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Power system formulas: cheat sheet

Power and current, transformers, short circuit (IEC 60909), per-unit and voltage drop

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1 Power and current

Three-phase: $S = \sqrt{3} \cdot U \cdot I$

U = line-to-line voltage, I = line current

$P = S \cdot \cos\varphi \quad \cdot \quad Q = S \cdot \sin\varphi \quad \cdot \quad S^2 = P^2 + Q^2$

Single-phase: $S = U \cdot I$ · DC: $P = U \cdot I$

Current per kVA	A / kVA
230 V single-phase	4.348
400 V three-phase	1.443
480 V three-phase	1.203
11 kV three-phase	0.0525

Motors: nameplate kW is shaft power, so $I = P / (\sqrt{3} \cdot U \cdot \cos\varphi \cdot \eta)$.

→ **kVA to amps calculator**

2 Transformers

$I_r = S_r / (\sqrt{3} \cdot U_r)$

Each side with its own voltage; $I_1 / I_2 = U_2 / U_1$

$Z_T = (u_k / 100) \cdot U_r^2 / S_r$

$I_{k,max} = I_r / (u_k / 100) \quad \cdot \quad S_k = S_r / (u_k / 100)$

Fault at the secondary terminals, infinite upstream network

Example: 1000 kVA, 20/0.4 kV, u_k = 6 % → 28.87 A / 1443 A, fault current 24.06 kA.

→ **Transformer full-load current calculator**

3 Short circuit (IEC 60909)

$I''_k = c \cdot U_n / (\sqrt{3} \cdot |Z_k|)$

$Z_Q = c \cdot U_n^2 / S''_{kQ} \quad \cdot \quad X_Q = 0.995\, Z_Q,\ R_Q = 0.1\, X_Q$

Upstream network when its R/X is not known

$i_p = \kappa \cdot \sqrt{2} \cdot I''_k \quad \cdot \quad \kappa = 1.02 + 0.98 \cdot e^{-3R/X}$

$S''_k = \sqrt{3} \cdot U_n \cdot I''_k$

Voltage factor c	c_{max}	c_{min}
Low voltage, +6 % tolerance	1.05	0.95
Low voltage, +10 % tolerance	1.10	0.90
Above 1 kV	1.10	1.00

→ **Short-circuit current calculator**

4 Per-unit system

$Z_{base} = U_{base}^2 / S_{base} \quad \cdot \quad I_{base} = S_{base} / (\sqrt{3} \cdot U_{base})$

$Z_{pu} = Z_\Omega / Z_{base}$

$Z_{new} = Z_{old} \cdot (S_{new} / S_{old}) \cdot (U_{old} / U_{new})^2$

Moves an impedance from the equipment base to the system base

One S_{base} for the whole network (often 100 MVA), U_{base} = nominal voltage of each level.

→ **Per-unit calculator**

5 Voltage drop

$\Delta U = \sqrt{3} \cdot I \cdot L \cdot (R \cos\varphi + X \sin\varphi) / n$

Three-phase (line-to-line drop)

$\Delta U = 2 \cdot I \cdot L \cdot (R \cos\varphi + X \sin\varphi) / n$

Single-phase. DC: $\Delta U = 2 \cdot I \cdot L \cdot R / n$. L in km, R and X in Ω/km, n = cables in parallel

$R_T = R_{20} \cdot (1 + \alpha\,(T - 20))$

α = 0.00393 /°C copper, 0.00403 /°C aluminium

IEC 60364-5-52 Annex G suggests 3 % for lighting and 5 % for other uses from a public LV supply (6 % and 8 % with a private supply).

→ **Voltage drop calculator**

Power system formulas: cheat sheet

Cable sizing, power factor correction, harmonics (IEEE 519) and arc flash

6 Cable sizing

Short circuit: $S \geq I_k \cdot \sqrt{t} / k$

Adiabatic equation, disconnection time t up to 5 s

k (IEC 60364-4-43)	PVC	XLPE / EPR
Copper	115 (103 > 300 mm²)	143
Aluminium	76 (68 > 300 mm²)	94

$I_{z,table} \geq I_b / (k_\theta \cdot k_g)$

Required tabulated current-carrying capacity

$k_\theta = \sqrt{((\theta_{max} - \theta_a) / (\theta_{max} - \theta_{ref}))}$

θ_{max} 70 °C PVC, 90 °C XLPE; θ_{ref} 30 °C in air, 20 °C in the ground

Bunched circuits k_g: 2 → 0.80, 3 → 0.70, 4 → 0.65, 6 → 0.57, 9 → 0.50. Protection: $I_b \leq I_n \leq I_z$.

→ Cable sizing calculator

7 Power factor correction

$Q_c = P \cdot (\tan \varphi_1 - \tan \varphi_2)$

$C_\Delta = Q_c / (3 \cdot \omega \cdot U^2)$ · $C_Y = Q_c / (\omega \cdot U^2)$

Capacitance per phase, delta or star; $\omega = 2\pi f$, U = line-to-line voltage

$P_{loss,2} / P_{loss,1} = (\cos \varphi_1 / \cos \varphi_2)^2$

Voltage rise when the bank switches on: $\Delta U \approx Q_c / S''_k$. Parallel resonance near harmonic $h_r \approx \sqrt{(S''_k / Q_c)}$.

→ Power factor correction calculator

8 Harmonics (IEEE 519)

$THD = \sqrt{(\Sigma_{h \geq 2} V_h^2)} / V_1 \cdot 100\ \%$

Voltage at the PCC	Individual	THD
V ≤ 1 kV	5.0 %	8.0 %
1 kV < V ≤ 69 kV	3.0 %	5.0 %
69 kV < V ≤ 161 kV	1.5 %	2.5 %
V > 161 kV	1.0 %	1.5 %

→ Harmonic analysis guide

9 Arc flash

PPE category (NFPA 70E)	Min. arc rating
1	4 cal/cm²
2	8 cal/cm²
3	25 cal/cm²
4	40 cal/cm²

Arc-flash boundary: where the incident energy falls to 1.2 cal/cm² (5.0 J/cm²). 1 cal/cm² = 4.184 J/cm². Incident energy per IEEE 1584-2018.

→ Arc flash guide

10 Conductor resistance

Size	Copper Ω/km	Aluminium Ω/km
1.5 mm²	12.1	—
2.5 mm²	7.41	—
4 mm²	4.61	—
6 mm²	3.08	—
10 mm²	1.83	—
16 mm²	1.15	1.91
25 mm²	0.727	1.20
35 mm²	0.524	0.868
50 mm²	0.387	0.641
70 mm²	0.268	0.443
95 mm²	0.193	0.320
120 mm²	0.153	0.253
150 mm²	0.124	0.206
185 mm²	0.0991	0.164
240 mm²	0.0754	0.125
300 mm²	0.0601	0.100

Maximum DC resistance at 20 °C, IEC 60228 class 2 (stranded). Correct to the operating temperature with R_T (card 5).

Run the whole network, not one formula

Electrisim runs load flow, IEC 60909 short circuit, arc flash, harmonics and stability on the open-source engines pandapower, OpenDSS and ANDES, in your browser.

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