Formulas of power engineering

Cross section

- for direct current and single phase alternative current of known **current**: $q = \frac{2 \cdot I \cdot l}{\kappa \cdot u}$ (mm²)
  for three-phase current: $q = \frac{1{,}732 \cdot I \cdot \cos\varphi \cdot l}{\kappa \cdot u}$ (mm²)
- for direct current and single phase alternative current of known **power**: $q = \frac{2 \cdot l \cdot P}{\kappa \cdot u \cdot U}$ (mm²)
  for three-phase current: $q = \frac{l \cdot P}{\kappa \cdot u \cdot U}$ (mm²)

Voltage drop

For low voltage cable network of normal operation, it is advisable of a voltage drop of 3 – 5%.
On exceptional case, higher values (up to 7%) can be permitted in case of network-extension or in short-circuit.

- for direct current of known **current**: $u = \frac{2 \cdot I \cdot l}{\kappa \cdot q}$ (V)
  for single phase alternative current: $u = \frac{2 \cdot I \cdot \cos\varphi \cdot l}{\kappa \cdot q}$ (V)
  for three-phase current: $u = \frac{1{,}732 \cdot I \cdot \cos\varphi \cdot l}{\kappa \cdot q}$ (V)
- for direct current of known **power**: $u = \frac{2 \cdot l \cdot P}{\kappa \cdot q \cdot U}$ (V)
  for single phase alternative current: $u = \frac{2 \cdot l \cdot P}{\kappa \cdot q \cdot U}$ (V)
  for three-phase current: $u = \frac{l \cdot P}{\kappa \cdot q \cdot U}$ (V)

u = voltage drop (V) — q = cross-section (mm²)
U = operating voltage (V) — I = working current (A)
P = power (W) — l = length of the line (m)
R_w = effective resistance (Ω/km)
L = Inductance (mH/km) — κ (Kappa) = electrical conductivity of conductors
ωL = inductive resistance (Ω)/km) ($\omega = 2 \cdot \pi \cdot f$ at 50 Hz = 314)

κ-copper : 58
κ-Alu : 33

Nominal voltage

The nominal voltage is to be expressed with two values of alternative current U_0/U in V (Volt).

U_0/U = phase-to-earth voltage
U_0 : Voltage between conductor and earth or metallic covering (shields, armouring, concentric conductor)
U : Voltage between two outer conductors
U_0 : $U/\sqrt{3}$ for three-phase current systems
U_0 : U/2 for single-phase and direct current systems
U_0/U_0 : an outer conductor is earth-connected for A.C.- and D.C.-systems

Nominal current

I in (A)

Active current

$I_w = I \cdot \cos\varphi$

Reactive current

$I_0 = I \cdot \sin\varphi$

Apparent power (VA)

$S = U \cdot I$ — for single phase current (A.C.)
$S = 1{,}732 \cdot U \cdot I$ — for three-phase current

Active power (W)

$P = U \cdot I \cdot \cos\varphi$ — for single phase current (A.C.)
$P = 1{,}732 \cdot U \cdot I \cdot \cos\varphi$ — for three-phase current
$P = U \cdot I$ — for direct current

Reactive power (var)

$Q = U \cdot I \cdot \sin\varphi$ — for single phase current (A.C.)
$Q = 1{,}732 \cdot U \cdot I \cdot \sin\varphi$ — for three-phase current
(Voltampere reactiv) — $Q = P \cdot \tan\varphi$

Phase angle

φ is a phase angle between voltage and current

cos φ =	1,0	0,9	0,8	0,7	0,6	0,5
sin φ =	0	0,44	0,6	0,71	0,8	0,87

Insulation resistance

$R_{iso} = \frac{S_{iso}}{l} \cdot \ln \frac{Da}{d} \cdot 10^{-8}$ (MΩ · km)

Specific Insulation resistance

$R_s = \frac{R \cdot 2\pi \cdot l \cdot 10^8}{\ln \frac{Da}{di}}$

D_a = outer diameter over insulation (mm)
d = conductor diameter (mm)
di = inner diameter of insulation (mm)
l = length of the line (m)
S_{iso} = Spec. resistance of insulation materials (Ω · cm)

Mutual capacity

(C_B) for single-core, three-core and H-cable)

$C_B = \frac{\varepsilon r \cdot 10^3}{18 \ln \frac{Da}{d}}$ (nF/km)

Inductance

Single-phase: $0{,}4 \cdot (\ln \frac{Da}{r} + 0{,}25)$ mH/km
three-phase: $0{,}2 \cdot (\ln \frac{Da}{r} + 0{,}25)$ mH/km

D_a = distance – mid to mid of both conductors
r = radius of conductor (mm)
εr = dielectric constant
0,25 = factor for low frequency

Earth capacitance

$E_C = 0{,}6 \cdot C_B$

Charging current (only for three-phase current)

$I_{Lad} = U \cdot 2\pi f \cdot C_B \cdot 10^{-6}$ A/km per core at 50 Hz

Charging power

$P_{Lad} = I_{Lad} \cdot U$

Leakage and loss factor

$G = \tan\delta \cdot \omega C$ (S)
$\tan\delta = \frac{G}{\omega C}$

ω = 2 π f
C = Capacity
tanδ = loss factor
S = Siemens = $\frac{1}{1\Omega}$

Dielectric loss

$D_v = U^2 \cdot 2\pi f \cdot C_B \cdot \tan \cdot 10^{-6}$ (W/km)
f bei 50 Hz

tanδ PE/VPE (XLPE)	~0,0005
EPR	~0,005
Paper-single core, three-core, H-cable	~0,003
Oil-filled and pressure cable	~0,003
PVC cable	~0,05

It should be noted that for the current load of the insulated cables and wires of selected cross-section, the power ratings table is also be considered.

To estimate the voltage drop of insulated wires and cables for heavy (big) cross-sections of single- and three-phase-overhead line, the active resistance as well as the inductive resistance must be considered.
The formula for single-phase (A.C.):

$U = 2 \cdot l \cdot I \cdot (R_w \cdot \cos\varphi + \omega L \cdot \sin\varphi) \cdot 10^{-3}$ (V)

Three-phase:

$U = 1{,}732 \cdot l \cdot I \cdot (R_w \cdot \cos\varphi + \omega L \cdot \sin\varphi) \cdot 10^{-3}$ (V)

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