Report

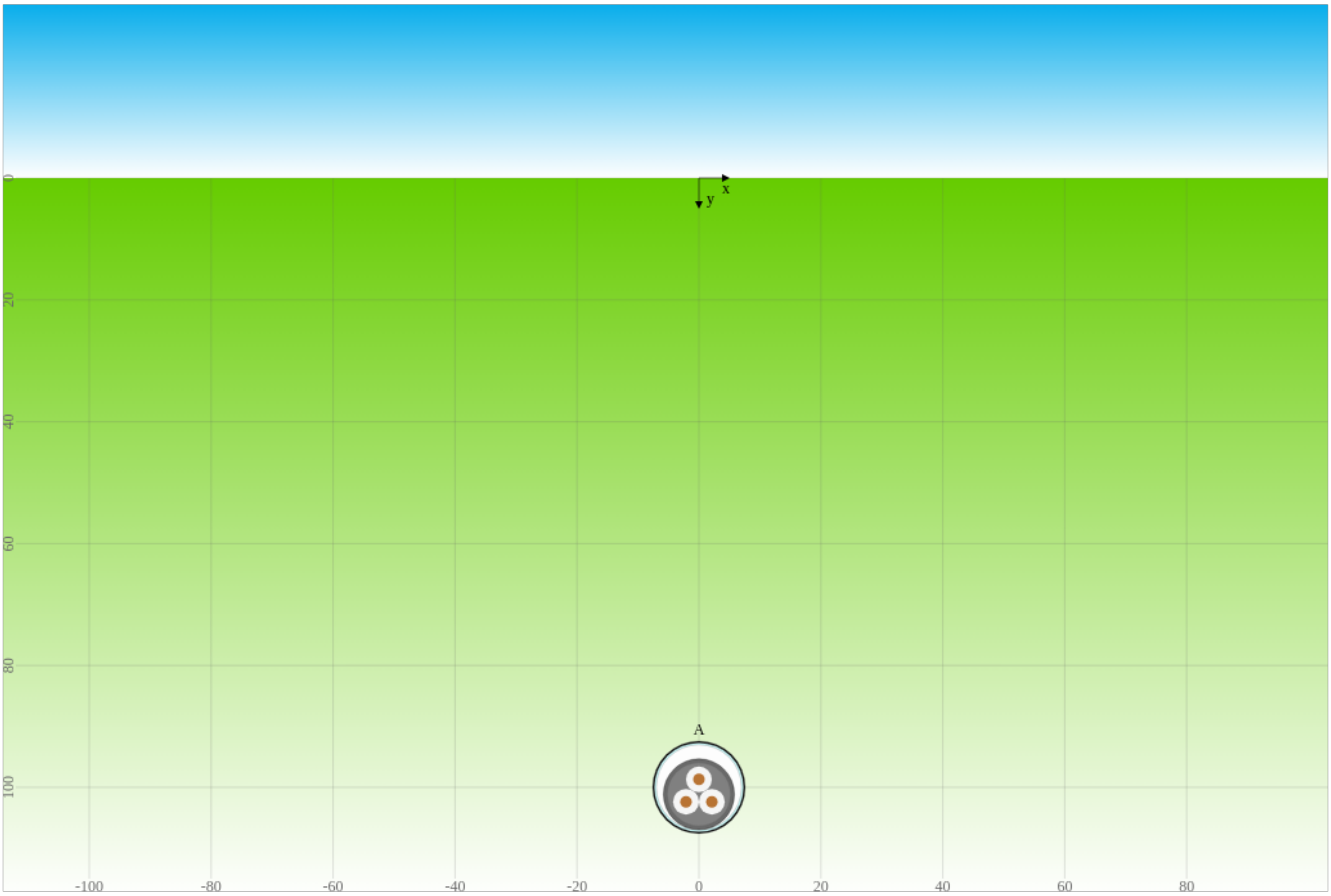
Title	Case study 9: A 110kV retrofitted cable
Project	Verification CIGRE TB 880
Created	Date: 2025-05-14 Time: 21:18 Software version: 51cac (2025-05-14)

Arrangement

Arrangement	**buried project** (#46695)
Options	None
CIGRE TB 880, guidance points	02, 06, 26, 31
Systems	A

Statistics

Number of iterations of the solver	N_{calc}	10
Sum of currents from all systems	I_{sum}	572.43 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}	74.759 W/m



Systems

Following systems are active in the arrangement:

#	Object	Current [A] I_c	Temp. [°C] θ_c | θ_e (θ_{de})	Losses [W/m] W_{sys}	Load LF
A	16305 CIGRE TB 880 Case 9 110kV retrofitted...	572.4	90.0 | 76.9 (58.9)	74.8	1.00

Objects

Following objects are used:

16305 CIGRE TB 880 Case 9 110kV retrofitted cable

Ambient

Calculation method		IEC Standard (directly buried)
Ambient temperature	θ_a	20 °C
Thermal resistivity soil	ρ_4	1 K.m/W
Thermal conductivity soil	k_4	1 W/(m.K)
Volumetric heat capacity soil material $10^{-4}\frac{{k_4}^{0.2}}{4.68}$	$c_{p,soil}$	2136.8 J/(kg.K)
Thermal diffusivity soil	δ_{soil}	5.00e-7 m^2/s
Ratio thermal resistivity dry/moist soil $\frac{\rho_{4d}}{\rho_4}$	v_4	1

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 9 110kV retrofitted cable
Rounded value, CIGRE TB 880	I_c	570 A
Conductor current	I_c	572.43 A

$$\sqrt{\frac{\theta_c - \theta_a + (v_4 - 1)\,\Delta\theta_x - v_4\Delta\theta_p - \Delta\theta_d}{R_c\left(T_1 + n_{ph}\left(1+\lambda_1\right)T_2 + \left(1+\lambda_1+\lambda_2+\lambda_3\right)\left(n_{ph}T_3 + n_{cc}\left(T_{4i} + T_{4ii} + T_{4\mu}v_4\right)\right) + n_{cc}\lambda_4\left(\frac{T_{4ii}}{2} + T_{4\mu}v_4\right)\right)}}$$

Operating voltage	U_o	110 kV
Angular frequency $2\pi f$	ω	314.2 rad/s
Number of sources in system	N_c	1
Number of conductors combined $N_c n_{ph}$	n_{cc}	3

Load

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

Arrangement

Duct material	M_d	steel pipe, non-magnetic
Diameter duct inner, outer	$Di_d\|Do_d$	140.0 | 152.0 mm
Equivalent diameter of a group of round objects $F_{eq}D_e$	D_{eq}	106 mm
Factor for envelope circle for a group of equal circles	F_{eq}	1
Thermal resistivity duct material	ρ_d	3.5 K.m/W
Volumetric heat capacity duct material	σ_d	3.80e6 J/(K.m^3)
Absorption coefficient solar radiation	σ_{sun}	0.3
Arrangement		individual
Position duct 1	$x_1\|y_1$	0.0 | 1000.0 mm
Separation of conductors in a system	s_c	52.1 mm
Mean distance between the phases	a_m	52.1 mm
Geometric mean distance between phases of the same system GMR_{cc}	GMD	0.01091 m
Depth of laying of sources	L_c	1000 mm
Depth of laying	L_{cm}	1 m
Outer diameter	D_o	0.152 m
Substitution coefficient u $\frac{2L_{cm}}{D_o}$	u	13.1579
Geometric constant of circle buried $u + \sqrt{u^2 - 1}$	g_u	26.2777

Temperature

Temperature conductor $\theta_a + \Delta\theta_c - (v_4 - 1)\,\Delta\theta_x + v_4\Delta\theta_p$	θ_c	90 °C
Temperature screen/sheath	θ_s	81.73 °C

Temperature sheath θ_{sh} 81.73 °C

$$\theta_c - T_1\left(W_c + \frac{W_d}{2}\right)$$

Temperature armour θ_{ar} 76.87 °C

$$\theta_c - T_1\left(W_c + \frac{W_d}{2}\right) - n_{ph}T_2\left(W_c\left(1+\lambda_1\right) + W_d\right)$$

External temperature object θ_e 76.87 °C

$$\theta_c - T_1\left(W_c + \frac{W_d}{2}\right) - n_{ph}T_2\left(W_c\left(1+\lambda_1\right) + W_d\right) - n_{ph}T_3\left(W_I + W_d\right)$$

Duct

Mean temperature medium in the duct θ_{dm} 68.72 °C

$$\frac{\theta_e}{2} + \frac{\theta_{di}}{2}$$

Temperature duct inner surface θ_{di} 60.57 °C

$$\theta_e - T_{4i}n_{cc}\left(W_I + W_d\right)$$

Temperature duct outer surface θ_{de} 58.89 °C

$$\theta_{di} - T_{4ii}n_{cc}W_t + \frac{T_{4ii}W_{duct}}{2}n_{cc}$$

Temperature rise

Temperature rise conductor $\Delta\theta_c$ 70 K

$$n_{ph}\left(W_cT_{int} + W_dT_d\right) + n_{cc}\left(W_d\left(T_{4i} + T_{4ii} + v_4T_{4ss}\right) + \left(W_c + W_s + W_{ar} + W_{sp}\right)\left(T_{4i} + T_{4ii} + v_4T_{4\mu}\right) + W_{duct}\left(\frac{T_{4ii}}{2} + v_4T_{4\mu}\right)\right)$$

Temperature rise dielectric losses $\Delta\theta_d$ 0.8215 K

$$W_d\left(n_{ph}T_d + n_{cc}\left(T_{4i} + T_{4ii} + T_{4ss}v_4\right)\right)$$

Temperature rise duct (magnetic) $\Delta\theta_{duct}$ 0 K

Temperature rise by other buried objects $\Delta\theta_p$ 0 K

$$\sum_{k=1}^{q}\Delta\theta_{kp}$$

Critical soil temperature rise $\Delta\theta_x$ 0 K

Losses

Ohmic

Conductor losses (phase) W_c 20.867 W/m

$${I_c}^2R_c$$

Screen/sheath losses (phase) W_s 0.889 W/m

$$\lambda_1W_c$$

Armour losses (phase) W_{ar} 2.859 W/m

$$\lambda_2W_c$$

Duct losses W_{duct} 0 W/m

Ohmic losses (phase) W_I 24.615 W/m

$$W_c\left(1+\lambda_1+\lambda_2+\lambda_3+\lambda_4\right)$$

Dielectric

Dielectric losses (phase) W_d 0.304 W/m

$$\omega C_b\left(1000\frac{U_o}{\sqrt{3}}\right)^2\tan\delta_i$$

Total

Total losses (phase) $W_I + W_d$	W_t	24.92 W/m
Total losses (object) $n_{ph} W_t$	W_{tot}	74.759 W/m
Total losses (system)	W_{sys}	74.759 W/m

Thermal resistance

Thermal resistance ambient $= T_{4ss} = T_{4iii} = \frac{\rho_4}{2\pi} \left(\ln(g_u) + \ln(F_{mh})\right)$	$T_{4\mu}$	0.5202 K.m/W
Mutual heating coefficient	F_{mh}	1

Duct

Thermal resistance medium in the duct $\frac{U_d}{1 + 0.1\left(V_d + Y_d \theta_{dm}\right) D_{eq}}$	T_{4i}	0.2181 K.m/W
Constant U for cables in ducts	U_d	5.2
Constant V for cables in ducts	V_d	1.4
Constant Y for cables in ducts	Y_d	0.011
Thermal resistance duct wall $\frac{\rho_d}{2\pi} \ln\left(\frac{Do_d}{Do_d - 2t_{dp}}\right)$	T_{4ii}	0.0224 K.m/W

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}	0.2077 K.m/W
Internal thermal resistance for dielectric losses $\frac{T_1}{2n_c} + T_2 + T_3$	T_d	0.13892 K.m/W

Other characteristics

Earthing

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

Loss factor

Loss factor shield (screen/sheath) $\lambda_{11} + F_e \lambda_{12}$	λ_1	0.0426
Loss factor shield, circulating currents $\frac{1.5 \frac{R_e}{R_c}}{1 + \left(\frac{R_e}{X_e}\right)^2}$	λ_{11}	0.0358
Loss factor shield, eddy currents $\frac{R_{sh}}{R_c} \left(g_s \lambda_0 (1 + \Delta_1 + \Delta_2) + \frac{(\beta_1 t_{sh})^4}{12 \cdot 10^{12}}\right)$	λ_{12}	0.0068
Electrical resistance shield/armour	R_e	1.5765e0 Ω/km

Substitution coefficient λ_0 for eddy-currents $3\frac{m_0{}^2}{1+m_0{}^2}\left(\frac{d_e}{2s_c}\right)^2$	λ_0	0.0003
Substitution coefficient Δ_1 for eddy-currents $\left(1.14m_0{}^{2.45}+0.33\right)\left(\frac{d_e}{2s_c}\right)^{0.92m_0+1.66}$	Δ_1	0.0897
Substitution coefficient Δ_2 for eddy-currents	Δ_2	0
Substitution coefficient m_0 for eddy-currents $10^{-7}\frac{\omega}{R_{sh}}$	m_0	0.0199 Hz.m/Ω
Substitution coefficient β_1 for eddy-currents $\sqrt{\frac{4\pi\omega}{10^7\rho_{sh}\left(1+\alpha_{sh}\left(\theta_{sh}-20\right)\right)}}$	β_1	105.5072
Substitution coefficient g_s for eddy-currents $1+\left(\frac{t_{sh}}{D_{sh}}\right)^{1.74}\left(10^{-3}\beta_1 D_{sh}-1.6\right)$	g_s	1.000151
Factor F_e eddy-current losses $\frac{4M_e{}^2N_e{}^2+\left(M_e+N_e\right)^2}{4\left(M_e{}^2+1\right)\left(N_e{}^2+1\right)}$	F_e	0.999
Substitution coefficient M_e to calculate factor F_e $\frac{R_e}{X_e}$	M_e	32.1839
Substitution coefficient N_e to calculate factor F_e $\frac{R_e}{X_e}$	N_e	32.1839
Loss factor armour $\max\left(\left(1-\frac{R_c}{R_s}\lambda_{11}\right)\lambda_{21},0\right)$	λ_2	0.137
Loss factor armour, circulating currents $1.23\frac{R_{ar}}{R_c}\left(\frac{2c_c}{d_{ar}}\right)^2\frac{1}{\left(\frac{2.77R_{ar}\cdot 10^6}{\omega}\right)^2+1}$	λ_{21}	0.1372

Drying-out of soil

Characteristic diameter drying zone	D_{dry}	0.152 m
Depth characteristic diameter drying zone	L_{dry}	1 m
Geometric constant of circle drying zone	g_{dry}	1 p.u.
Substitution coefficient g	g_a	1

Electrical parameters

System

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

Resistance

Electrical resistance conductor $R_{cDC}\left(1+1.5\left(y_s+y_p\right)\right)$	R_c	6.3681e-5 Ω/m → 0.0637 Ω
Electrical resistance DC conductor $R_{c20}\left(1+\alpha_c\left(\theta_c-20\right)\right)$	R_{cDC}	5.9930e-5 Ω/m → 0.0599 Ω

Skin effect factor conductor $\frac{{x_s}^4}{192+0.8{x_s}^4}$	y_s	0.02249
Factor for skin effect on conductor $\sqrt{10^{-7}\frac{8\pi f}{R_{cDC}}k_s}$	x_s	1.44805
Proximity effect factor conductor $\frac{{x_p}^4}{192+0.8{x_p}^4}\left(\frac{d_c}{s_c}\right)^2\left(0.312\left(\frac{d_c}{s_c}\right)^2+\frac{1.18}{\frac{{x_p}^4}{192+0.8{x_p}^4}+0.27}\right)$	y_p	0.01924
Factor for proximity effect of conductors $\sqrt{10^{-7}\frac{8\pi f}{R_{cDC}}k_p}$	x_p	1.44805
Electrical resistance sheath $R_{sh}\left(1+\alpha_{sh}\left(\theta_{sh}-20\right)\right)$	R_{sh}	1.5695e-03 Ω/m
Electrical resistance sheath, CIGRE TB 880 $F_{lay,3c}R_{sh}$	R_{sh}	1.5765e-03 Ω/m
Electrical resistance shield	R_s	1.5765e-3 Ω/m → 1.5765 Ω
Reduction factor $\frac{R_s}{\sqrt{{R_s}^2+{X_s}^2}}$	RF	0.9216
Electrical resistance armour $R_{ar}\left(1+\alpha_{ar}\left(\theta_{ar}-20\right)\right)$	R_{ar}	5.9019e-4 Ω/m → 0.5902 Ω

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	8.611 | 4.817 kV/mm
Radius to point x in insulation	r_x	12.7 | 22.7 mm
Line-to-ground voltage $\frac{1000U_o}{\sqrt{3}}$	U_e	63508.53 V
Capacitance insulation $\frac{1}{2\pi\epsilon_0}\frac{10^{-9}}{18}C_b$	C_b	2.402e-10 F/m → 0.2402 μF
Capacitive load current $U_e\omega C_b$	I_C	4.793e-3 A/m → 4.7927 A
Charging capacity $n_{ph}{U_e}^2\omega C_b$	P_C	913.1241 var/m → 913.1241 kvar
Capacitive earth short-circuit current $3U_e\omega C_E$	I_{Ce}	1.438e-2 A/m

Reactance

Self reactance conductor $\omega\frac{\mu_0}{2\pi}\ln\left(\frac{D_E}{GMR_c}\right)$	X_a	7.241e-4 Ω/m → 0.7241 Ω

Self reactance screen/sheath $\omega \frac{\mu_0}{2\pi} \ln\left(\frac{2a_m}{d_s}\right)$	X_e	4.877e-05 Ω/m
Self reactance screen/sheath, CIGRE TB 880 $F_{lay,3c} X_e$	X_e	4.898e-05 Ω/m

Induced current (approximate)

Induced circulating current shield $\max\left(I_c \sqrt{\frac{\lambda_{11,sb} R_c}{R_s}}\right)$	I_s	21.773+0.000j A
Loss factor shield, circulating currents	$\lambda_{11,sb}$	0.0358+0.0000j
Induced circulating current armour $\max\left(I_c \sqrt{\frac{\lambda_{21} R_c}{R_{ar}}}\right)$	I_{ar}	69.653 A

Load, Voltage drop

Apparent power generator-side $\sqrt{3} U_o I_c$	S_G	109.063 MVA
Voltage drop $\sqrt{3}\left(R_c \cos\varphi + \omega L_m \sin\varphi\right)$	V_{drop}	0.11 V/(A.km) → 63.1 V = 0.06%
Inductance (mean) $\frac{\mu_0}{2\pi} \ln\left(\frac{GMD}{GMR_c}\right)$	L_m	3.441e-8+0.000e0j H/m → 0.0344 mH

Telegrapher equation

Surge impedance $\sqrt{\frac{Z_1}{Y_1}}$	Z_C	22.9947-19.6340j Ω
Propagation constant $\sqrt{Z_1 Y_1}$	γ_C	1.482e-6+1.735e-6j

Impedance valid up to 100 Hz without earth return

Positive sequence admittance $G + j\omega C_b$	Y_1	0.000e0+7.546e-8j S/m → 0.0000+0.0001j S
Positive sequence impedance $R_1 + jX_1$	Z_1	6.814e-5+1.081e-5j Ω/m → 0.0681+0.0108j Ω
Positive sequence reactance $\omega \frac{\mu_0}{2\pi} \ln\left(\frac{GMD}{GMR_c}\right)$	X_1	1.081e-5 Ω/m → 0.0108 Ω

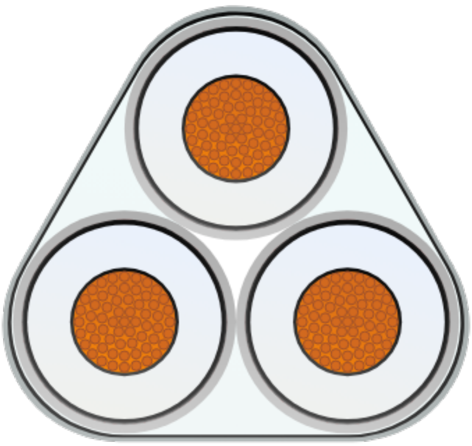
Cable datasheet

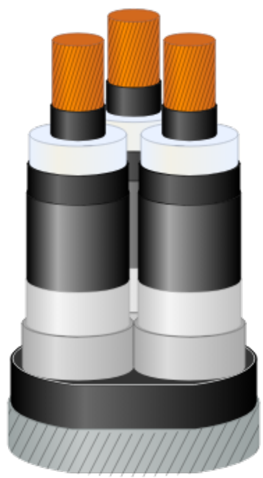
Title	CIGRE TB 880 Case 9 110kV retrofitted cable (#16305)

Info! Electric stress is higher than recommended in NF-C33-252 ($U_n \geq 60$ kV).
Cable is used in following systems: A
CIGRE TB 880, guidance points 15, 20, 23, 25, 30, 32, 33, 34, 38, 39, 42, 44, 45

General Data

Rated line-to-line voltage	U_n	110 kV
Base voltage for tests	U_0	64 kV
Highest voltage for equipment	U_m	123 kV
Nominal system frequency	f	50 Hz
Number of conductors cable	n_c	3
Number of phases in a cable	n_{ph}	3





Cable elements

Conductor

Cross-sectional area conductor	A_c	3 x 400 mm^2
Conductor material	M_c	Copper, round stranded
External diameter conductor	d_c	23.8 mm
Radius conductor $\frac{d_c}{2}$	r_c	11.9 mm
Geometrical distance factor for multi-core cables $1+\frac{1}{sin\left(\frac{\pi}{3}\right)}$	F_x	2.1547
Distance conductor axis—cable axis $\frac{D_f - s_c}{2}$	c_c	30.45 mm
Separation of conductors in a system D_{shj}	s_c	52.1 mm

Insulation

Insulation material	M_i	Crosslinked polyethylene (XLPE)
Thickness conductor shield	t_{cs}	0.8 mm
Thickness insulation	t_{ins}	10 mm
Thickness insulation screen	t_{is}	0.8 mm
Thickness insulation $t_{ct} + t_{cs} + t_{ins} + t_{is}$	t_i	11.6 mm
Thickness of insulation between conductors $2t_i$	t_{i1}	23.2 mm
Thickness of insulation between conductor and metallic sheath $t_i + t_{scb} + t_{scs} + t_f$	t_{i2}	12.37 mm

Screen bedding

Screen bedding material		Water-blocking tapes, semi-conducting
Thickness screen bedding	t_{scb}	0.4 mm

Sheath

Sheath material	M_{sh}	Aluminium
Thickness sheath	t_{sh}	0.15 mm
corrugated		No

Jacket over each core

Sheath jacket material	M_{shj}	Polyethylene (LD/MDPE)
Thickness sheath jacket	t_{shj}	2 mm

Filler

Filler material	M_f	Air
Thickness of filler/belt insulation	t_f	0.37 mm

Armour bedding

Armour bedding material	M_{ab}	Compounded jute
Thickness armour bedding	t_{ab}	0.85 mm

Armour

Construction of armour	a_{type}	Steel wires flat
Thickness armour	t_{ar}	1.2 mm
Factor between AC and DC resistance armour $\frac{1.4 - 1.2}{5 - 2}(t_{ar} - 2) + 1.2$	f_{ar}	1.1467e0 Ω/m
Number of wires armour	n_{ar}	42
Diameter armour wire $\sqrt{\frac{4 t_{ar} w_{ar}}{\pi}}$	d_f	3.27 mm
Width armour	w_{ar}	7 mm

Overall

External diameter object	D_e	105.95 mm
$\frac{n_c D_{shj} + (D_{shj} + 2t_{ab} + 2t_{ar} + 2(t_j + t_{jj}))\pi}{\pi}$		
Absorption coefficient solar radiation	σ_{sun}	0.2
Emissivity cable	ϵ_e	0.9
Reflectivity cable	η_e	0.1
$1 - \epsilon_e$		
Mass cable	m_{tot}	18.451 kg/m
$m_{hollow} + m_{metal}$		

Electrical

Conductor

Electrical resistance DC conductor 20°C	R_{c20}	4.7000e-5 Ω/m
Effective length per unit lay length twisted conductors	$F_{lay,3c}$	1.0044
$\sqrt{1 + \left(\frac{\pi D_{lay,3c}}{L_{lay,3c}}\right)^2}$		
Length of lay twisted conductors	$L_{lay,3c}$	2237 mm
Diameter of mechanical neutral line	$D_{lay,3c}$	67.21 mm
Standard DC resistance of conductor	R_{co}	0.047 Ω/km
Coating of wires		plain
Skin effect coefficient	k_s	1
Proximity effect coefficient	k_p	1
Geometric mean radius conductor bundle	GMR_{cc}	0.01091 mm
$\left(GMR_c \left(\frac{s_c}{1000}\right)^{n_c}\right)^{\frac{1}{n_c}}$		
Geometric mean radius conductor	GMR_c	0.00919 m
$K_{GMR} r_{z1}$		
Factor geometric mean radius	K_{GMR}	0.772
Constant relating to conductor formation	K_{BICC}	0.0514
Number of wires conductor	n_{cw}	61
Diameter of wires conductor (average)	d_{cw}	2.89 mm

Insulation

Capacitance, with approximation (CIGRE TB 880)	C_b	2.402e-10 F/m
$\frac{1}{2\pi\epsilon_0}\frac{10^{-9}}{18} C_b$		
Capacitance (exact)	C_b	2.405e-10 F/m
$F_{lay,3c} C_b$		
Capacitance insulation	C_b	2.395e-10 F/m
$\frac{2\pi\epsilon_0\epsilon_i}{\ln\left(\frac{r_{osc}}{r_{isc}}\right)}$		
Capacitance to earth	C_E	2.402e-10 F/m
C_b		
Vacuum permittivity	ϵ_0	8.854187817620389e-12 F/m
Radius above the inner semi-conducting layer	r_{isc}	12.7 mm
$\frac{d_c}{2} + t_{ct} + t_{cs}$		

Radius over capacitive insulation layers $\frac{D_{ins}}{2}$	r_{osc}	22.7 mm
Velocity of propagation $\frac{1}{1000\sqrt{\mu_0\epsilon_0\epsilon_i}}$	v_{prop}	189605.4 km/s

Screen + Sheath

Electrical resistance sheath $10^6\frac{\rho_{sh}}{A_{sh}}$	R_{sh}	1.2569e-3 Ω/m
Electrical resistance screen/sheath 20°C	R_{so}	1.257e0 Ω/km
Electrical resistance screen/sheath, CIGRE TB 880	R_{so}	1.2625e-03 Ω/m

Armour

Electrical resistance armour $10^6\frac{f_{ar}\rho_{ar}}{A_{ar}}$	R_{ar}	4.4853e-04 Ω/m
Electrical resistance armour, CIGRE TB 880 $F_{lay,ar}R_{ar}$	R_{ar}	4.6992e-04 Ω/m
Effective length per unit lay length armour $\sqrt{1+\left(\frac{S_{ar}}{L_{lay,ar}}\right)^2}$	$F_{lay,ar}$	1.0477
Circumference armour $n_cD_{core}+(D_{core}+2t_{ab}+t_{a,1}+t_{a,2})\,\pi$	S_{ar}	329.09 mm
Length of lay armour	$L_{lay,ar}$	1053 mm

Radius

Radius conductor	r_{z1}	0.0119 m
Radius shield (inner)	r_{z2}	0.02382 m
Radius shield (outer)	r_{z3}	0.02382 m
Radius sheath (inner)	$r_{z2,sh}$	0.02382 m
Radius sheath (outer)	$r_{z3,sh}$	0.02412 m
Radius armour (inner)	r_{z4}	0.05735 m
Radius armour (outer)	r_{z5}	0.05855 m
Radius outersheath	r_{z6}	0.05298 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
Insulation screen		
Thermal resistivity insulation screen	ρ_{is}	2.5 K.m/W

Screen bedding

Thermal resistivity screen bedding	ρ_{scb}	12 K.m/W
Volumetric heat capacity screen bedding	σ_{scb}	2.00e6 J/(K.m^3)
Density tape material	ζ_{tape}	0.34 g/cm^3

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 over each core

Thermal resistivity sheath jacket material	ρ_{shj}	3.5 K.m/W
Volumetric heat capacity sheath jacket material	σ_{shj}	2.40e6 J/(K.m^3)
Density metallic screen material	ζ_{sc}	0 g/cm^3

Filler

Thermal resistivity filler	ρ_f	not considered for air K.m/W
Volumetric heat capacity filler	σ_f	1.20e3 J/(K.m^3)
Density filler material	ζ_f	0.001 g/cm^3

Armour bedding

Thermal resistivity armour bedding	ρ_{ab}	6 K.m/W
Volumetric heat capacity armour bedding	σ_{ab}	2.00e6 J/(K.m^3)
Density armour bedding material	ζ_{ab}	1.28 g/cm^3

Armour

Specific electrical resistivity armour material	ρ_{ar}	1.380e-7 Ω.m
Temperature coefficient armour material	α_{ar}	4.50e-3 1/K
Reciprocal of temperature coefficient armour material	β_{ar}	2.022e2 K
Volumetric heat capacity armour material	σ_{ar}	3.80e6 J/(K.m^3)
Thermal conductivity armour material	k_{ar}	36.1 W/(m.K)
Density armour material	ζ_{ar}	7.85 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	0.3954 K.m/W
Thermal resistance conductor—sheath, CIGRE TB 880 $\frac{1}{F_{lay,3c}} T_1$	T_1	0.3937 K.m/W
Thermal resistance armour bedding $\frac{1}{3} \frac{1}{F_{lay,3c}} \frac{\rho_{shj}}{2\pi} \ln\left(1 + \frac{2t_{shj}}{D_{sh} - (H_{sh} + \Delta H)}\right) + \frac{\rho_f}{6\pi} G_2$	T_2	0.0733 K.m/W
Thermal resistance jacket $T_j + T_{jj}$	T_3	0 K.m/W
Thickness conductor—sheath $t_i + t_{scb} + t_{scs} + \frac{H_{sh} + \Delta H}{2}$	t_1	12 mm
Thickness sheath—armour $\frac{H_{sh} + \Delta H}{2} + t_{shj} + t_f + t_{ab}$	t_2	3.22 mm
Thickness armour—surface $t_j + t_{jj}$	t_3	0 mm
Geometric factor G_2 cables with separate sheaths $2\pi \left(0.00022619 + 2.11429 X_{G2} - 20.4762 {X_{G2}}^2\right)$	G_2	0.1839
Factor X_{G2} $\frac{t_{sha}}{D_{shj}}$	X_{G2}	0.0163
Total thickness between separate sheath and armour $\frac{D_{ab} - D_f}{2}$	t_{sha}	0.9 mm

Cable elements

Thermal resistance, transient $T_1 + T_2 + T_3$	T_{tot}	0.467 K.m/W
Thermal resistance insulation $T_{ct} + T_{cs} + T_{ins} + T_{is}$	T_i	0.36318 K.m/W
Thermal resistance conductor shield $\frac{\rho_{cs}}{2\pi} \ln\left(\frac{D_{cs}}{D_{cs} - 2t_{cs}}\right)$	T_{cs}	0.02589 K.m/W
Thermal resistance insulation $\frac{\rho_i}{2\pi} \ln\left(\frac{D_{ins}}{D_{ins} - 2t_{ins}}\right)$	T_{ins}	0.32351 K.m/W
Thermal resistance insulation screen $\frac{\rho_{is}}{2\pi} \ln\left(\frac{D_{ins} + 2t_{is}}{D_{ins}}\right)$	T_{is}	0.01378 K.m/W
Thermal resistance screen bedding $\frac{\rho_{scb}}{2\pi} \ln\left(\frac{D_{scb}}{D_i}\right)$	T_{scb}	0.03223 K.m/W

Thermal resistance sheath jacket $\frac{\rho_{shj}}{2\pi}\ln\left(\frac{D_{shj}}{D_{sh}-(H_{sh}+\Delta H)}\right)$	T_{shj}	0.0445 K.m/W
Thermal resistance sheath jacket, CIGRE TB 880 $F_{lay,3c}T_{shj}$	T_{shj}	0.0447 K.m/W
Thermal resistance armour bedding $\frac{\rho_{ab}}{2\pi}\ln\left(\frac{D_{ab}}{F_x D_{shj}}\right)$	T_{ab}	0.02053 K.m/W
Thermal resistance jacket	T_j	0 K.m/W

Dimensions

Diameter

External diameter conductor	d_c	23.8 mm
Diameter over conductor shield $d_c+2\left(t_{ct}+t_{cs}\right)$	D_{cs}	25.4 mm
Diameter over insulation $d_c+2\left(t_{ct}+t_{cs}+t_{ins}\right)$	D_{ins}	45.4 mm
Diameter over insulation incl. insulation screen $d_c+2\left(t_{ct}+t_{cs}+t_{ins}+t_{is}\right)$	D_i	47 mm
Diameter over insulation screen d_c+2t_i	D_{is}	47 mm
Diameter over screen bedding $d_c+t_{i1}+2t_{scb}$	D_{scb}	47.8 mm
Equivalent diameter of screen and sheath	d_s	47.95 mm
Mean diameter sheath $D_{shb}+t_{sh}+H_{sh}+\Delta H$	d_{sh}	47.95 mm
Diameter over sheath $D_{shb}+2\left(t_{sh}+H_{sh}+\Delta H\right)$	D_{sh}	48.1 mm
Diameter over sheath jacket $D_{sh}+2t_{shj}$	D_{shj}	52.1 mm
Diameter over core cable	D_{core}	52.1 mm
Diameter over filler $F_x D_{shj}+2t_f$	D_f	113 mm
Diameter over armour bedding $F_x D_{shj}+2\left(t_f+t_{ab}\right)$	D_{ab}	114.7 mm
Equivalent diameter of screen/sheath and armour	d_e	47.95 mm
Mean diameter armour $\frac{S_{ar}}{\pi}$	d_{ar}	104.752 mm
Diameter over armour $D_{ab}+2\left(t_{a,1}+t_{a,2}\right)$	D_{ar}	117.1 mm

Area

		values are per phase
Cross-sectional area conductor	A_c	400 mm^2
Cross-sectional area insulation $\frac{\pi}{4}\left({D_{is}}^2-{d_c}^2\right)$	A_i	1290.1 mm^2

Cross-sectional area screen bedding $\pi t_{scb} \left(D_{scb} - t_{scb}\right)$	A_{scb}	59.6 mm^2
Cross-sectional area sheath $d_{sh} t_{sh} \pi$	A_{sh}	22.6 mm^2
Cross-sectional area sheath jacket $\frac{\pi}{4}\left({D_{shj}}^2 - \left(D_{sh} - \left(H_{sh} + \Delta H\right)\right)^2\right)$	A_{shj}	314.8 mm^2
Cross-sectional area filler $\pi\left(\frac{D_f}{2}\right)^2 - 3\pi {r_{core}}^2 + \frac{\sqrt{3}}{4}{D_{core}}^2 - 3\frac{{r_{core}}^2}{2}\left(\frac{\pi}{3} - sin\left(\frac{\pi}{3}\right)\right)$	A_f	4624 mm^2
Cross-sectional area armour bedding $n_c D_{shj} + \left(D_{shj} + t_{ab}\right)\pi t_{ab}$	A_{ab}	297.7 mm^2
Cross-sectional area armour $n_{ar} t_{ar} w_{ar}$	A_{ar}	352.8 mm^2