Report

Title	Case study 8: A 220kV 3-core submarine export cable
Project	Verification CIGRE TB 880
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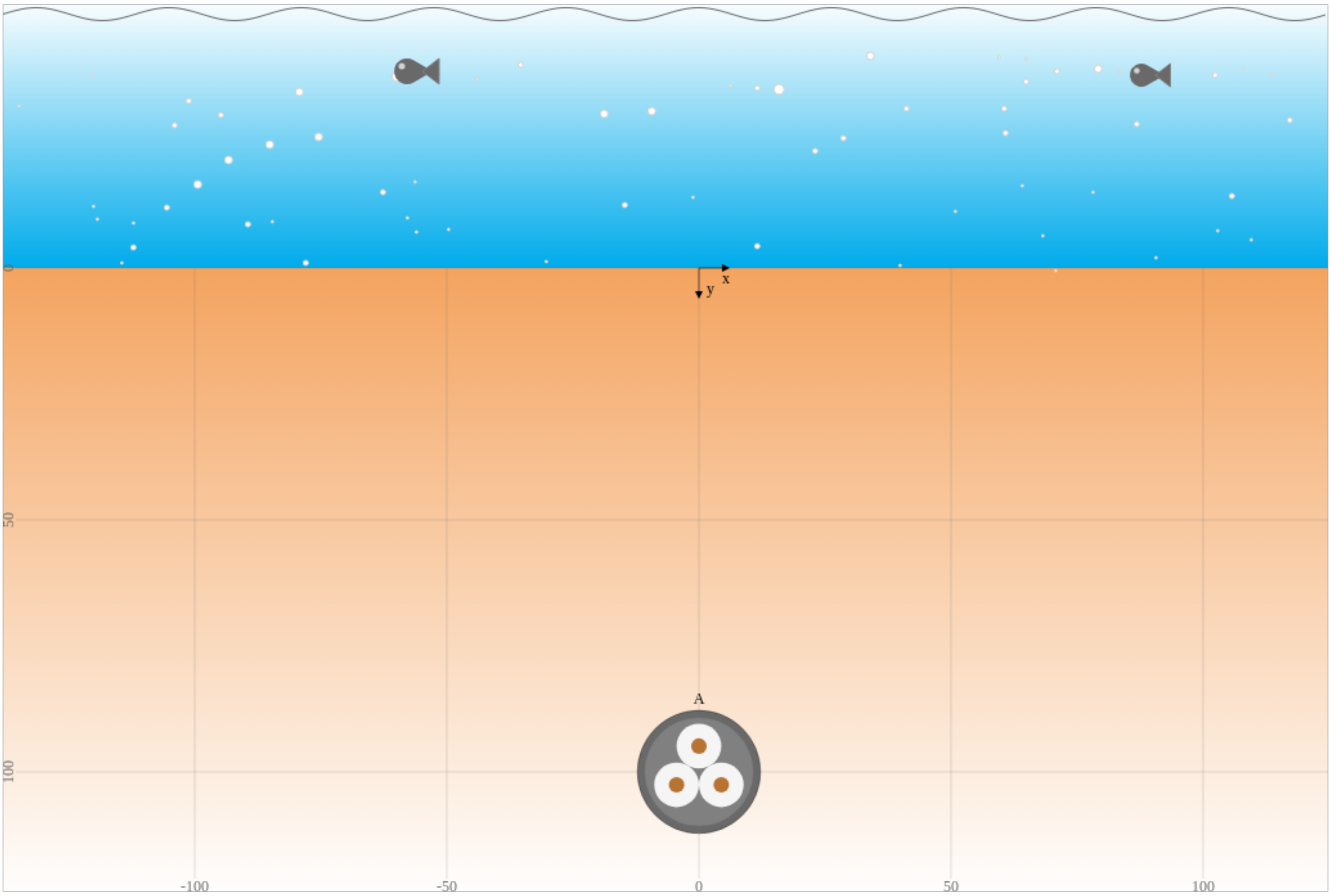
Arrangement

Arrangement	**buried project** (#46686)
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}	1134.82 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}	156.297 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	728 CIGRE TB 880 Case 8 220kV 3-core subm...	1134.8	90.0 | 63.6	156.3	1.00

Objects

Following objects are used:

728 CIGRE TB 880 Case 8 220kV 3-core submarine export cable

Ambient

Calculation method		IEC Standard subsea (preview)
Ambient temperature	θ_a	15 °C
Thermal resistivity soil	ρ_4	0.7 K.m/W
Thermal conductivity soil	k_4	1.429 W/(m.K)
Volumetric heat capacity soil material	$c_{p,soil}$	2294.7 J/(kg.K)

$$10^{-4} \frac{{k_4}^{0.2}}{4.68}$$

Thermal diffusivity soil	δ_{soil}	5.00e-7 m^2/s
Ratio thermal resistivity dry/moist soil	v_4	1

$$\frac{\rho_{4d}}{\rho_4}$$

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	1.25663706143591730e-6 H/m
Vacuum permittivity	ϵ_0	8.854187817620389e-12 F/m

System A (High voltage cable)

Ampacity

Cable		CIGRE TB 880 Case 8 220kV 3-core submarine export cable
Rounded value, CIGRE TB 880	I_c	1130 A
Conductor current	I_c	1134.82 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	220 kV
Angular frequency	ω	314.2 rad/s

$2\pi f$

Number of sources in system	N_c	1
Number of conductors combined	n_{cc}	3

$N_c n_{ph}$

Load

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

Arrangement

Arrangement		individual
Position cable 1	$x_1 \vert y_1$	0.0 | 1000.0 mm
Separation of conductors in a system	s_c	104.6 mm
Mean distance between the phases	a_m	104.6 mm
Geometric mean distance between phases of the same system	GMD	0.02576 m

GMR_{cc}

Depth of laying of sources	L_c	1000 mm
Depth of laying	L_{cm}	1 m
Outer diameter	D_o	0.245 m
Substitution coefficient u	u	8.1632

$$\frac{2L_{cm}}{D_o}$$

Geometric constant of circle buried	g_u	16.2649

$u + \sqrt{u^2 - 1}$

Temperature

Temperature conductor	θ_c	90 °C

$\theta_a + \Delta\theta_c - (v_4 - 1)\,\Delta\theta_x + v_4\Delta\theta_p$

Temperature screen/sheath	θ_s	72.65 °C
Temperature sheath	θ_{sh}	72.65 °C

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

Temperature armour	θ_{ar}	68.52 °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	63.56 °C

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

Temperature rise

Temperature rise conductor $\Delta\theta_c$ 75 K

$$n_{ph}\left(W_c T_{int} + W_d T_d\right) + n_{cc}\left(W_d\left(T_{4i} + T_{4ii} + v_4 T_{4ss}\right) + \left(W_c + W_s + W_{ar} + W_{sp}\right)\left(T_{4i} + T_{4ii} + v_4 T_{4\mu}\right) + W_{duct}\left(\frac{T_{4ii}}{2} + v_4 T_{4\mu}\right)\right)$$

Temperature rise dielectric losses $\Delta\theta_d$ 1.3001 K

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

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 35.128 W/m

$$I_c{}^2 R_c$$

Screen/sheath losses (phase) W_s 16.008 W/m

$$\lambda_1 W_c$$

Armour losses (phase) W_{ar} 0 W/m

$$\lambda_2 W_c$$

Duct losses W_{duct} 0 W/m

Ohmic losses (phase) W_I 51.136 W/m

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

Dielectric

Dielectric losses (phase) W_d 0.963 W/m

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

Total

Total losses (phase) W_t 52.099 W/m

$$W_I + W_d$$

Total losses (object) W_{tot} 156.297 W/m

$$n_{ph} W_t$$

Total losses (system) W_{sys} 156.297 W/m

Thermal resistance

Thermal resistance ambient $T_{4\mu}$ 0.3107 K.m/W

$$= T_{4ss} = T_{4iii} = \frac{\rho_4}{2\pi}\left(\ln\left(g_u\right) + \ln\left(F_{mh}\right)\right)$$

Mutual heating coefficient F_{mh} 1

Cable

Internal thermal resistance for current losses T_{int} 0.247 K.m/W

$$\frac{T_1}{n_{ph}} + \left(1 + \lambda_1\right) T_2 + \left(1 + \lambda_1 + \lambda_2 + \lambda_3\right) T_3$$

Internal thermal resistance for dielectric losses T_d 0.13933 K.m/W

$$\frac{T_1}{2 n_c} + T_2 + T_3$$

Other characteristics

Earthing

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

Loss factor

Loss factor shield (screen/sheath) λ_1 0.4557

$\lambda_{11} + F_e \lambda_{12}$

Loss factor shield, circulating currents λ_{11} 0.3585

$$\frac{\frac{R_e}{R_c}}{1+\left(\frac{R_e}{X_e}\right)^2}$$

Loss factor shield, eddy currents λ_{12} 0.1013

$$\frac{R_{sh}}{R_c}\left(g_s\lambda_0\left(1+\Delta_1+\Delta_2\right)+\frac{\left(\beta_1 t_{sh}\right)^4}{12{\cdot}10^{12}}\right)$$

Electrical resistance shield/armour R_e 2.4193e-1 Ω/km

Substitution coefficient λ_0 for eddy-currents λ_0 0.0104

$$3\frac{{m_0}^2}{1+{m_0}^2}\left(\frac{d_e}{2s_c}\right)^2$$

Substitution coefficient Δ_1 for eddy-currents Δ_1 0.0841

$$\left(1.14{m_0}^{2.45}+0.33\right)\left(\frac{d_e}{2s_c}\right)^{0.92m_0+1.66}$$

Substitution coefficient Δ_2 for eddy-currents Δ_2 0

Substitution coefficient m_0 for eddy-currents m_0 0.1299 Hz.m/Ω

$$10^{-7}\frac{\omega}{R_{sh}}$$

Substitution coefficient β_1 for eddy-currents β_1 39.0368

$$\sqrt{\frac{4\pi\omega}{10^7\rho_{sh}\left(1+\alpha_{sh}\left(\theta_{sh}-20\right)\right)}}$$

Substitution coefficient g_s for eddy-currents g_s 1.007088

$$1+\left(\frac{t_{sh}}{D_{sh}}\right)^{1.74}\left(10^{-3}\beta_1 D_{sh}-1.6\right)$$

Factor F_e eddy-current losses F_e 0.9596

$$\frac{4{M_e}^2{N_e}^2+\left(M_e+N_e\right)^2}{4\left({M_e}^2+1\right)\left({N_e}^2+1\right)}$$

Substitution coefficient M_e to calculate factor F_e M_e 4.8724

$$\frac{R_e}{X_e}$$

Substitution coefficient N_e to calculate factor F_e N_e 4.8724

$$\frac{R_e}{X_e}$$

Loss factor armour λ_2 0

Drying-out of soil

Characteristic diameter drying zone	D_{dry}	0.245 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 $R_{cDC}\left(1+y_s+y_p\right)$	R_c	2.6959e-05 Ω/m
Electrical resistance conductor, CIGRE TB 880 $F_{lay,3c}R_c$	R_c	2.7277e-05 Ω/m
Electrical resistance DC conductor $R_{c20}\left(1+\alpha_c\left(\theta_c-20\right)\right)$	R_{cDC}	2.2442e-5 Ω/m → 0.0224 Ω
Skin effect factor conductor $\frac{{x_s}^4}{192+0.8{x_s}^4}$	y_s	0.14444
Factor for skin effect on conductor $\sqrt{10^{-7}\frac{8\pi f}{R_{cDC}}k_s}$	x_s	2.36634
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	0.05684
Factor for proximity effect of conductors $\sqrt{10^{-7}\frac{8\pi f}{R_{cDC}}k_p}$	x_p	2.36634
Electrical resistance sheath $R_{sh}\left(1+\alpha_{sh}\left(\theta_{sh}-20\right)\right)$	R_{sh}	2.3911e-04 Ω/m
Electrical resistance sheath, CIGRE TB 880 $F_{lay,3c}R_{sh}$	R_{sh}	2.4193e-04 Ω/m
Electrical resistance shield	R_s	2.4193e-4 Ω/m → 0.2419 Ω
Reduction factor $\frac{R_s}{\sqrt{{R_s}^2+{X_s}^2}}$	RF	0.3633
Electrical resistance armour $R_{ar}\left(1+\alpha_{ar}\left(\theta_{ar}-20\right)\right)$	R_{ar}	2.8980e-4 Ω/m → 0.2898 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	8.177 | 3.903 kV/mm
Radius to point x in insulation	r_x	21 | 44 mm
Line-to-ground voltage $\frac{1000U_o}{\sqrt{3}}$	U_e	127017.06 V
Capacitance insulation $\frac{1}{2\pi\epsilon_0}\frac{10^{-9}}{18}C_b$	C_b	1.900e-10 F/m → 0.19 μF

Capacitive load current $U_e \omega C_b$	I_C	7.581e-3 A/m → 7.5813 A
Charging capacity $n_{ph} {U_e}^2 \omega C_b$	P_C	2888.8555 var/m → 2888.8555 kvar
Capacitive earth short-circuit current $3 U_e \omega C_E$	I_{Ce}	2.274e-2 A/m

Reactance

Self reactance conductor $\omega \frac{\mu_0}{2\pi} \ln\left(\frac{D_E}{GMR_c}\right)$	X_a	6.936e-4 Ω/m → 0.6936 Ω
Self reactance screen/sheath $\omega \frac{\mu_0}{2\pi} \ln\left(\frac{2a_m}{d_s}\right)$	X_e	4.907e-05 Ω/m
Self reactance screen/sheath, CIGRE TB 880 $F_{lay,3c} X_e$	X_e	4.965e-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	228.150+0.000j A
Loss factor shield, circulating currents	$\lambda_{11,sb}$	0.3585+0.0000j
Induced circulating current armour	I_{ar}	undefined A

Load, Voltage drop

Apparent power generator-side $\sqrt{3} U_o I_c$	S_G	432.425 MVA
Voltage drop $\sqrt{3}\left(R_c \cos\varphi + \omega L_m \sin\varphi\right)$	V_{drop}	0.047 V/(A.km) → 53.6 V = 0.02%
Inductance (mean) $\frac{\mu_0}{2\pi} \ln\left(\frac{GMD}{GMR_c}\right)$	L_m	1.090e-7+0.000e0j H/m → 0.109 mH

Telegrapher equation

Surge impedance $\sqrt{\frac{Z_1}{Y_1}}$	Z_C	25.0953-7.4912j Ω
Propagation constant $\sqrt{Z_1 Y_1}$	γ_C	4.471e-7+1.498e-6j

Impedance valid up to 100 Hz without earth return

Positive sequence admittance $G + j\omega C_b$	Y_1	0.000e0+5.969e-8j S/m → 0.0000+0.0001j S
Positive sequence impedance $R_1 + jX_1$	Z_1	2.244e-5+3.424e-5j Ω/m → 0.0224+0.0342j Ω

Positive sequence reactance $\omega \frac{\mu_0}{2\pi} \ln\left(\frac{GMD}{GMR_c}\right)$	X_1	3.424e-5 Ω/m $\rightarrow$ 0.0342 Ω

Cable datasheet

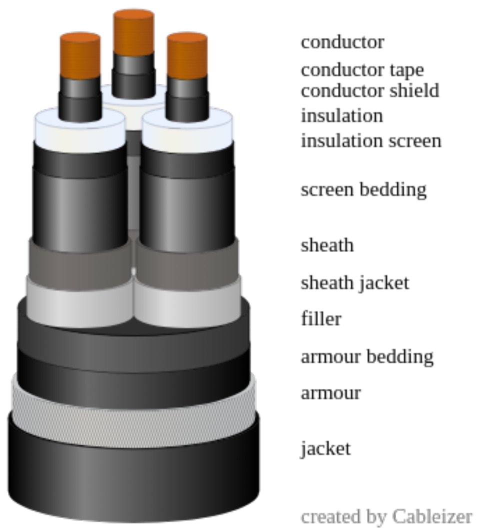
Title CIGRE TB 880 Case 8 220kV 3-core submarine export cable (#728)

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	220 kV
Base voltage for tests	U_0	127 kV
Highest voltage for equipment	U_m	245 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 1000 mm^2
Conductor material	M_c	Copper, round stranded
External diameter conductor	d_c	38.6 mm
Radius conductor $\frac{d_c}{2}$	r_c	19.3 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	60.701 mm
Separation of conductors in a system D_{shj}	s_c	104.6 mm

Insulation

Insulation material	M_i	Crosslinked polyethylene (XLPE)
Thickness conductor tape	t_{ct}	0.2 mm
Thickness conductor shield	t_{cs}	1.5 mm
Thickness insulation	t_{ins}	23 mm
Thickness insulation screen	t_{is}	1.4 mm
Thickness insulation $t_{ct} + t_{cs} + t_{ins} + t_{is}$	t_i	26.1 mm
Thickness of insulation between conductors $2t_i$	t_{i1}	52.2 mm
Thickness of insulation between conductor and metallic sheath $t_i + t_{scb} + t_{scs} + t_f$	t_{i2}	27.11 mm
Material of conductor tapes		Semiconducting tapes

Screen bedding

Screen bedding material		Water-blocking tapes, semi-conducting
Thickness screen bedding	t_{scb}	0.7 mm

Sheath

Sheath material	M_{sh}	Lead
Thickness sheath	t_{sh}	3.6 mm
corrugated		No

Jacket over each core

Sheath jacket material	M_{shj}	Polyethylene (LD/MDPE)
Thickness sheath jacket	t_{shj}	2.6 mm

Filler

Filler material	M_f	Shaped polyethylene (LDPE)
Thickness of filler/belt insulation	t_f	0.31 mm

Armour bedding

Armour bedding material	M_{ab}	Water-blocking tapes
Thickness armour bedding	t_{ab}	0.5 mm

Armour

Construction of armour	a_{type}	Stainless steel wires round
Thickness armour	t_{ar}	5 mm
Number of wires armour	n_{ar}	133

Jacket

Jacket material	M_j	Polypropylene (PP)
Thickness jacket	t_j	4 mm

Overall

External diameter object	D_e	245 mm
Absorption coefficient solar radiation	σ_{sun}	0.6
Emissivity cable	ϵ_e	0.9
Reflectivity cable $1-\epsilon_e$	η_e	0.1
Mass cable $m_{hollow}+m_{metal}$	m_{tot}	78.726 kg/m

Electrical

Conductor

Electrical resistance DC conductor 20°C	R_{c20}	1.7600e-5 Ω/m
Effective length per unit lay length twisted conductors $\sqrt{1+\left(\frac{\pi D_{lay,3c}}{L_{lay,3c}}\right)^2}$	$F_{lay,3c}$	1.0118
Length of lay twisted conductors	$L_{lay,3c}$	2750 mm
Diameter of mechanical neutral line	$D_{lay,3c}$	134.93 mm
Standard DC resistance of conductor	R_{co}	0.0176 Ω/km
Coating of wires		plain
Skin effect coefficient	k_s	1
Proximity effect coefficient	k_p	1
Geometric mean radius conductor bundle $\left(GMR_c\left(\frac{s_c}{1000}\right)^{n_c}\right)^{\frac{1}{n_c}}$	GMR_{cc}	0.02576 mm
Geometric mean radius conductor $K_{GMR}r_{z1}$	GMR_c	0.01494 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}	3.74 mm

Insulation

Capacitance, with approximation (CIGRE TB 880) $\frac{1}{2\pi\epsilon_0}\frac{10^{-9}}{18}C_b$	C_b	1.900e-10 F/m
Capacitance (exact) $F_{lay,3c}C_b$	C_b	1.903e-10 F/m
Capacitance insulation $\frac{2\pi\epsilon_0\epsilon_i}{\ln\left(\frac{r_{osc}}{r_{isc}}\right)}$	C_b	1.880e-10 F/m
Capacitance to earth C_b	C_E	1.900e-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}	21 mm
Radius over capacitive insulation layers $\frac{D_{ins}}{2}$	r_{osc}	44 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}	1.9751e-4 Ω/m
Electrical resistance screen/sheath 20°C	R_{so}	1.975e-1 Ω/km
Electrical resistance screen/sheath, CIGRE TB 880	R_{so}	1.9985e-04 Ω/m

Armour

Electrical resistance armour $10^6\frac{\rho_{ar}}{A_{ar}}$	R_{ar}	2.6805e-04 Ω/m
Electrical resistance armour, CIGRE TB 880 $F_{lay,ar}R_{ar}$	R_{ar}	2.7639e-04 Ω/m
Effective length per unit lay length armour $\text{Min}\left(2, \sqrt{1+\left(\frac{\pi d_{ar}}{L_{lay,ar}}\right)^2}\right)$	$F_{lay,ar}$	1.0311
Length of lay armour	$L_{lay,ar}$	2900 mm
Geometric mean radius armour $\left(0.7788\frac{t_{ar}}{2}n_{ar}\left(\frac{t_{ar}}{2}\right)^{n_{ar}-1}\right)^{\frac{1}{n_{ar}}}\frac{1}{1000}$	GMR_{ar}	0.00259 m

Radius

Radius conductor	r_{z1}	0.0193 m
Radius shield (inner)	r_{z2}	0.0443 m
Radius shield (outer)	r_{z3}	0.0443 m
Radius sheath (inner)	$r_{z2,sh}$	0.0443 m
Radius sheath (outer)	$r_{z3,sh}$	0.0515 m
Radius armour (inner)	r_{z4}	0.1135 m
Radius armour (outer)	r_{z5}	0.1185 m
Radius outersheath	r_{z6}	0.1225 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 tape		
Thermal resistivity conductor tape	ρ_{ct}	6 K.m/W
Density tape material	ζ_{tape}	0.34 g/cm^3
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}	2.140e-7 Ω.m
Temperature coefficient sheath material	α_{sh}	4.00e-3 1/K
Reciprocal of temperature coefficient sheath material	β_{sh}	2.300e2 K
Volumetric heat capacity sheath material	σ_{sh}	1.45e6 J/(K.m^3)
Thermal conductivity sheath material	k_{sh}	33.4 W/(m.K)
Density sheath material	ζ_{sh}	11.34 g/cm^3

Jacket over each core

Thermal resistivity sheath jacket material	ρ_{shj}	2.5 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	6 K.m/W
Volumetric heat capacity filler	σ_f	2.40e6 J/(K.m^3)
Density filler material	ζ_f	0.93 g/cm^3

Armour bedding

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

Armour

Specific electrical resistivity armour material	ρ_{ar}	7.000e-7 Ω.m
Temperature coefficient armour material	α_{ar}	1.00e-3 1/K
Reciprocal of temperature coefficient armour material	β_{ar}	9.800e2 K
Volumetric heat capacity armour material	σ_{ar}	3.80e6 J/(K.m^3)
Thermal conductivity armour material	k_{ar}	14.4 W/(m.K)
Density armour material	ζ_{ar}	7.48 g/cm^3

Jacket

Thermal resistivity jacket material	ρ_j	6 K.m/W
Thermal resistivity additional layer	ρ_{jj}	2.5 K.m/W
Volumetric heat capacity jacket material	σ_j	1.80e6 J/(K.m^3)
Electrical conductivity jacket material	κ_j	1.00e-14 S/m
Density jacket material	ζ_j	0.91 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	0.4930 K.m/W
Thermal resistance conductor—sheath, CIGRE TB 880 $\frac{1}{F_{lay,3c}}T_1$	T_1	0.4873 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	0.0264 K.m/W
Thermal resistance jacket T_j+T_{jj}	T_3	0.0317 K.m/W
Thickness conductor—sheath $t_i+t_{scb}+t_{scs}+\frac{H_{sh}+\Delta H}{2}$	t_1	26.8 mm
Thickness sheath—armour $\frac{H_{sh}+\Delta H}{2}+t_{shj}+t_f+t_{ab}$	t_2	3.41 mm
Thickness armour—surface t_j+t_{jj}	t_3	4 mm
Geometric factor G_2 cables with separate sheaths $2\pi\left(0.00022619+2.11429X_{G2}-20.4762{X_{G2}}^2\right)$	G_2	0.062
Factor X_{G2} $\frac{t_{sha}}{D_{shj}}$	X_{G2}	0.0048
Total thickness between separate sheath and armour $\frac{D_{ab}-D_f}{2}$	t_{sha}	0.5 mm

Cable elements

Thermal resistance, transient $T_1+T_2+T_3$	T_{tot}	0.5454 K.m/W
Thermal resistance insulation $T_{ct}+T_{cs}+T_{ins}+T_{is}$	T_i	0.46382 K.m/W
Thermal resistance conductor tape $\frac{\rho_{ct}}{2\pi}\ln\left(\frac{d_c+2t_{ct}}{d_c}\right)$	T_{ct}	0.00984 K.m/W
Thermal resistance conductor shield $\frac{\rho_{cs}}{2\pi}\ln\left(\frac{D_{cs}}{D_{cs}-2t_{cs}}\right)$	T_{cs}	0.02949 K.m/W

Thermal resistance insulation $\frac{\rho_i}{2\pi}\ln\left(\frac{D_{ins}}{D_{ins}-2t_{ins}}\right)$	T_{ins}	0.41203 K.m/W
Thermal resistance insulation screen $\frac{\rho_{is}}{2\pi}\ln\left(\frac{D_{ins}+2t_{is}}{D_{ins}}\right)$	T_{is}	0.01246 K.m/W
Thermal resistance screen bedding $\frac{\rho_{scb}}{2\pi}\ln\left(\frac{D_{scb}}{D_i}\right)$	T_{scb}	0.02922 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}	0.0203 K.m/W
Thermal resistance sheath jacket, CIGRE TB 880 $F_{lay,3c}T_{shj}$	T_{shj}	0.0205 K.m/W
Thermal resistance armour bedding $\frac{\rho_{ab}}{2\pi}\ln\left(\frac{D_{ab}}{F_x D_{shj}}\right)$	T_{ab}	0.01368 K.m/W
Thermal resistance jacket $\frac{\rho_j}{2\pi}\ln\left(\frac{D_j-2t_{jj}}{D_j-2\left(t_j+t_{jj}\right)}\right)$	T_j	0.0317 K.m/W

Dimensions

Diameter

External diameter conductor	d_c	38.6 mm
Diameter over conductor shield $d_c+2\left(t_{ct}+t_{cs}\right)$	D_{cs}	42 mm
Diameter over insulation $d_c+2\left(t_{ct}+t_{cs}+t_{ins}\right)$	D_{ins}	88 mm
Diameter over insulation incl. insulation screen $d_c+2\left(t_{ct}+t_{cs}+t_{ins}+t_{is}\right)$	D_i	90.8 mm
Diameter over insulation screen d_c+2t_i	D_{is}	90.8 mm
Diameter over screen bedding $d_c+t_{i1}+2t_{scb}$	D_{scb}	92.2 mm
Equivalent diameter of screen and sheath	d_s	95.8 mm
Mean diameter sheath $D_{shb}+t_{sh}+H_{sh}+\Delta H$	d_{sh}	95.8 mm
Diameter over sheath $D_{shb}+2\left(t_{sh}+H_{sh}+\Delta H\right)$	D_{sh}	99.4 mm
Diameter over sheath jacket $D_{sh}+2t_{shj}$	D_{shj}	104.6 mm
Diameter over core cable $\frac{D_f-2t_f}{F_x}$	D_{core}	104.6 mm
Diameter over filler $F_x D_{shj}+2t_f$	D_f	226 mm

Diameter over armour bedding $F_x D_{shj} + 2\left(t_f + t_{ab}\right)$	D_{ab}	227 mm
Equivalent diameter of screen/sheath and armour	d_e	95.8 mm
Mean diameter armour $D_{ab} + t_{a,1} + t_{a,2}$	d_{ar}	232.002 mm
Diameter over armour $D_{ab} + 2\left(t_{a,1} + t_{a,2}\right)$	D_{ar}	237 mm
Diameter over jacket $D_{ar} + 2\left(t_j + t_{jj}\right)$	D_j	245 mm

Area

		values are per phase
Cross-sectional area conductor	A_c	1000 mm^2
Cross-sectional area insulation $\frac{\pi}{4}\left({D_{is}}^2 - {d_c}^2\right)$	A_i	5305.1 mm^2
Cross-sectional area screen bedding $\pi t_{scb}\left(D_{scb} - t_{scb}\right)$	A_{scb}	201.2 mm^2
Cross-sectional area sheath $d_{sh} t_{sh} \pi$	A_{sh}	1083.47 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}	833.2 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	18330.4 mm^2
Cross-sectional area armour bedding $\frac{\pi}{4}\left({D_{ab}}^2 - \left(D_{ab} - t_{ab}\right)^2\right)$	A_{ab}	178.1 mm^2
Cross-sectional area armour $n_{ar}\left(\frac{t_{ar}}{2}\right)^2 \pi$	A_{ar}	2611.45 mm^2
Cross-sectional area jacket $\frac{\pi}{4}\left({D_j}^2 - \left(D_j - 2\left(t_j + t_{jj}\right)\right)^2\right)$	A_j	3028.5 mm^2