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

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

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)

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

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

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 angle (°)

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 $\mathrm{Nu}_N = f(\mathrm{Re})$

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%)

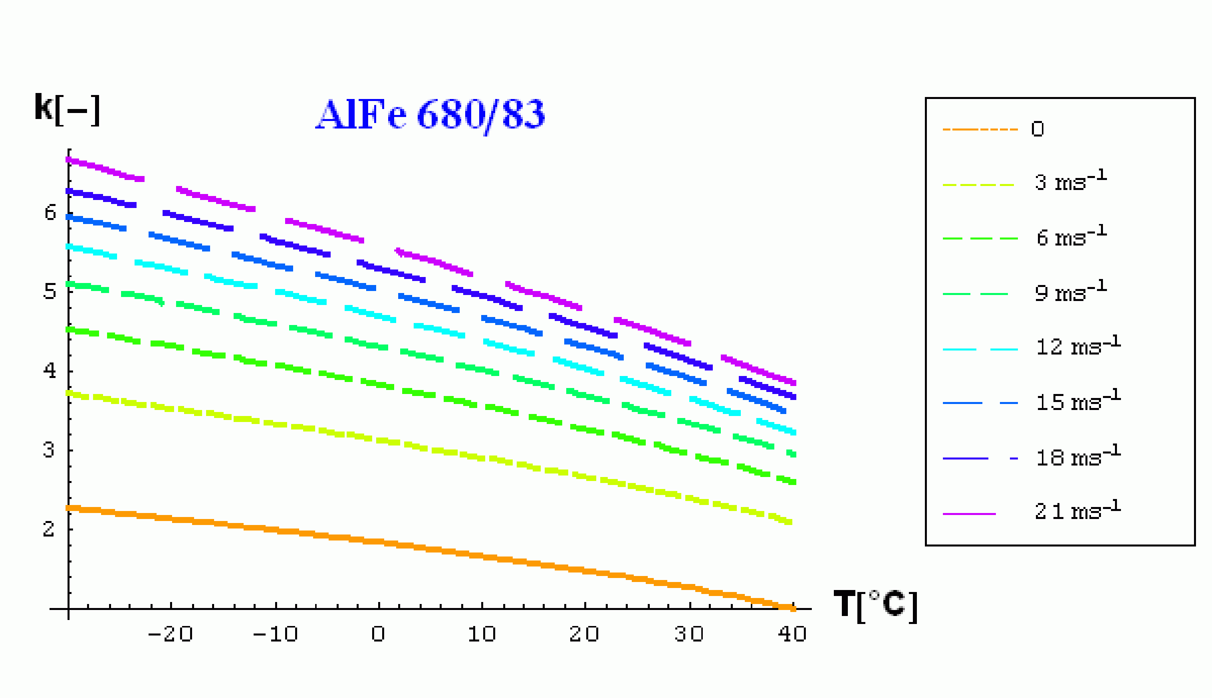
Steady states

Ampacity for given temperature

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

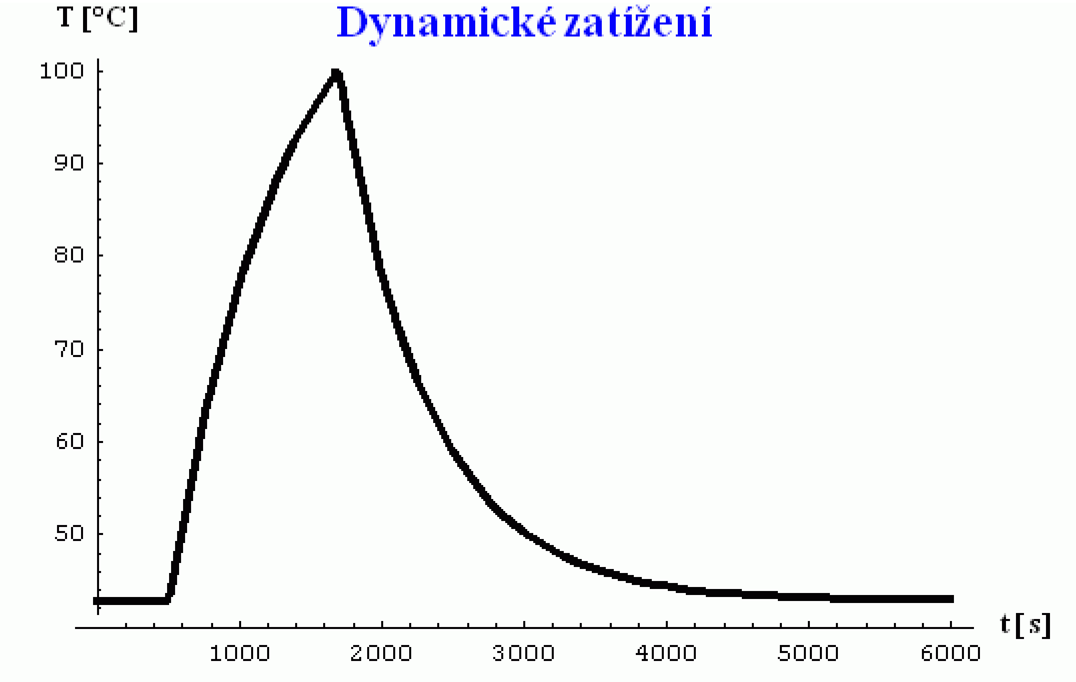
Steady temperature – 4th order algebraic equation

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 2292A.

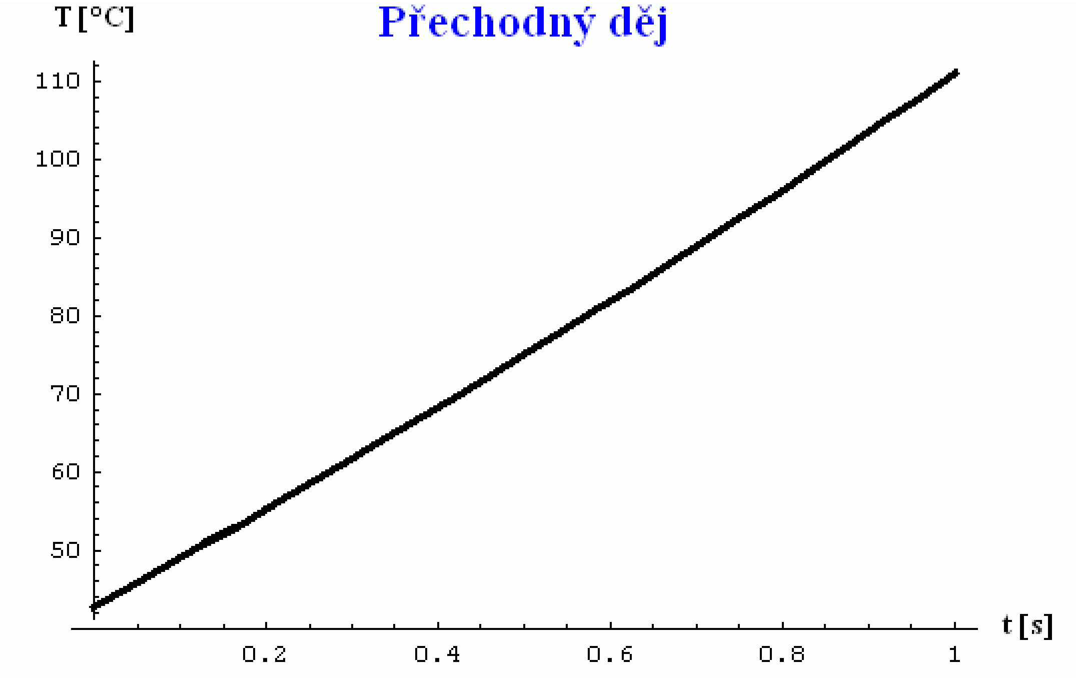


Transient events

- 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 50kA for 1s



OHL ampacity

Limit factors for loading

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

Temperature measurement

- contact
- thermovision
- sag by means of laser → T
- phasor measurement → average T
- mechanical auto-oscillations → sag → T
- longitudinal temperature by means of reflections in optical wires

Loading

- static – constant limits, sometimes summer x winter (protections setting)
- dynamic
    - online – conductor temperature measurement → data to dispatching → 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

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 conditions		
		sub-critical	critical	limiting
T_a (ºC)	-30 to 35	30	35	40
w_S (m/s)	0,6 to 30	1,34	0,6	0
I_{gm} (W/m^2)	0 to 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

OHL conductors

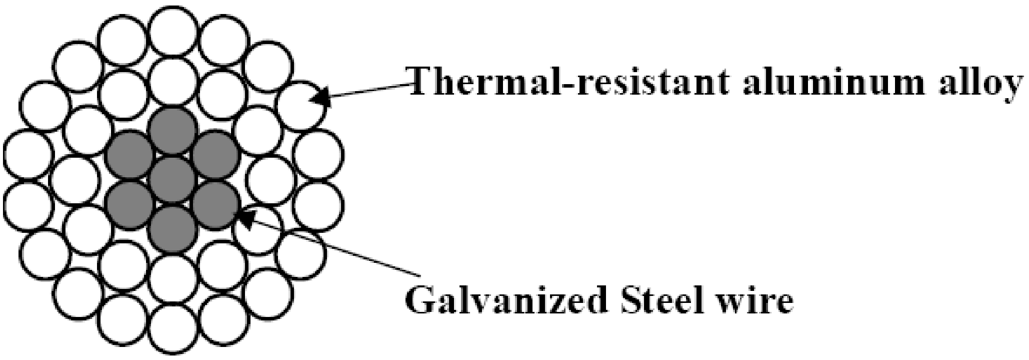
Usually more materials, strength + conductivity.

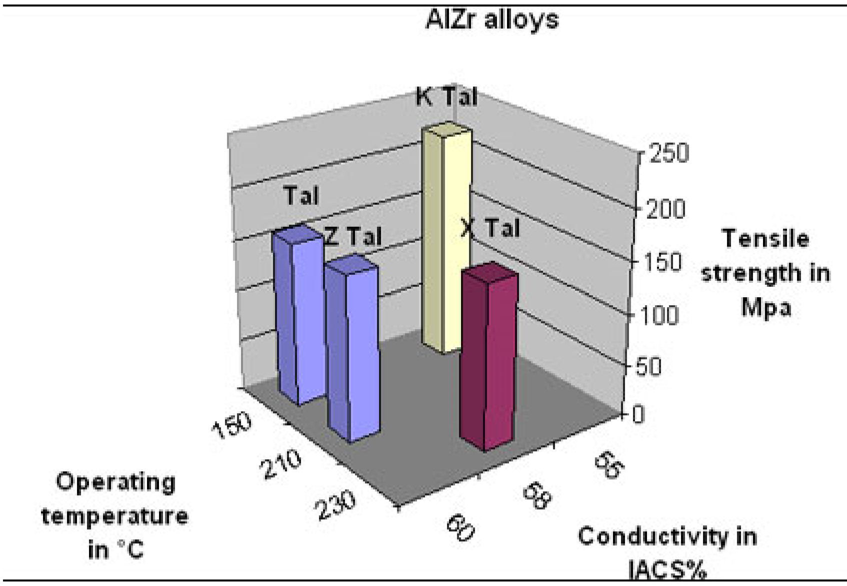
- ACSR (Aluminium Conductor Steel Reinforced)
- AAAC (All-Aluminium Alloy Conductor)
- ACAR (Aluminium Conductor Alloy Reinforced)
- AACSR (Aluminium Alloy Conductor Steel Reinforced)
- AAC (All Aluminium Conductor)

Compact conductors – „without air gaps“, more conductive x more heavy

High-temperature conductors

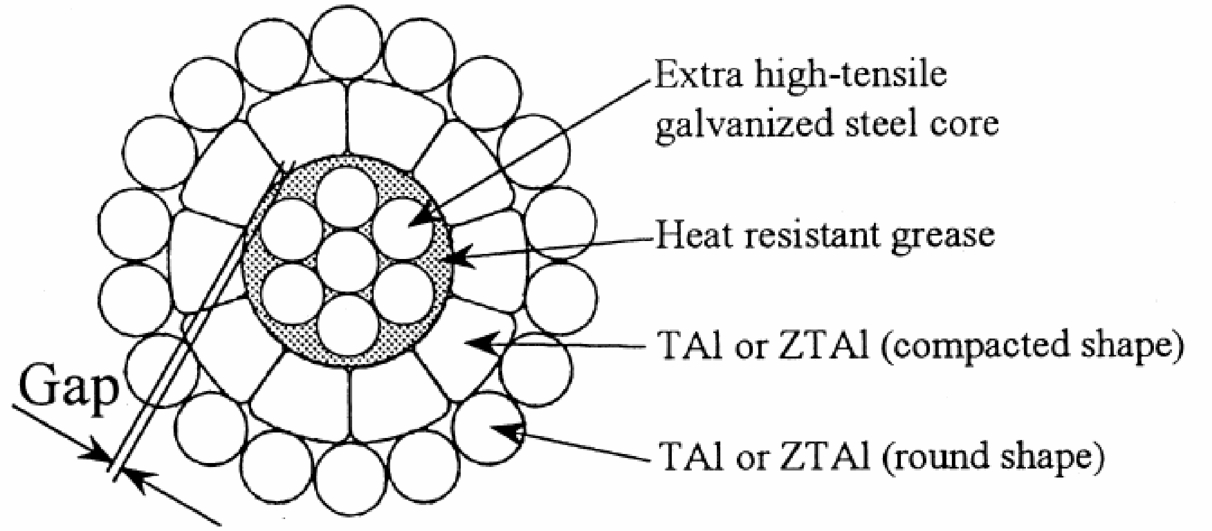
- aluminium and zirconium alloy with strength up to higher temperatures (TAl, ZTAl, XTAl) → e.g. TACSR
  Permitted steady temperature
  TAl: 150°C, ZTAl: 210°C, XTAl: 230°C



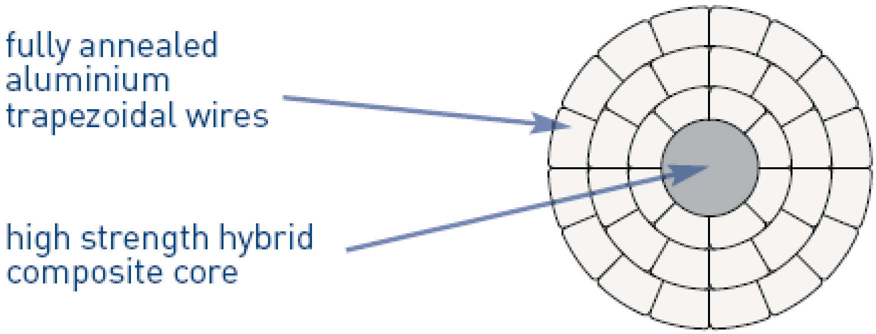


- strength given by both materials up to a knee-point, further only core, $T_{kn} \approx 100°C$
- low core expansion: Invar (Fe + Ni), 1/3 against steel, c. $3\cdot10^{-6}\ K^{-1}$, small sag x lower strength → e.g. TACIR

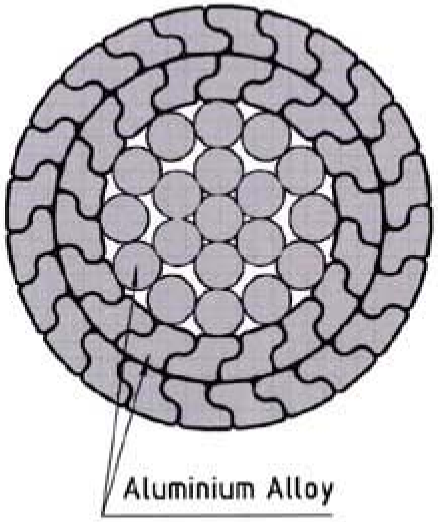
- conductors with a gap between Fe and Al: GZTACSR (Gap-type ZT-Aluminium Conductor Steel Reinforced) – only the core stressed by tensile, i.e. core expansion ($11{,}5\cdot10^{-6}$ K^{-1} for Fe x $18\cdot10^{-6}$ K^{-1} u AlFe)

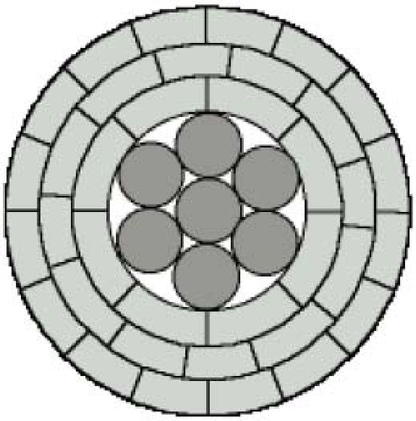


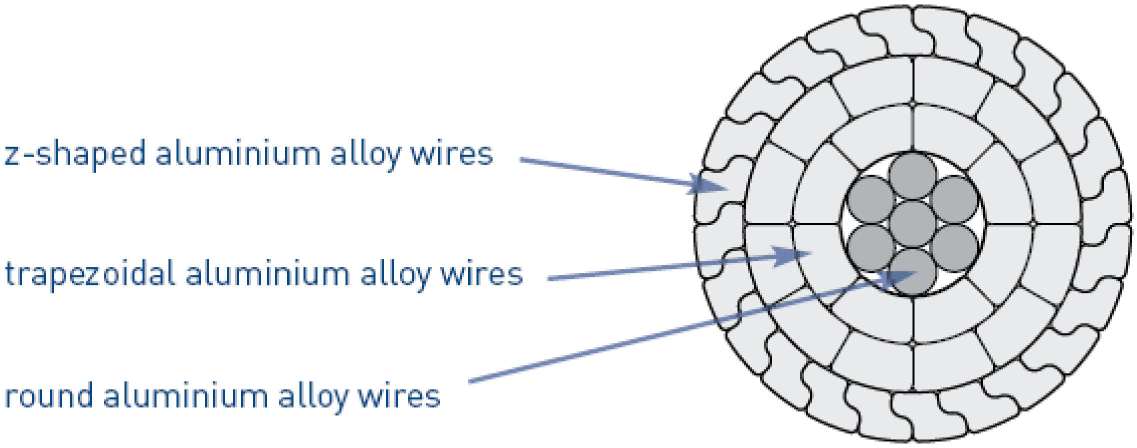
- composite materials: ACFR (Aluminium Conductor Carbon Fibre Reinforced), ACCC (Aluminium Conductor Composite Core) – small expansion, light, more Al, do 150°C



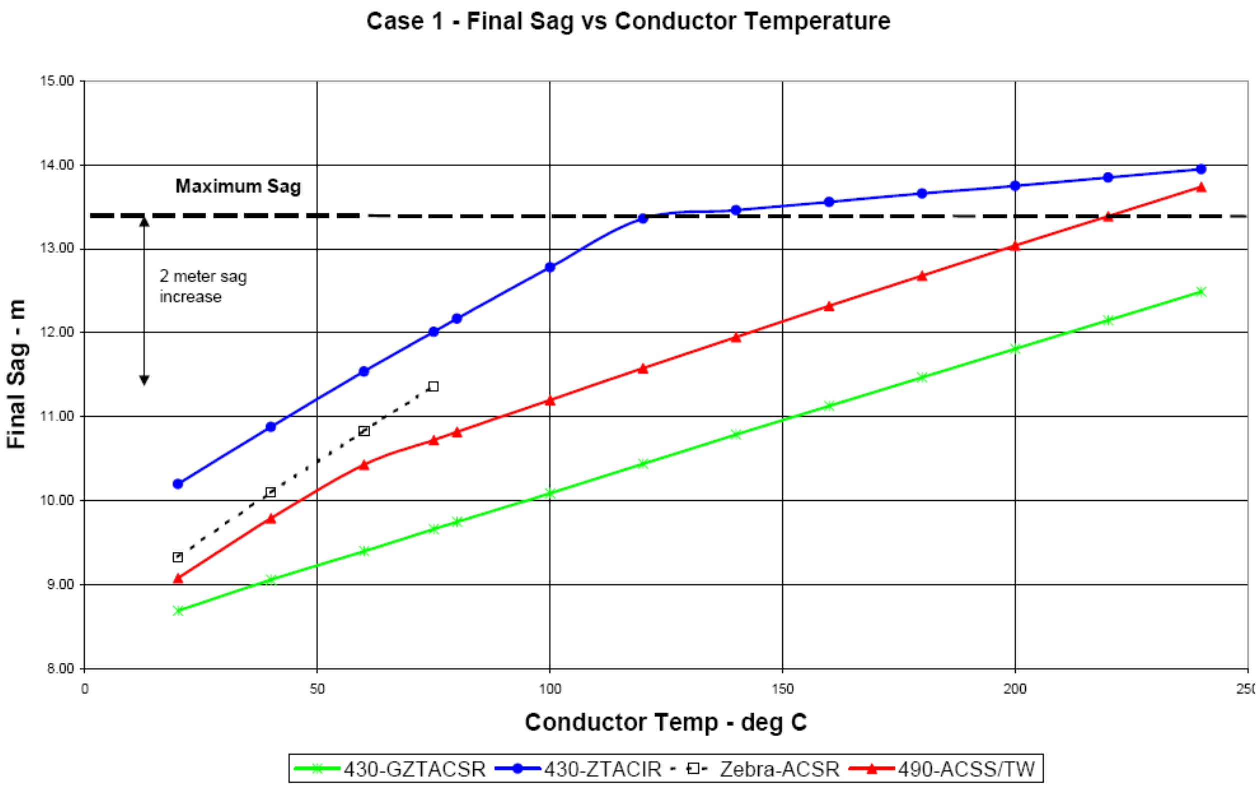
- compact profiles: ACSR/TW, AERO-Z – smaller diameter sufficient, higher endurance against wind







- optical wires: OPGW (Optical Ground Wire)
  – most often in ground wires
  – communication


Case 1 - Final Sag vs Conductor Temperature
Maximum Sag
2 meter sag increase
Final Sag - m
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
0
50
100
150
200
25
Conductor Temp - deg C
430-GZTACSR
430-ZTACIR
Zebra-ACSR
490-ACSS/TW