OVERHEAD LINE AMPACITY

Ampacity = Ampere Capacity

- limitation – maximal permitted operational conductor temperature; given by the conductor type and operational state
- influences – climatic (ambient temperature, wind, Sun)
- other limitations: mechanics (sag), magnetic field, stability

ACSR operational temperature (ACSR – Aluminium Conductor Steel Reinforced; AlFe)
in accordance with ČSN EN 50341-3-19

- normal loading: 80°C
- short-term increasing during special loading (up to 150°C)
- during short-circuit: 200°C

x manufacturer requirements, optical and mechanical characteristics downgrade, sag

Overhead Line Thermal Models

Conductor heat conductivity λ high → conductor temperature considered constant in the cross-section: T_{AV} (°C)

Conductor temperature differential equation

$$M \cdot c_P \frac{dT_{AV}}{dt} = P_J + P_S + P_M - P_R - P_C \qquad (W/m)$$

M .... conductor mass (kg/m)
c_P .... specific heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$)
P_J .... Joule losses (W/m)
P_S .... solar radiation heat power (W/m)
P_M ...... magnetic field heating (W/m)
P_R .... radiation cooling (W/m)
P_C .... convective cooling (W/m)

(also corona heating, evaporation cooling – usually not considered)

AC resistance respecting el. and mag. influences

$$P_Z = P_J + P_M = R_{ac} I^2 \quad (W/m\,;\Omega/m\,,A)$$

Steady state – algebraic equation

$$\frac{dT_{AV}}{dt} = 0$$

ASCR conductors parameters

$$M = \rho_{Al} \cdot S_{Al} + \rho_{Fe} \cdot S_{Fe} \quad (kg/m\,;kg/m^3\,,m^2)$$

$$c_P = \frac{c_{Al} \cdot \rho_{Al} \cdot S_{Al} + c_{Fe} \cdot \rho_{Fe} \cdot S_{Fe}}{\rho_{Al} \cdot S_{Al} + \rho_{Fe} \cdot S_{Fe}} \quad (J \cdot kg^{-1} \cdot K^{-1})$$

$\rho_{Al} = 2703\ kg \cdot m^{-3}$, $\rho_{Fe} = 7780\ kg \cdot m^{-3}$

$c_{Al} = 897\ J \cdot kg^{-1} \cdot K^{-1}$, $c_{Fe} = 477\ J \cdot kg^{-1} \cdot K^{-1}$

Joule losses

$$P_Z = I_P^2 \cdot R_{dc0} \cdot k_{ac}\left[1 + b\left(T_{AV} - T_0\right)\right] \quad (W/m)$$

R_{dco} .... relative DC (Ω/m) for temperature T_0

T_0....... reference temperature, usually 20°C

b......... resistance temperature coefficient (K^{-1})

$$b \approx 4 \cdot 10^{-3}\ K^{-1}$$

k_{ac} ...... AC and DC resistance ratio

$$k_{ac} = R_{ac} / R_{dc} > 1$$

Solar radiation heating

$$P_S = a \cdot D \cdot I_{př} \sin \omega \quad (W/m)$$

a......... solar radiation absorption coefficient (-)

$$a \approx 0{,}5 \div 1$$

D........ conductor diameter (m)

$I_{př}$ .... direct solar radiation (W/m^2)

solar constant $I_0 \approx 1370\ W/m^2$

ω........ angle between solar beams and conductor axis (°)

Radiation cooling

$$P_R = \sigma \cdot \varepsilon \cdot \pi \cdot D \cdot \left[\left(T_{AV} + 273{,}15 \right)^4 - \left(T_a + 273{,}15 \right)^4 \right] \quad (W/m)$$

T_a....... ambient temperature (°C)

σ .... Stefan-Boltzmann constant

$$\sigma = 5{,}67 \cdot 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$$

ε......... heat radiation emissivity (-), $\varepsilon \approx 0{,}5$

Convective cooling

$$P_C = \alpha \cdot \pi \cdot D \cdot \left(T_{AV} - T_a\right) \quad (W/m)$$

α .... convection heat-transfer coefficient

$$\alpha = k_w \cdot \frac{Nu \cdot \lambda}{D} \quad (W \cdot m^{-2} \cdot K^{-1})$$

λ......... air heat conductivity $(W \cdot m^{-1} \cdot K^{-1})$

Nu...... Nusselt number (-)

free convection $Nu_V = f(Gr, Pr)$

forced convection $Nu_N = f(Re)$

k_W....... wind angle coefficient (-)

$$k_w = 1{,}194 - \sin\psi - 0{,}194\cos 2\psi + 0{,}364\sin 2\psi$$

ψ .... angle between wind direction and conductor normal line

Conductor bundle influence

P_Z – each conductor 1/3 total current (losses)
P_S – no changes, variable shadowing
P_C – no changes, boundary layer x cm
P_R – lower, partial radiation to the same temperature

$$k_{rad} = 1 - \frac{2 \cdot \mathrm{Arctg}\left(\frac{D}{2l}\right)}{\pi}$$

l ... bundle step (m)

→ lower cooling, lower ampacity (c. by 0,5%)

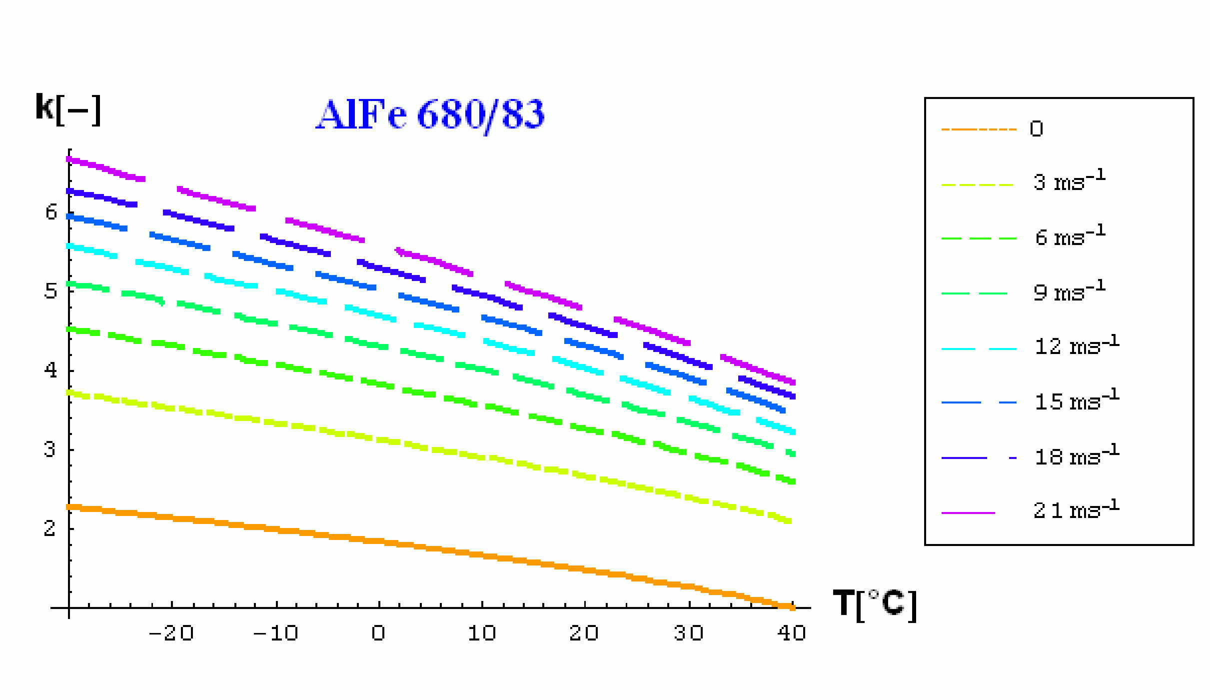
Steady states

Ampacity for given conductor temperature

$$I = \sqrt{\frac{P_R + P_C - P_S}{k_{ac} \cdot R_{dc}}} \quad (A)$$

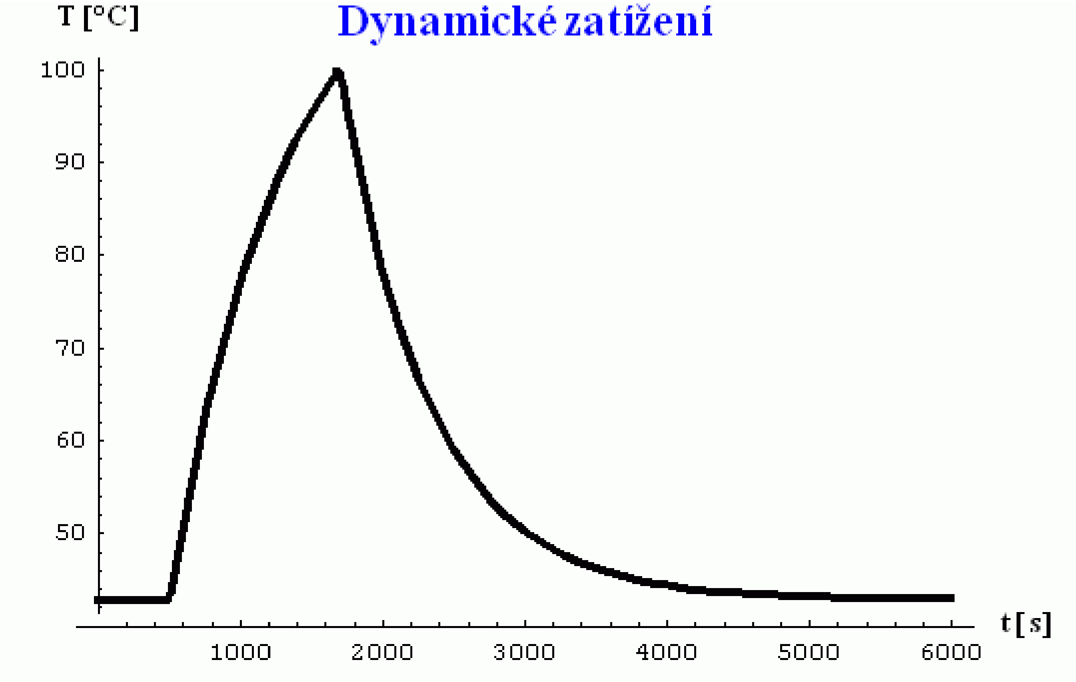
Steady temperature – 4th order algebraic equation

Climatic parameters influence on ampacity



Dynamic states

- Changes in ES configuration, production, loading, 10x minutes, heat energy accumulation.
- Events dynamics depends on heat time constant: e.g. for 434-AL1/59-ST1A $\tau_{vod} = 16{,}5 \text{ min}$.
- E.g.: AlFe 680/83 overloaded 20 min up to 100°C → dynamic ampacity 2292 A.

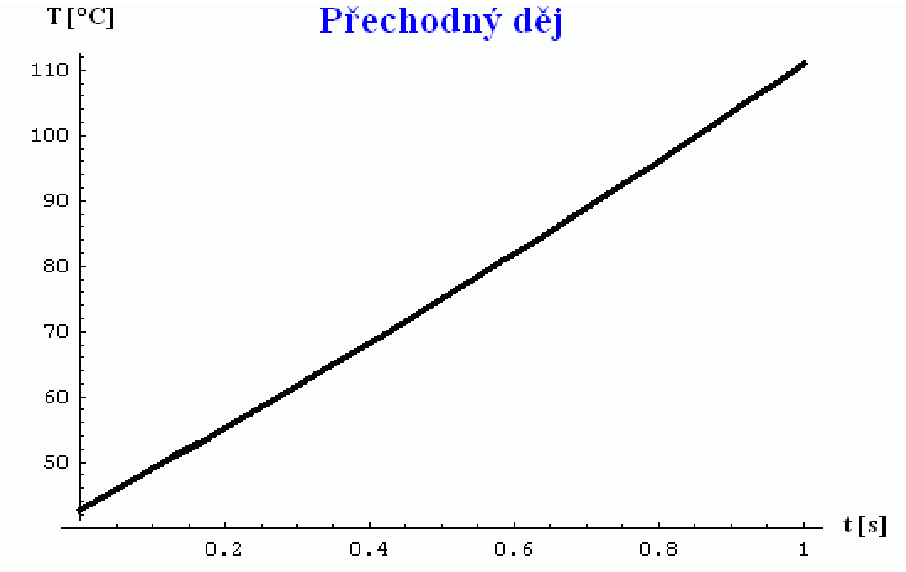


Transient events

- Lightning, short-circuit currents.
- Adiabatic condition
  ($P_S = 0$, $P_R = 0$, $P_C = 0$).

$$M \cdot c_P \frac{dT_{AV}}{dt} = P_Z = I_Z^2 \cdot R_{ac0}\left[1 + b\left(T_{AV} - T_0\right)\right] \ (W/m)$$

E.g.: AlFe 680/83, short-circuit 50 kA for 1 s



OHL ampacity

Limit factors for loading

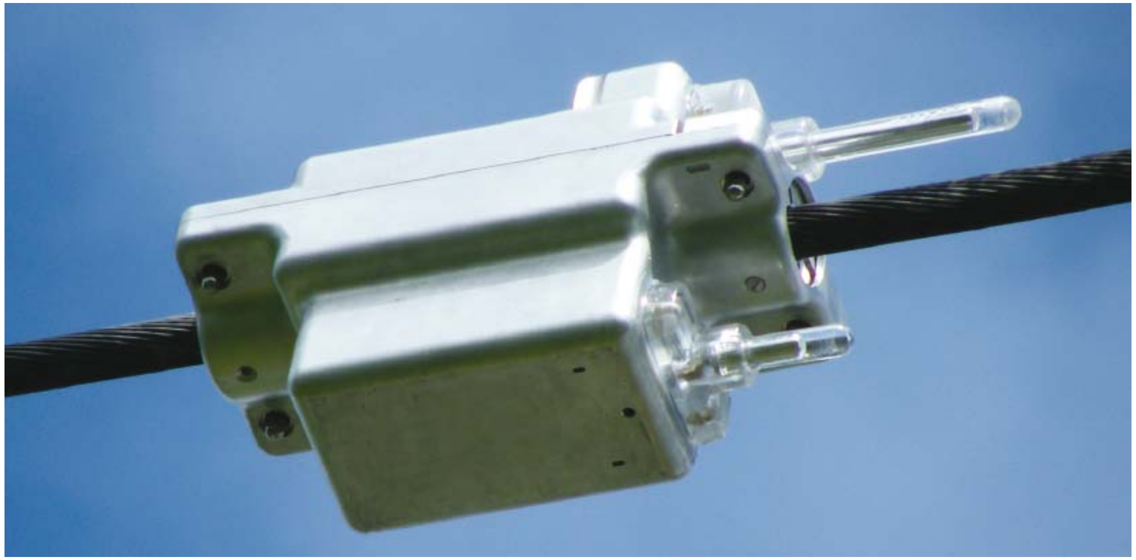
- sag
- substation equipment (CT, disconnectors)
- wire

Temperature (sag) measurement

- contact
- mechanical tension measurement (CAT-1 – Nexans)
- thermovision
- sag by means of laser → T
- phasor measurement → average T
- mechanical auto-oscillations → sag → T (Ampacimon)
- longitudinal temperature by means of reflections in optical wires (*Distributed Temperature Sensing*)

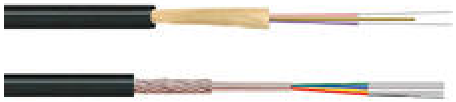
CAT-1

Ampacimon



DTS

AP Sensing



Valcap - NKT Cables (V444 – Nošovice - Wielopole (PL))

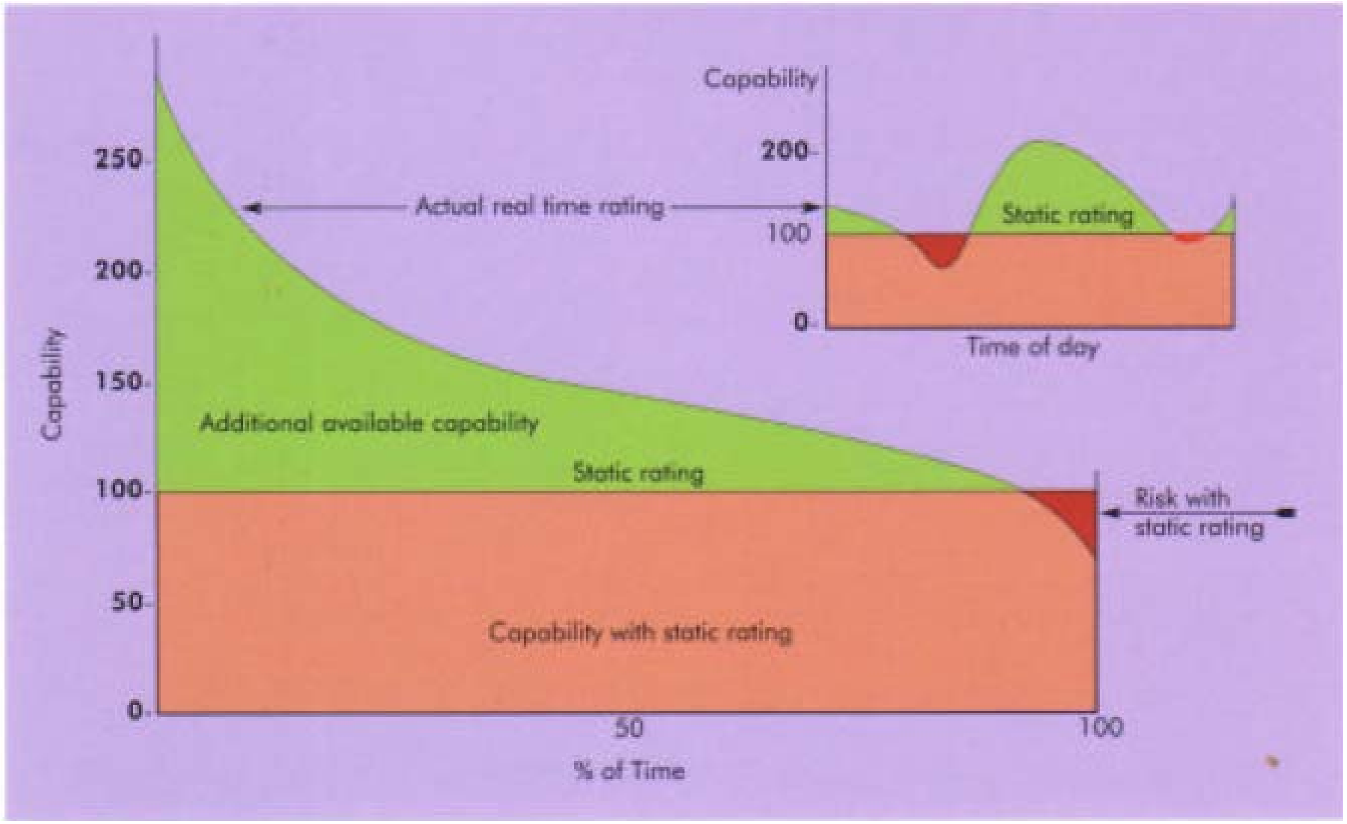
OPPC
Přímá spojka

Koncovka
OPPC,
zavěšení

Loading

- static – constant limits, sometimes summer x winter (protections setting)
- dynamic (*dynamic line rating*, *real-time line rating*)
    - online – conductor temperature measurement ⟶ data to dispatch centre ⟶ loading reduction
    - online – conductor temperature measurement + meteorological data ⟶ heat models for decisions
    - offline – only meteodata into models
    - prediction systems based on meteostations network (USA)
- normal x extraordinary states – decision time for dispatcher

Dynamic Line Rating



Loading control

- reconfiguration
- sources redispatch
- FACTS
- extraordinary states (consumers reducing)

Critical places and states

- power plants outlets
- international connections
- long “parallel” lines
- transit x internal loading
- renewable energy sources

Conductor dimensioning

Border conditions determining approaches

climatic parameter	operational conditions range	border values		
		sub-critical	critical	limiting
T_a (°C)	-30 až 35	30	35	40
w_S (m/s)	0,6 až 30	1,34	0,6	0
I_{gm} (W/m^2)	0 až 800	800	800	1100

Conditions in accordance with ČSN EN 50341-3-19 for determining the highest conductor design temperature:

- ambient temperature 35 °C
- wind speed 0,5 m/s with angle 45° to the conductor axis
- global solar radiation intensity 1000 W/m^2
- absorption coefficient 0,5
- emissivity coefficient 0,5

Transmission capacity increasing (“uprating“)

Increasing	**Method**	**Tool**
Current	temperature increase	higher conductor suspension point conductor mechanical strain change
	conductor change	compact / smooth conductors high-temperature conductors
	special method	statistical methods real-time methods
Voltage	insulation	insulators exchange / additional insul. fixing modification
	distance to the ground	higher conductor suspension point conductor mechanical strain change
	phase-to-phase distance	double line change to a simple one new tower head

OHL conductors

Usually more materials, strength + conductivity.

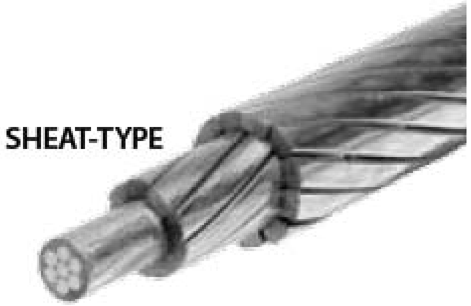
Classical conductors

- ACSR (Aluminium Conductor Steel Reinforced)
- AAAC (All-Aluminium Alloy Conductor)
  - stronger than ACSR, more resistant against corrosion, more resistant surface
- ACAR (Aluminium Conductor Alloy Reinforced)
  - higher ampacity and mech. strength for the same weight as ACSR
- AACSR (Aluminium Alloy Conductor Steel Reinforced)
  - for more severe climate, river crossings,…
- AAC (All Aluminium Conductor)
  - high ampacity, for shorter spans

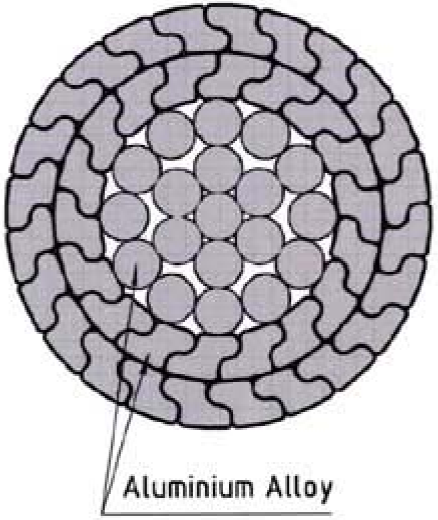
Compact conductors – “without air gaps”, extremely “sheath-type” – full material;

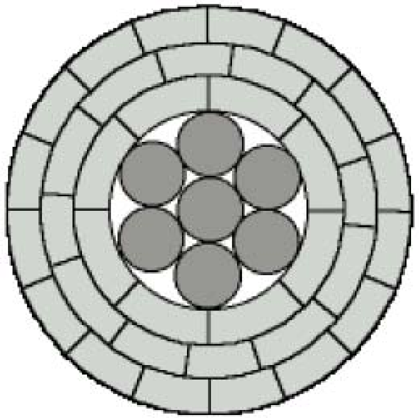
  - more conductive x more heavy, smaller diameter enough, lower power losses, higher endurance against wind (conductors galloping reducing), corrosion reducing (lower grease losses), frost reducing

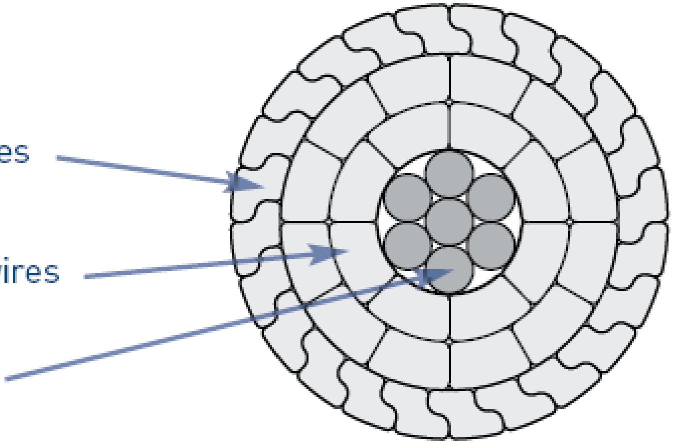
- sheath-type – smaller diameters, shorter spans



- compact profiles: ACSR/TW, AERO-Z







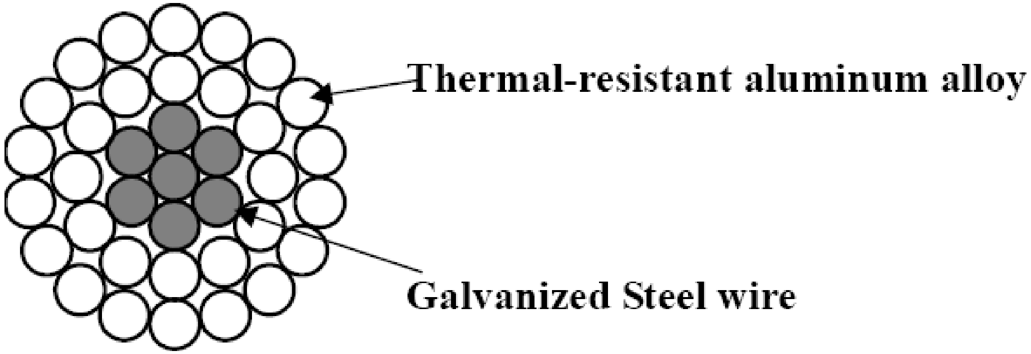
z-shaped aluminium alloy wires

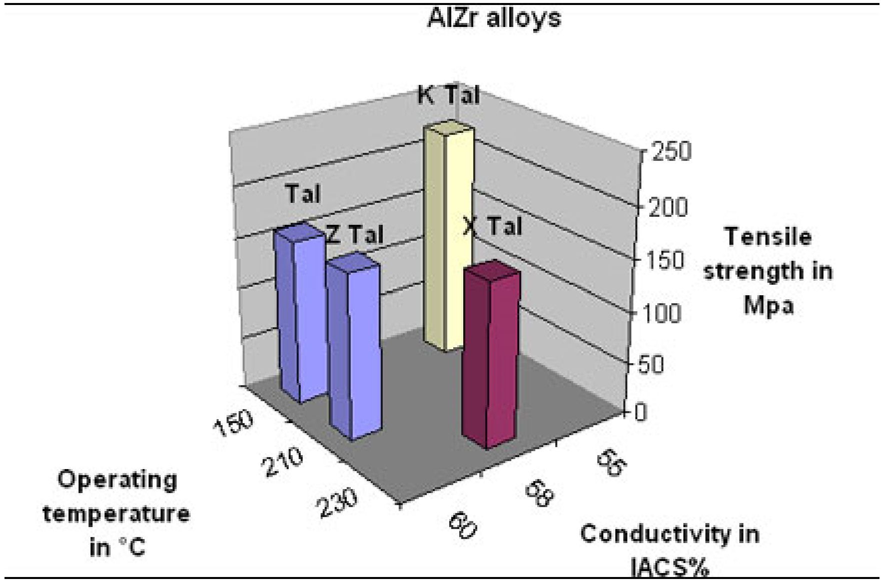
trapezoidal aluminium alloy wires

round aluminium alloy wires

High-temperature conductors

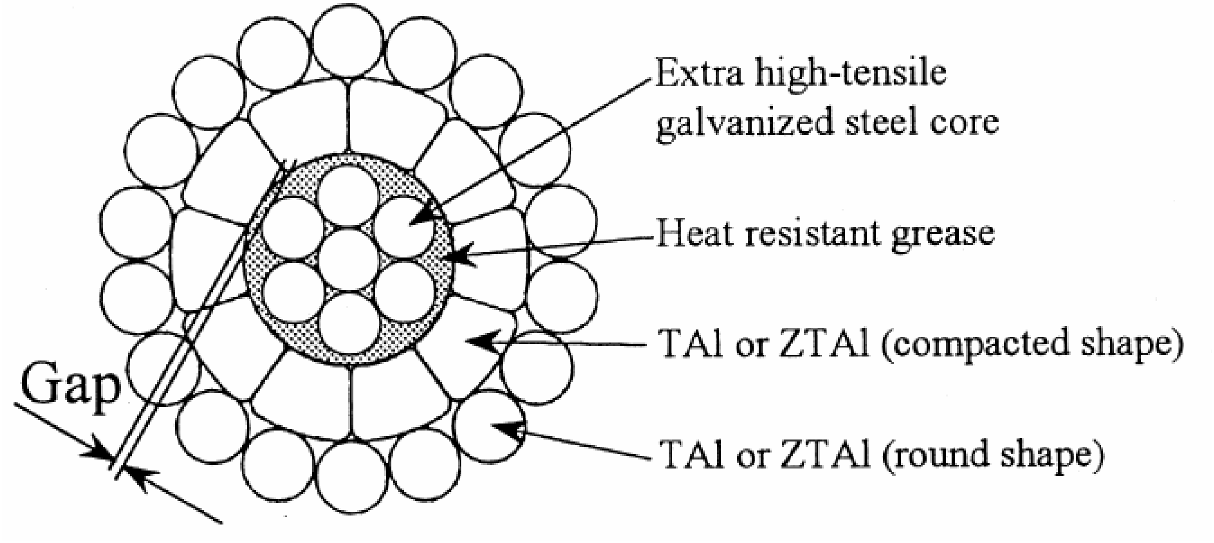
- aluminium and zirconium alloy with strength up to higher temperatures (TAl, ZTAl, XTAl) → e.g. TACSR
  Permitted steady temperature
  TAl: 150°C, ZTAl: 210°C, XTAl: 230°C



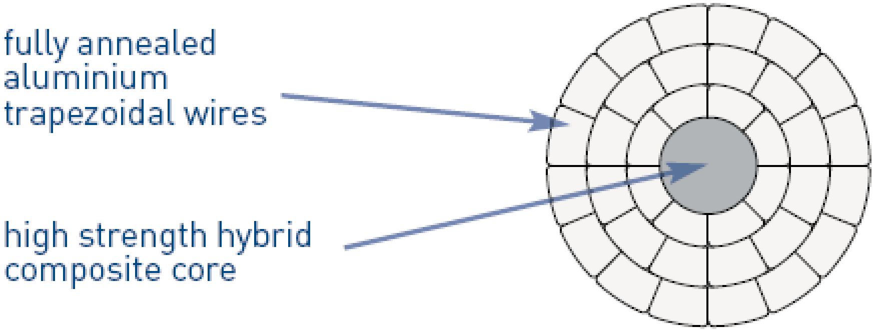


- strength given by both materials up to a knee-point, further only core, T_{kn} ≈ 100°C
- low core expansion: Invar (Fe + Ni), 1/3 against steel, c. $3\cdot10^{-6}\ K^{-1}$, small sag x lower strength (for shorter spans) → e.g. TACIR

- conductors with a gap between Fe and Al: GZTACSR (Gap-type ZT-Aluminium Conductor Steel Reinforced) – only the core stressed by tensile, i.e. core expansion
  ($11{,}5 \cdot 10^{-6}\ K^{-1}$ for Fe x $18 \cdot 10^{-6}\ K^{-1}$ u AlFe)



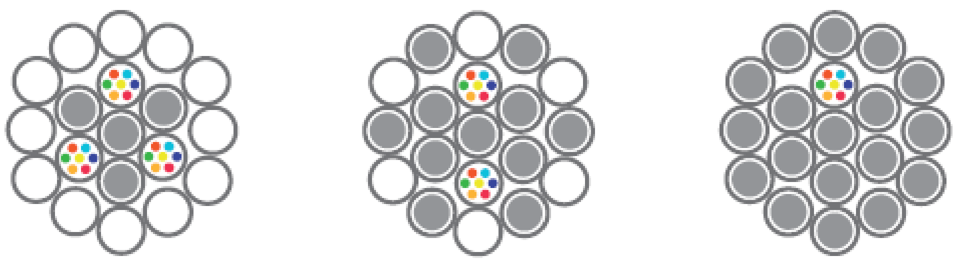
- composite materials: ACFR (Aluminium Conductor Carbon Fibre Reinforced), ACCC (Aluminium Conductor Composite Core)
    - composite of carbon and glass fibres, high strength, small expansion, without corrosion, long spans (up to 2,5 km), light, more Al, up to 150°C

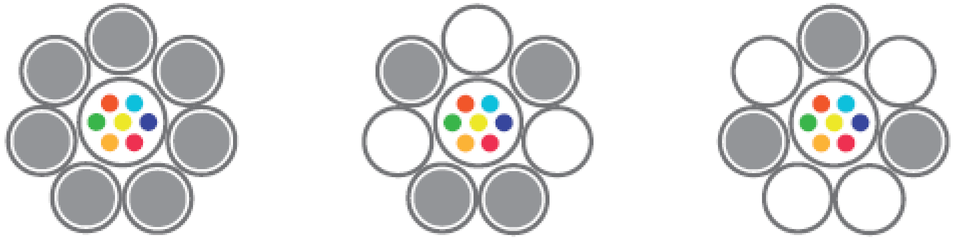


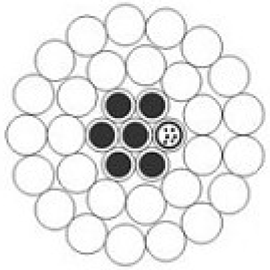
fully annealed aluminium trapezoidal wires

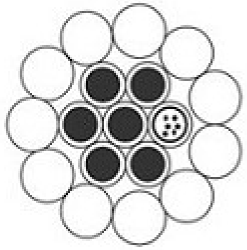
high strength hybrid composite core

- ACSS (Aluminium Conductor Steel Supported) – core covered by Zn-Al against corrosion, it carries the full strain, coat from annealed aluminium, up to 200°C
- optical fibres: OPGW (Optical Ground Wire) – most often in ground wires, communication

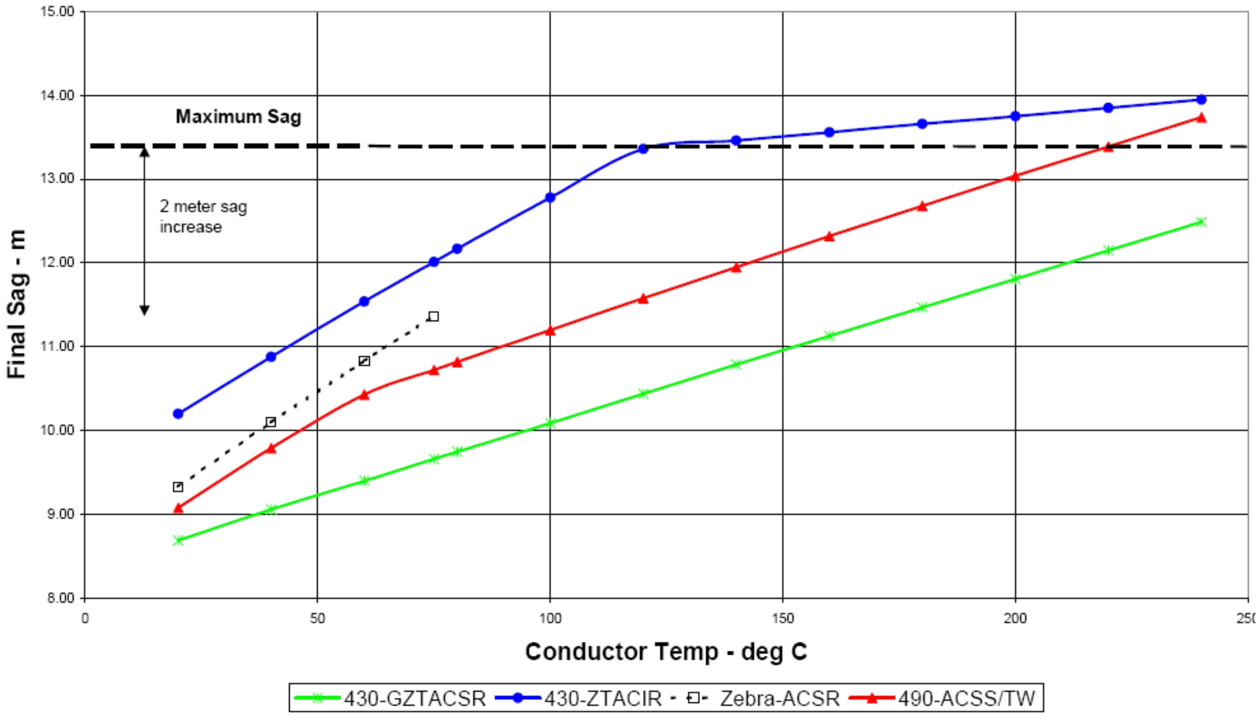

Konstrukce OPGW se slaněnou trubičkou


Konstrukce OPGW se středovou trubičkou





Case 1 - Final Sag vs Conductor Temperature



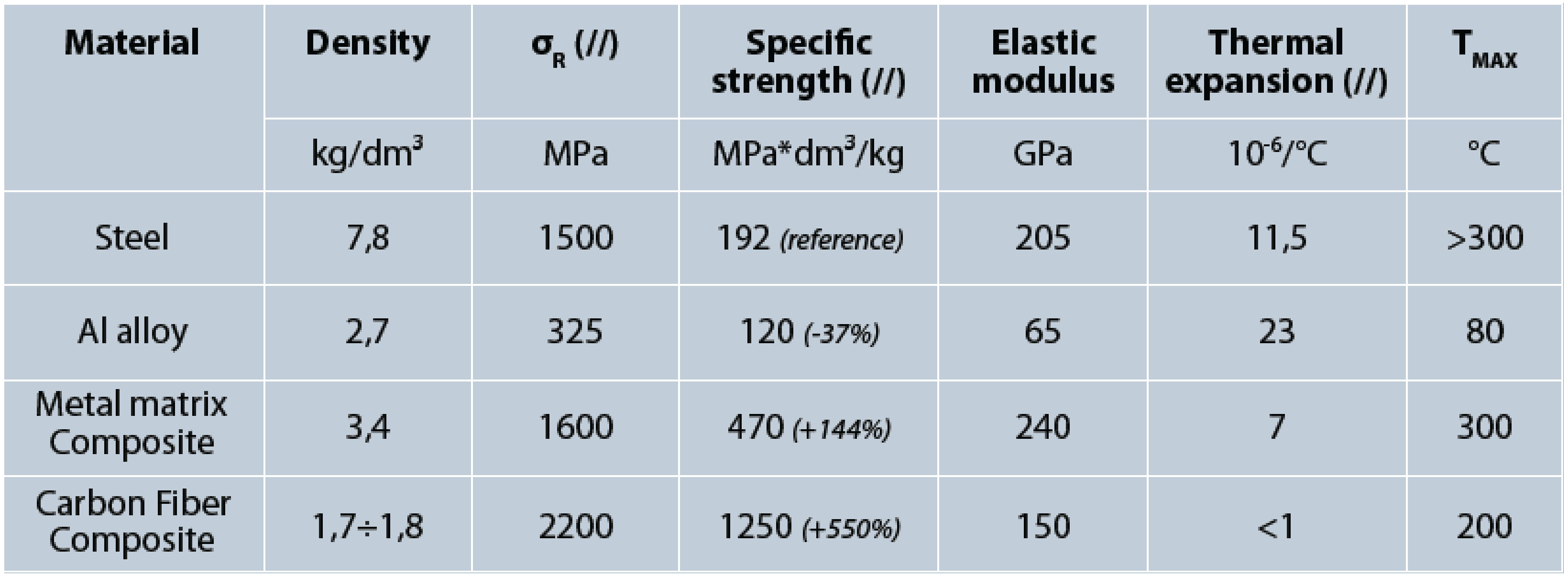
Most often used aluminium alloys characteristics

Type of aluminium		**Conductivity (%IACS)**	**Min. tensile strength (MPa)**	**Allowed operating temperature (°C)**	
				Steady-state	**Emergency**
Hard drawn	1350-H19	61,2	159 – 200	90	120
Thermal resistant	TAL	60	159 – 176	150	180
Extra thermal resistant	ZTAL	60	159 – 176	210	240
Fully annealed	1350-0	63	59 – 97	200 – 250	250

Most often used steels characteristics

	Min. tensile strength (MPa)	**Modulus of elasticity (GPa)**	**Coef. of linear expansion $(x10^{-6})$**
Galvanized steel HS	1230 – 1320	206	11,5
Galvanized steel EHS	1765		
Al clad steel 20,3 % I.A.C.S	1103 – 1344	162	13,0
Zinc – 5 % Al			
Mischmetal		206 (initial)	11,5
Standart	1380 – 1450	186 (final)	
HS	1520 – 1620		
Galv. Invar Alloy	1030 – 1080	162	2,8 – 3,6

Other core materials characteristics



Material	**Density**	**σ_R (//)**	**Specific strength (//)**	**Elastic modulus**	**Thermal expansion (//)**	**T_{MAX}**
	kg/dm^3	MPa	MPa*dm^3/kg	GPa	10^{-6}/°C	°C
Steel	7,8	1500	192 *(reference)*	205	11,5	>300
Al alloy	2,7	325	120 *(-37%)*	65	23	80
Metal matrix Composite	3,4	1600	470 *(+144%)*	240	7	300
Carbon Fiber Composite	1,7÷1,8	2200	1250 *(+550%)*	150	<1	200