

Report

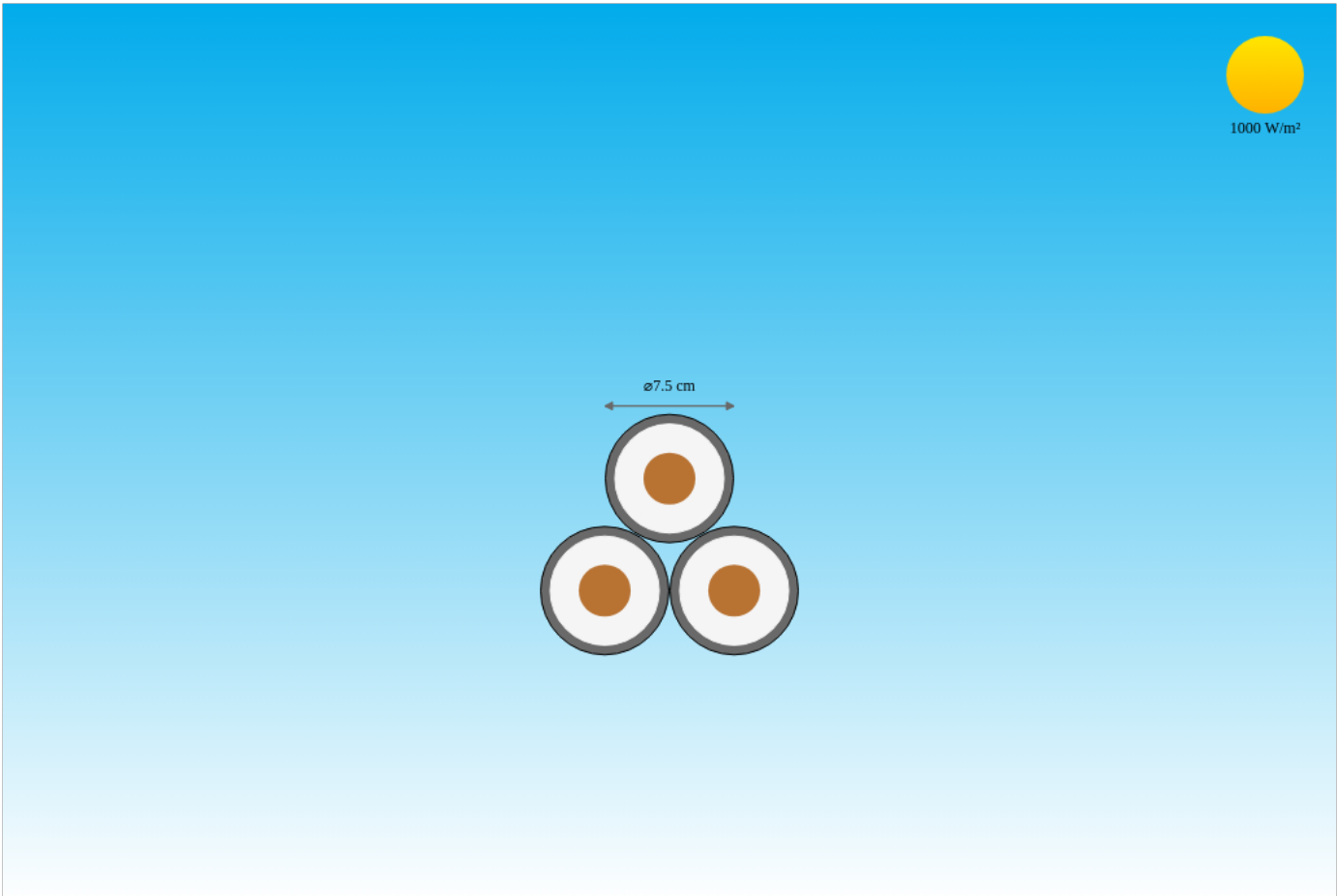
Title	Case study 0-4: Introductory (in air)
Project	Verification CIGRE TB 880
Description	Sub-case study with cables laid in free air directly exposed to solar radiation
Created	Date: 2025-05-14 Time: 21:28 Software version: 51cac (2025-05-14)

Arrangement

Arrangement	in air project (#3934)
Options	None
CIGRE TB 880, guidance points	02, 06, 26, 31
Systems	A

Statistics

Number of iterations of the solver	N_{calc}	16
Sum of currents from all systems	I_{sum}	990.94 A
Sum of average conductor temperatures from all systems	θ_{sum}	90 °C
Number of overheated electrical systems		0
Sum of losses from all systems	W_{sum}	152.31 W/m



Systems

Following systems are active in the arrangement:

#	Object	Current [A]	Temp. [°C]	Losses [W/m]	Load
		I_c	θ_c θ_e	W_{sys}	LF
A	16173 CIGRE TB 880 Case 0 XLPE insulated ca...	990.9	90.0 70.9	152.3	1.00

Objects

Following objects are used:

16173 CIGRE TB 880 Case 0 XLPE insulated cable 132 kV

Ambient

Ambient temperature	θ_a	25 °C
Intensity of solar radiation	H_{sun}	1000 W/m ²

Constants

Standard acceleration of gravity	g	9.80665 m/s ²
Archimedes' constant π	π	3.141592653589793
Absolute temperature	θ_{abs}	273.15 K
Stefan Boltzmann constant	σ	5.67036713e-8 W/m ² K ⁴
Vacuum permeability	μ_0	1.2566370614359173e-6 H/m
Vacuum permittivity	ϵ_0	8.854187817620389e-12 F/m

System A (High voltage cable)**Ampacity**

Cable		CIGRE TB 880 Case 0 XLPE insulated cable 132 kV
Rounded value, CIGRE TB 880	I_c	990 A
Conductor current	I_c	990.94 A
$\sqrt{\frac{\theta_c - \theta_a - \Delta\theta_d - \Delta\theta_{sun}}{R_c (T_1 + n_{ph} (1 + \lambda_1) T_2 + (1 + \lambda_1 + \lambda_2 + \lambda_3) (n_{ph} T_3 + n_{cc} (T_{4i} + T_{4ii} + T_{4iii})) + n_{cc} \lambda_4 \left(\frac{T_{4ii}}{2} + T_{4iii}\right))}}$		
Operating voltage	U_o	132 kV
Angular frequency $2\pi f$	ω	314.2 rad/s
Number of sources in system	N_c	3
Number of conductors combined	n_{cc}	1

Load

System frequency	f	50 Hz
Continuous load	LF	1 p.u.

Arrangement

Arrangement		trefoil
Position cable 1	$x_1 y_1$	0.0 -43.6 mm
Position cable 2	$x_2 y_2$	-37.7 21.8 mm
Position cable 3	$x_3 y_3$	37.7 21.8 mm
Separation of conductors in a system	s_c	75.5 mm
Mean distance between the phases	a_m	95.124 mm
Geometric mean distance between phases of the same system	GMD	95.12404 m
Outer diameter	D_o	0.0755 m

Temperature

Temperature conductor $\theta_a + \Delta\theta_c + \Delta\theta_{sun}$	θ_c	90 °C
Temperature screen/sheath	θ_s	73.62 °C
Temperature sheath $\theta_c - T_1 \left(W_c + \frac{W_d}{2}\right)$	θ_{sh}	73.62 °C
External temperature object $\theta_c - T_1 \left(W_c + \frac{W_d}{2}\right) - n_{ph} T_2 (W_c (1 + \lambda_1) + W_d) - n_{ph} T_3 (W_I + W_d)$	θ_e	70.87 °C

Temperature rise

Temperature rise conductor $n_{ph} (W_c T_{int} + W_d T_d) + n_{cc} \left((W_c + W_s + W_{ar} + W_{sp} + W_d) (T_{4i} + T_{4ii} + T_{4iii}) + W_{duct} \left(\frac{T_{4ii}}{2} + T_{4iii}\right) \right)$	$\Delta\theta_c$	47.8905 K
Temperature rise dielectric losses $W_d (n_{ph} T_d + n_{cc} (T_{4i} + T_{4ii} + T_{4iii}))$	$\Delta\theta_d$	0.3199 K
Temperature difference surface—ambient $\frac{\Delta\theta_s + T_{4iii} n_{cc} W_t + \Delta\theta_{sun}}{2}$	$\Delta\theta_s$	45.8726 K

Temperature difference solar radiation $\sigma_{sun} D_o H_{sun} T_{4iii}$	$\Delta\theta_{sun}$	17.1095 K
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Losses**Ohmic**

Conductor losses (phase) $I_c^2 R_c$	W_c	38.809 W/m
Screen/sheath losses (phase) $\lambda_1 W_c$	W_s	11.576 W/m
Duct losses	W_{duct}	0 W/m
Ohmic losses (phase) $W_c (1 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$	W_I	50.385 W/m

Dielectric

Dielectric losses (phase) $\omega C_b \left(1000 \frac{U_o}{\sqrt{3}}\right)^2 \tan\delta_i$	W_d	0.385 W/m
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Total

Total losses (phase) $W_I + W_d$	W_t	50.77 W/m
Total losses (object) $n_{ph} W_t$	W_{tot}	50.77 W/m
Total losses (system)	W_{sys}	152.31 W/m

Thermal resistance

Thermal resistance ambient $\frac{1}{\pi D_o h_{bs} \Delta\theta_s^{\frac{1}{4}}}$	T_{4iii}	0.5665 K.m/W
Intensity of solar radiation	H_{sun}	1000 W/m ²
Heat dissipation coefficient for black surfaces in free air $\frac{Z_{bs}}{D_o^{g_{bs}}} + E_{bs}$	h_{bs}	2.859 W/m ² /K ^{5/4}
Installation constant E	E_{bs}	1.25
Installation constant g	g_{bs}	0.2
Installation constant Z	Z_{bs}	0.96

Cable

Internal thermal resistance for current losses $\frac{T_1}{n_{ph}} + (1 + \lambda_1) T_2 + (1 + \lambda_1 + \lambda_2 + \lambda_3) T_3$	T_{int}	0.4902 K.m/W
Internal thermal resistance for dielectric losses $\frac{T_1}{2n_c} + T_2 + T_3$	T_d	0.26414 K.m/W

Other characteristics

Earthing

earthing screen/sheath	both-side bonding
Variation of spacing	No variation

Loss factor

Loss factor shield (screen/sheath)	λ_1	0.2983
$\lambda_{11} + \lambda_{12}$		
Loss factor shield, circulating currents	λ_{11}	0.2983
$\frac{\frac{R_e}{R_c}}{1 + \left(\frac{R_e}{X_e}\right)^2}$		
Loss factor shield, eddy currents	λ_{12}	0
Electrical resistance shield/armour	R_e	2.0298e-1 Ω/km
Factor F_e eddy-current losses	F_e	1
Loss factor armour	λ_2	0

Electrical parameters

System

System length	L_{sys}	1000 m
Power factor	$\cos\varphi$	1

Resistance

Electrical resistance conductor	R_c	3.9522e-5 $\Omega/\text{m} \rightarrow 0.0395 \Omega$
$R_{cDC} (1 + y_s + y_p)$		
Electrical resistance DC conductor	R_{cDC}	3.6085e-5 $\Omega/\text{m} \rightarrow 0.0361 \Omega$
$R_{c20} (1 + \alpha_c (\theta_c - 20))$		
Skin effect factor conductor	y_s	0.06012
$\frac{x_s^4}{192 + 0.8x_s^4}$		
Factor for skin effect on conductor	x_s	1.86612
$\sqrt{10^{-7} \frac{8\pi f}{R_{cDC}} k_s}$		
Proximity effect factor conductor	y_p	0.0351
$\frac{x_p^4}{192 + 0.8x_p^4} \left(\frac{d_c}{s_c}\right)^2 \left(0.312 \left(\frac{d_c}{s_c}\right)^2 + \frac{1.18}{\frac{x_p^4}{192 + 0.8x_p^4} + 0.27}\right)$		
Factor for proximity effect of conductors	x_p	1.86612
$\sqrt{10^{-7} \frac{8\pi f}{R_{cDC}} k_p}$		
Electrical resistance sheath	R_{sh}	2.0298e-4 $\Omega/\text{m} \rightarrow 0.203 \Omega$
$R_{sh} (1 + \alpha_{sh} (\theta_{sh} - 20))$		
Electrical resistance shield	R_s	2.0298e-4 $\Omega/\text{m} \rightarrow 0.203 \Omega$
Reduction factor	RF	0.3014
$\frac{R_s}{\sqrt{R_s^2 + X_s^2}}$		

Electrical field strength, capacitive load current

Electrical field strength insulation inner/outer $\frac{U_e}{1000} \frac{1}{r_x \ln \left(\frac{r_{osc}}{r_{isc}} \right)}$	E_i	6.956 3.603 kV/mm
Radius to point x in insulation $\frac{1000 U_o}{\sqrt{3}}$	r_x	16.65 32.15 mm
Line-to-ground voltage $\frac{1000 U_o}{\sqrt{3}}$	U_e	76210.24 V
Capacitance insulation $\frac{1}{2\pi\epsilon_0} \frac{10^{-9}}{18} C_b$	C_b	2.111e-10 F/m $\rightarrow$ 0.2111 μ F
Capacitive load current $U_e \omega C_b$	I_C	5.054e-3 A/m $\rightarrow$ 5.0536 A
Charging capacity $n_{ph} U_e^2 \omega C_b$	P_C	385.1382 var/m $\rightarrow$ 385.1382 kvar
Capacitive earth short-circuit current $U_e \omega C_E$	I_{Ce}	5.054e-3 A/m

Reactance

Self reactance conductor $\omega \frac{\mu_0}{2\pi} \ln \left(\frac{D_E}{GMR_c} \right)$	X_a	7.088e-4 Ω /m $\rightarrow$ 0.7088 Ω
Self reactance screen/sheath $\omega \frac{\mu_0}{2\pi} \ln \left(\frac{2s_c}{d_s} \right)$	X_e	5.040e-5 Ω /m $\rightarrow$ 0.0504 Ω

Induced current (approximate)

Induced circulating current shield $\max \left(I_c \sqrt{\frac{\lambda_{11, sb} R_c}{R_s}} \right)$	I_s	238.810+0.000j A
Loss factor shield, circulating currents	$\lambda_{11, sb}$	0.2983+0.0000j

Load, Voltage drop

Apparent power generator-side $\sqrt{3} U_o I_c$	S_G	226.56 MVA
Voltage drop $\sqrt{3} (R_c \cos \varphi + \omega L_m \sin \varphi)$	V_{drop}	0.068 V/(A.km) $\rightarrow$ 67.8 V = 0.05%
Inductance (mean) $\frac{\mu_0}{2\pi} \ln \left(\frac{GMD}{GMR_c} \right)$	L_m	1.800e-6+0.000e0j H/m $\rightarrow$ 1.8002 mH

Telegrapher equation

Surge impedance $\sqrt{\frac{Z_1}{Y_1}}$	Z_C	92.4076-3.2248j Ω
Propagation constant $\sqrt{Z_1 Y_1}$	γ_C	2.138e-7+6.128e-6j

Impedance valid up to 100 Hz without earth return

Positive sequence admittance $G + j\omega C_b$	Y_1	$0.000e0 + 6.631e-8j \text{ S/m} \rightarrow 0.0000 + 0.0001j \text{ S}$
Positive sequence impedance $R_1 + jX_1$	Z_1	$3.952e-5 + 5.656e-4j \text{ }\Omega/\text{m} \rightarrow 0.0395 + 0.5656j \text{ }\Omega$
Positive sequence reactance $\omega \frac{\mu_0}{2\pi} \ln\left(\frac{GMD}{GMR_c}\right)$	X_1	$5.656e-4 \text{ }\Omega/\text{m} \rightarrow 0.5656 \text{ }\Omega$

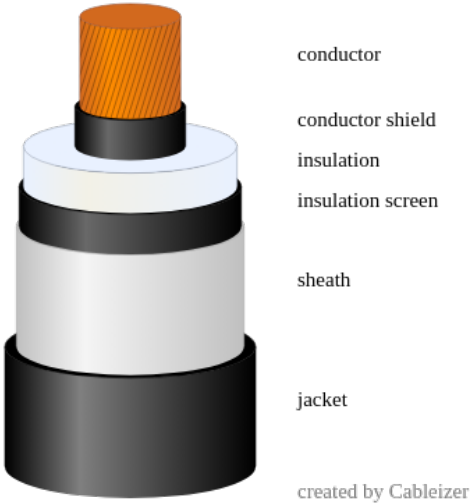
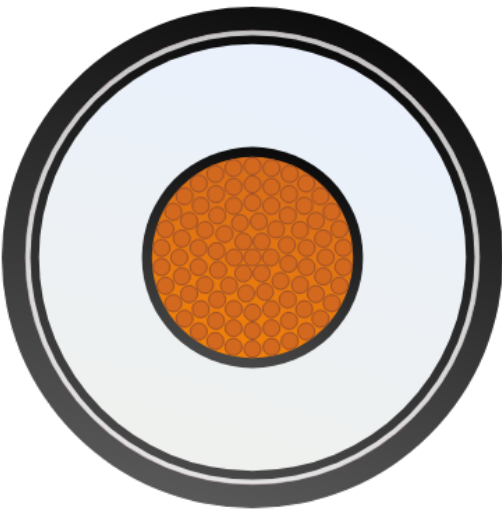
Cable datasheet

TitleCIGRE TB 880 Case 0 XLPE insulated cable 132 kV (#16173)

Cable is used in following systems: AIR
CIGRE TB 880, guidance points15, 20, 23, 25, 30, 32, 33, 34, 38, 39, 42, 44, 45

General Data

Rated line-to-line voltage	U_n	132 kV
Base voltage for tests	U_0	76 kV
Highest voltage for equipment	U_m	145 kV
Nominal system frequency	f	50 Hz
Number of conductors cable	n_c	1
Number of phases in a cable	n_{ph}	1



Cable elements

Conductor

Cross-sectional area conductor	A_c	1 x 630 mm ²
Conductor material	M_c	Copper, round stranded
External diameter conductor	d_c	30.3 mm
Radius conductor	r_c	15.15 mm
$\frac{d_c}{2}$		

Insulation

Insulation material	M_i	Crosslinked polyethylene (XLPE)
Thickness conductor shield	t_{cs}	1.5 mm
Thickness insulation	t_{ins}	15.5 mm
Thickness insulation screen	t_{is}	1.3 mm
Thickness insulation	t_i	18.3 mm
$t_{ct} + t_{cs} + t_{ins} + t_{is}$		

Sheath

Sheath material	M_{sh}	Aluminium
Thickness sheath corrugated	t_{sh}	0.8 mm No

Jacket

Jacket material	M_j	High density polyethylene (HDPE, ST7)
Thickness jacket	t_j	3.5 mm

Overall

External diameter object	D_e	75.5 mm
Absorption coefficient solar radiation	σ_{sun}	0.4
Emissivity cable	ϵ_e	0.9
Reflectivity cable $1 - \epsilon_e$	η_e	0.1
Mass cable $m_{hollow} + m_{metal}$	m_{tot}	9.418 kg/m

Electrical**Conductor**

Electrical resistance DC conductor 20°C	R_{c20}	2.8300e-5 Ω /m
Standard DC resistance of conductor	R_{co}	0.0283 Ω /km
Coating of wires		plain
Skin effect coefficient	k_s	1
Proximity effect coefficient	k_p	1
Geometric mean radius conductor $K_{GMR} r_{z1}$	GMR_c	0.01173 m
Factor geometric mean radius	K_{GMR}	0.774
Constant relating to conductor formation	K_{BICC}	0.0512
Number of wires conductor	n_{cw}	91
Diameter of wires conductor (average)	d_{cw}	2.97 mm

Insulation

Capacitance, with approximation (CIGRE TB 880) $\frac{1}{2\pi\epsilon_0} \frac{10^{-9}}{18} C_b$	C_b	2.111e-10 F/m
Capacitance (exact) $\frac{2\pi\epsilon_0\epsilon_i}{\ln\left(\frac{r_{osc}}{r_{isc}}\right)}$	C_b	2.114e-10 F/m
Capacitance to earth C_b	C_E	2.111e-10 F/m
Vacuum permittivity	ϵ_0	8.854187817620389e-12 F/m
Radius above the inner semi-conducting layer $\frac{d_c}{2} + t_{ct} + t_{cs}$	r_{isc}	16.65 mm
Radius over capacitive insulation layers $\frac{D_{ins}}{2}$	r_{osc}	32.15 mm

Velocity of propagation	v_{prop}	189605.4 km/s
$\frac{1}{1000\sqrt{\mu_0\epsilon_0\epsilon_i}}$		

Screen + Sheath

Electrical resistance sheath	R_{sh}	1.6691e-4 Ω /m
$10^6 \frac{\rho_{sh}}{A_{sh}}$		
Electrical resistance screen/sheath 20°C	R_{so}	1.669e-1 Ω /km

Radius

Radius conductor	r_{z1}	0.01515 m
Radius shield (inner)	r_{z2}	0.03305 m
Radius shield (outer)	r_{z3}	0.03305 m
Radius sheath (inner)	$r_{z2,sh}$	0.03305 m
Radius sheath (outer)	$r_{z3,sh}$	0.03465 m
Radius outersheath	r_{z6}	0.03775 m

Material parameters

Conductor

Electrical resistivity conductor material	ρ_c	1.724e-8 Ω .m
Temperature coefficient conductor material	α_c	3.93e-3 1/K
Reciprocal of temperature coefficient conductor material	β_c	2.345e2 K
Volumetric heat capacity conductor material	σ_c	3.45e6 J/(K.m ³)
Thermal conductivity conductor material	k_c	384.62 W/(m.K)
Density conductor material	ζ_c	8.94 g/cm ³

Insulation

Relative permittivity insulation material	ϵ_i	2.5
Loss factor insulation material	$\tan\delta_i$	0.001
Thermal resistivity insulation material	ρ_i	3.5 K.m/W
Volumetric heat capacity insulation material	σ_i	2.40e6 J/(K.m ³)
Density insulation material	ζ_i	0.923 g/cm ³
Max. temperature conductor	θ_{cmax}	90 °C
Max. temperature conductor, emergency overload	θ_{cmaxeo}	105 °C
Max. temperature conductor, short-circuit	θ_{cmaxsc}	250 °C

Conductor shield

Thermal resistivity conductor shield	ρ_{cs}	2.5 K.m/W
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Insulation screen

Thermal resistivity insulation screen	ρ_{is}	2.5 K.m/W
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Sheath

Specific electrical resistivity sheath material	ρ_{sh}	2.840e-8 Ω .m
Temperature coefficient sheath material	α_{sh}	4.03e-3 1/K
Reciprocal of temperature coefficient sheath material	β_{sh}	2.281e2 K
Volumetric heat capacity sheath material	σ_{sh}	2.50e6 J/(K.m ³)
Thermal conductivity sheath material	k_{sh}	208.3 W/(m.K)
Density sheath material	ζ_{sh}	2.712 g/cm ³

Jacket

Thermal resistivity jacket material	ρ_j	3.5 K.m/W
Thermal resistivity additional layer	ρ_{jj}	2.5 K.m/W
Volumetric heat capacity jacket material	σ_j	2.40e6 J/(K.m ³)
Electrical conductivity jacket material	κ_j	2.00e-15 S/m
Density jacket material	ζ_j	0.941 g/cm ³

Thermal resistance**Internal thermal resistances for rating calculation**

Thermal resistance conductor—sheath $T_{ct} + T_{cs} + T_{ins} + T_{is} + T_{scb} + T_{scs} + T_{dsh}$	T_1	0.4199 K.m/W
Thermal resistance armour bedding	T_2	0 K.m/W
Thermal resistance jacket $T_{ab} + T_j + T_{jj}$	T_3	0.0542 K.m/W
Thickness conductor—sheath $t_i + t_{scb} + t_{scs} + \frac{H_{sh} + \Delta H}{2}$	t_1	18.3 mm
Thickness sheath—armour $\frac{H_{sh} + \Delta H}{2} + t_{ab}$	t_2	0 mm
Thickness armour—surface $t_j + t_{jj}$	t_3	3.5 mm

Cable elements

Thermal resistance, transient $T_1 + T_2 + T_3$	T_{tot}	0.4741 K.m/W
Thermal resistance insulation $T_{ct} + T_{cs} + T_{ins} + T_{is}$	T_i	0.41987 K.m/W
Thermal resistance conductor shield $\frac{\rho_{cs}}{2\pi} \ln \left(\frac{D_{cs}}{D_{cs} - 2t_{cs}} \right)$	T_{cs}	0.03756 K.m/W
Thermal resistance insulation $\frac{\rho_i}{2\pi} \ln \left(\frac{D_{ins}}{D_{ins} - 2t_{ins}} \right)$	T_{ins}	0.36654 K.m/W
Thermal resistance insulation screen $\frac{\rho_{is}}{2\pi} \ln \left(\frac{D_{ins} + 2t_{is}}{D_{ins}} \right)$	T_{is}	0.01577 K.m/W
Thermal resistance jacket $\frac{\rho_j}{2\pi} \ln \left(\frac{D_j - 2t_{jj}}{D_j - 2(t_j + t_{jj})} \right)$	T_j	0.0542 K.m/W

Dimensions**Diameter**

External diameter conductor	d_c	30.3 mm
Diameter over conductor shield $d_c + 2(t_{ct} + t_{cs})$	D_{cs}	33.3 mm
Diameter over insulation $d_c + 2(t_{ct} + t_{cs} + t_{ins})$	D_{ins}	64.3 mm

Diameter over insulation incl. insulation screen $d_c + 2(t_{ct} + t_{cs} + t_{ins} + t_{is})$	D_i	66.9 mm
Diameter over insulation screen $d_c + 2t_i$	D_{is}	66.9 mm
Equivalent diameter of screen and sheath	d_s	67.7 mm
Mean diameter sheath $D_{shb} + t_{sh} + H_{sh} + \Delta H$	d_{sh}	67.7 mm
Diameter over sheath $D_{shb} + 2(t_{sh} + H_{sh} + \Delta H)$	D_{sh}	68.5 mm
Diameter over sheath jacket	D_{shj}	68.5 mm
Diameter over jacket $D_{ar} + 2(t_j + t_{jj})$	D_j	75.5 mm

Area

Cross-sectional area conductor	A_c	630 mm ²
Cross-sectional area insulation $\frac{\pi}{4} (D_{is}^2 - d_c^2)$	A_i	2794.1 mm ²
Cross-sectional area sheath $d_{sh} t_{sh} \pi$	A_{sh}	170.15 mm ²
Cross-sectional area jacket $\frac{\pi}{4} (D_j^2 - (D_j - 2(t_j + t_{jj}))^2)$	A_j	791.7 mm ²