I$	58.79 kA

4. Minimum short-circuit currents (E = 1 pu, no plant infeed)

Quantity	Reference	Formula	Result
230 kV Z1, Z0			0.501 + j6.412 Ω, 0.802 + j7.636 Ω
230 kV 3-phase I min	IEEE C37.010-2016 §5.2.2	$I_3 = \frac{E}{\lvert Z_1 \rvert}$	20.65 kA
230 kV 2-phase min	Phasor network at E	$I_2 = \frac{\sqrt{3}\,E}{\lvert Z_1 + Z_2 \rvert}$	17.88 kA
230 kV 2-phase-to-ground min	Phasor network at E	$I_{2E},\ 3I_0$	20.23 kA, ground 18.28 kA
230 kV line-to-ground I min	IEEE C37.010-2016 §5.2.2	$I_1 = \frac{3E}{\lvert Z_1 + Z_2 + Z_0 \rvert}$	19.39 kA
230 kV X/R, three-phase and line to ground	IEEE C37.010-2016 §5.2.3	$\frac{X}{R} = \frac{X_1}{R_1},\ \frac{X}{R} = \frac{2X_1 + X_0}{2R_1 + R_0}$	12.8, 14.9
230 kV closing and latching current min	IEEE C37.010-2016 Eq. 43	$I_{CL} = \max(2.6,\ \sqrt{2}\,(1 + e^{-\pi/(X/R)}))\,I$	53.68 kA
34.5 kV Z1, Z0			0.033 + j1.030 Ω, 59.776 + j0.797 Ω
34.5 kV 3-phase I min	IEEE C37.010-2016 §5.2.2	$I_3 = \frac{E}{\lvert Z_1 \rvert}$	19.34 kA
34.5 kV 2-phase min	Phasor network at E	$I_2 = \frac{\sqrt{3}\,E}{\lvert Z_1 + Z_2 \rvert}$	16.75 kA
34.5 kV 2-phase-to-ground min	Phasor network at E	$I_{2E},\ 3I_0$	16.99 kA, ground 0.50 kA
34.5 kV line-to-ground I min	IEEE C37.010-2016 §5.2.2	$I_1 = \frac{3E}{\lvert Z_1 + Z_2 + Z_0 \rvert}$	1.00 kA
34.5 kV X/R, three-phase and line to ground	IEEE C37.010-2016 §5.2.3	$\frac{X}{R} = \frac{X_1}{R_1},\ \frac{X}{R} = \frac{2X_1 + X_0}{2R_1 + R_0}$	30.8, 0.048
34.5 kV closing and latching current min	IEEE C37.010-2016 Eq. 43	$I_{CL} = \max(2.6,\ \sqrt{2}\,(1 + e^{-\pi/(X/R)}))\,I$	52.04 kA

5. Breaker duty

Up to the rated dc time constant of 45 ms (X/R 17 at 60 Hz) the symmetrical current is compared with the breaker's rated short-circuit current (IEEE C37.010-2016 §5.2.2). Above it the network's current is multiplied by the duty factor MF, the total current of the fault at the contact parting time (Eq. 39 to 42) over the breaker's asymmetrical capability at the same time (IEEE C37.04-2018 §5.6.2.2 Eq. 1). MF is taken at each rated interrupting time IEEE C37.04-2018 lists for the breaker's rated maximum voltage, and the larger is kept. The converter current is added without MF, as it has no dc component. MF takes no ac decrement, so it is at or above the local factors of Figs 22 and 23; on the example of Table 17 it is within 0.02 of Fig. 24. The derating method applies up to a dc time constant of 120 ms (X/R 45 at 60 Hz, §4.11.3.6).

Quantity	Value
230 kV breakers, rated interrupting time (contact parting time)	2-cycle (1.5 cycles), 3-cycle (2 cycles)
230 kV duty factor, three-phase (X/R 12.8)	1.000
230 kV duty factor, line to ground (X/R 14.9)	1.000
230 kV interrupting duty, three-phase and line to ground	22.52 kA, 20.41 kA
34.5 kV breakers, rated interrupting time (contact parting time)	3-cycle (2 cycles), 5-cycle (3 cycles)
34.5 kV duty factor, three-phase (X/R 30.8)	1.143
34.5 kV duty factor, line to ground (X/R 0.048)	1.000
34.5 kV interrupting duty, three-phase and line to ground	26.02 kA, 1.06 kA

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6. Plant infeed

Converter current k·Ir = 1.2 × 4404 A = 5285 A at 34.5 kV for the whole plant (793 A referred to 230 kV). A 34.5 kV section fault sees the share of its own feeders (50 %). The infeed is added to the 3-phase result (positive sequence only).

7. Equipment rating checks

Check	Calculated	Rating	Result
230 kV CB interrupting current, three-phase (E/Z × duty factor + plant)	22.52 kA	50.00 kA	Pass
230 kV CB interrupting current, line to ground (E/Z × duty factor)	20.41 kA	50.00 kA	Pass
230 kV CB closing and latching current (peak)	57.60 kA	130.00 kA	Pass
230 kV short-time current (1 s)	22.52 kA	50.00 kA	Pass
230 kV dc time constant within the C37.010 derating method	40 ms	120 ms	Pass
34.5 kV CB interrupting current, three-phase (E/Z × duty factor + plant)	26.02 kA	40.00 kA	Pass
34.5 kV CB interrupting current, line to ground (E/Z × duty factor)	1.06 kA	40.00 kA	Pass
34.5 kV CB closing and latching current (peak)	58.79 kA	104.00 kA	Pass
34.5 kV short-time current (2 s)	23.10 kA	40.00 kA	Pass
34.5 kV dc time constant within the C37.010 derating method	82 ms	120 ms	Pass
Ground-grid design current ≥ 230 kV ground fault	20.41 kA	50.00 kA	Pass

Ratings from the SLD: 230 kV 50 kA, 34.5 kV 40 kA. Rated closing and latching current = 2.6 × the rated short-circuit current at 60 Hz (IEEE C37.04-2018 §5.6.2.3). Short-time duration Y: 2 s below 100 kV, 1 s at 100 kV and above (IEEE C37.04-2018 Table 12, Table 16).

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