FORMULAS OF ELECTROTECHNIC AND ELECTRONIC

Cross-section for **single wire round**

$$q = \frac{D^2 \cdot \pi}{4} \quad \text{or} \quad D^2 \cdot 0{,}7854$$

Cross-section for **bunched wire**

$$q = \frac{d^2 \cdot \pi}{4} \cdot n \quad \text{or} \quad d^2 \cdot 0{,}7854 \cdot n$$

Diameter for
single wires cross-section

$$D = \sqrt{\frac{q \cdot 4}{\pi}} \quad \text{or} \quad \sqrt{q \cdot 1{,}2732}$$

Diameter for **bunched wires**

$$D = \sqrt{1{,}34 \cdot n \cdot d}$$

q = cross-section (mm^2)
D = conductor diameter (mm)
d = single wire diameter (mm)
n = number of wires

Conductor Resistance

$$R = \frac{l}{\kappa \cdot q} \quad \text{oder} \quad \frac{\rho \cdot l}{q}$$

$$R_{Schleife} = \frac{2 \cdot l}{\kappa \cdot q} \quad \text{oder} \quad \frac{2 \cdot l\ p}{q}$$

R = Electrical direct-current resistant (Ohm)
$R_{Schleife}$ = Resistance of a complete circuit
q = cross-section (mm^2 or q mm)
κ (Kappa) = Conductivity
ρ (Rho) = Specific resistance ($\rho = \frac{1}{\kappa}$)
l = Conductor length (m)

Materials	Conductivity $\frac{m}{\Omega \cdot mm^2}$	Spec. resistance $\frac{\Omega \cdot mm^2}{m}$
Copper	58,00	0,01724
Aluminium	33,00	0,0303
Silver	62,00	0,0161
Iron	7,70	0,1299
Constantan	2,00	0,50

Serial connection

Resistance: $R = R_1 + R_2 + R_3 + ... + R_n$

Capacitance: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$

Inductance: $L = L_1 + L_2 + L_3 + ... + L_n$

Parallel connection

Resistance: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... \frac{1}{R_n}$

Capacitance: $C = C_1 + C_2 + C_3 + ... C_n$

Inductance: $\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + ... \frac{1}{L_n}$

Equivalent resistance of 2 parallel connected resistance

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

Mutual capacity (C)

• coaxial cable $C = \frac{\xi r \cdot 10^3}{18 \cdot \ln\frac{Da}{d}}$ (nF/km)

• parallel core $C = \frac{\xi r \cdot 10^3}{36 \cdot \ln\frac{Da}{d}}$ (nF/km)

• shielded twisted pair

$$C_B = \frac{\xi r \cdot 10^3}{36 \ln \frac{2a}{d} \cdot \frac{(Da^2 - a^2)}{(Da^2 - a^2)}} \text{(nF/km)}$$

Da = Outer diameter over insulation
Ds = diameter over shield
d = diameter of conductor
a = distance - mid to mid of both conductors
ξ = dielectric constant

Ohm's Law

The current intensity (I) is proportional to voltage (U) and inversely proportional to resistance (R)

$$I = \frac{U}{R} \quad R = \frac{U}{I} \quad U = I \cdot R$$

I = current intensity (Amps - A)
R = electrical resistance (Ω)
U = electrical voltage (V)

Conductance

$$G = \frac{1}{R} \quad 1S = \frac{1}{1\ \Omega} \quad \text{or} \quad 1\ \mu S = \frac{1}{1\ M\Omega}$$

S (Siemens) = reziprocal value of a resistance is used as **conductance**
1 Siemens = 1/Ohm
G = electrical conductance

Capacitance

- Single core against earth

$$C_B = \frac{\xi r \cdot 10^3}{18 \ \ln \frac{Di}{d}} \text{(nF/km or pF/m)}$$

- Unshielded symmetrical twisted pair

$$C_B = \frac{\xi r \cdot 10^3}{36 \ \ln \frac{2a}{d}} \text{(nF/km or pF/m)}$$

- Coaxial pair

$$C_B = \frac{\xi r \cdot 10^3}{18 \ \ln \frac{Di}{d}} \text{(nF/km or pF/m)}$$

- Shielded symmetrical twistet pair

$$C_B = \frac{\xi r \cdot 10^3}{36 \ \ln \frac{2a}{d} \cdot \frac{(Da^2 - a^2)}{(Da^2 - a^2)}} \text{(nF/km or pF/m)}$$

Di = outer diameter over single core (mm)
Da = outer diameter of multicores (mm)
d = conductor diamete (mm)
a = distance between two conductors mid to mid of both conductors

Inductance of parallel cores

at low frequencies

$$L = 0{,}4\ (\ln\frac{Da}{r} + 0{,}25)\ \text{mH/km}$$

at high frequencies

$$L = 0{,}4\ (\ln\frac{Da}{r} + 0)\ \text{mH/km}$$

Inductance of coaxial cable

at high frequencies

$$L = 0{,}2\ (\ln\frac{Da}{r} + 0)\ \text{mH/km}$$

Da = distance between two conductors mid to mid of both conductors
r = radius of a conductor
ξr = dielectric constant

Impedance (Z)

for coaxial cable $Z = \frac{60}{\sqrt{\xi r}} \cdot \ln \frac{D}{d}$ (Ω)

D = diameter over insulation
d = conductor diameter

for communication cable

at low frequencies $Z = \sqrt{\frac{R}{\omega C}}$ (Ω) · tan φ = 1, φ = 45°

at high frequencies $Z = \sqrt{\frac{L}{C}}$ (Ω)

R = Resistance (Ω/km)
L = Inductance (mH/km)
C = Capacitance (nF/km)
ω = 2 π f

Wave length $\lambda = \frac{v}{f}$

λ = wave length
V = propagation velocity (velocity of light: 300 000 km/s)
f = frequency

units of attenuation - Neper (N), decibel (dB) and Bel (B)
1 Np = 8,686 dB
1 dB = 0,1151 Np = $\frac{1}{10}$ Bel
1 Bel = 10 dB = 1,1513 Np

FORMULAS OF POWER ENGINEERING

Cross section

- for direct current and single **phase** alternative current one-phase current of known current $q = \frac{2 \cdot I \cdot l}{\kappa \cdot u}$ (mm^2)

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

  for three-phase current $q = \frac{l \cdot P}{\kappa \cdot u \cdot U}$ (mm^2)

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)
U = operating voltage (V)
P = power (W)
R_w = effective resistance (Ω)/km)
L = Inductance (mH/km)
ωL = induktiver Widerstand (Ω)/km) (ω = 2 · π · f at 50 Hz = 314)

q = cross-section (mm^2)
I = working current (A = Ampere)
l = length of the line in m
κ (Kappa) = electrical conductivity of conductors $(m/\Omega \cdot mm^2)$
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 Nominal current

Active current

I in (A)

Reactive current

$I_w = I \cdot \cos\varphi$

Blindstrom

$I_0 = I \cdot \sin\varphi$

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

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

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)

$C_B = \frac{\xi r \cdot 10^3}{18 \ln \frac{Da}{d}}$ (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)
ξr = 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 je Ader bei 50 Hz

Charging power

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

Leakage and loss factor

G = tanδ · ω 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 on 50 Hz

tanδ PE/VPE cables	~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)