Report

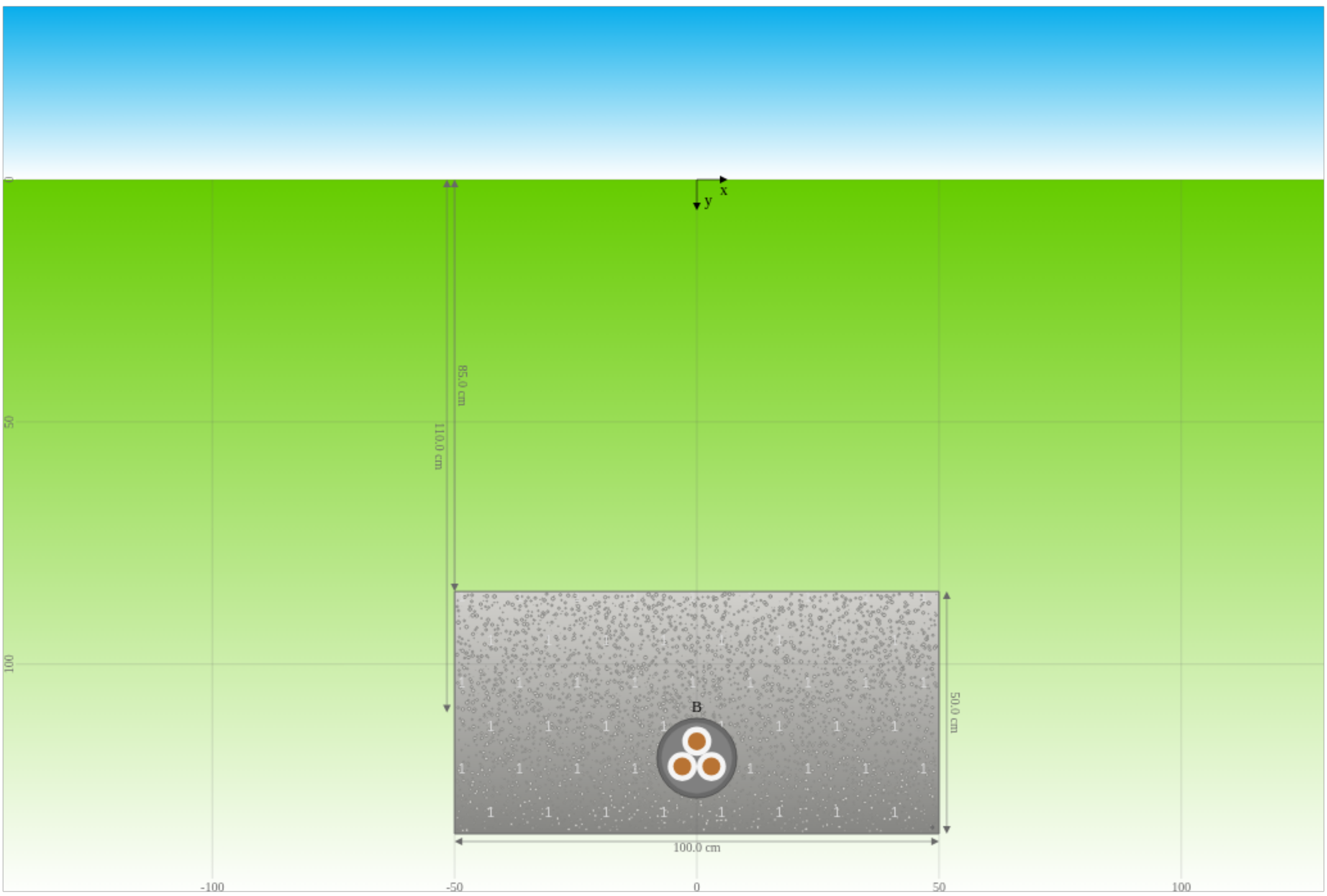
Title	Case study 3: A 230kV HPFF cable
Project	Verification CIGRE TB 880
Created	Date: 2025-05-20 Time: 13:22 Software version: 03eef9 (2025-05-19)

Arrangement

Arrangement	**buried project** (#46694)
Options	None
CIGRE TB 880, guidance points	02, 06, 26, 31
CIGRE TB 880, test setting	08
Systems	B

Statistics

Number of iterations of the solver	N_{calc}	10
Sum of currents from all systems	I_{sum}	1187.38 A
Sum of average conductor temperatures from all systems	θ_{sum}	85 °C
Number of overheated electrical systems		0
Sum of losses from all systems	W_{sum}	135.831 W/m



Systems

Following systems are active in the arrangement:

#	Object	Current [A] I_c | $I_{c_{LF}}$	Temp. [°C] θ_c | θ_e	Losses [W/m] W_{sys} | μW_{sys}	Load LF | μ
B	16304 CIGRE TB 880 Case 3 230kV HPFF cable SI	1187.4 | 1062.0	85.0 | 63.3	135.8 | 93.5	0.80 | 0.69

Objects

Following objects are used:

16304 CIGRE TB 880 Case 3 230kV HPFF cable SI

Ambient

Calculation method		IEC Standard (with backfill)
Ambient temperature	θ_a	25 °C
Thermal resistivity soil	ρ_4	1 K.m/W
Thermal conductivity soil	k_4	1 W/(m.K)
Volumetric heat capacity soil material	$c_{p,soil}$	2136.8 J/(kg.K)

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

Thermal diffusivity soil	δ_{soil}	4.68e-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	1.2566370614359173e-6 H/m
Vacuum permittivity	ϵ_0	8.854187817620389e-12 F/m

Zones

Backfill 1

Calculation method		IEC 60287-2-1 ed2.0 (2015)
Thermal resistivity backfill	ρ_b	0.55 K.m/W
Horizontal center backfill	x_b	0 mm
Vertical center backfill	L_b	1100 mm
Height backfill	h_b	500 mm
Width backfill	w_b	1000 mm
Geometric factor backfill	G_b	1.8387

$$\ln\left(u_b + \sqrt{{u_b}^2 - 1}\right)$$

Substitution coefficient u	u_b	3.224

$$\frac{L_b}{r_b}$$

Equivalent radius backfill	r_b	341.2 mm

$$e^{\frac{\mathrm{Min}(w_b,h_b)}{2\,\mathrm{Max}(w_b,h_b)}\left(\frac{4}{\pi}-\frac{\mathrm{Min}(w_b,h_b)}{\mathrm{Max}(w_b,h_b)}\right)\ln\left(1+\left(\frac{\mathrm{Max}(w_b,h_b)}{\mathrm{Min}(w_b,h_b)}\right)^2\right)+\ln\left(\frac{\mathrm{Min}(w_b,h_b)}{2}\right)}$$

System B (High voltage cable)

Warning! The conductor temperature exceeds the maximum allowable temperature of 80.0 °C under emergency overload operation.

Ampacity

Cable		CIGRE TB 880 Case 3 230kV HPFF cable SI
Rounded value, CIGRE TB 880	I_c	1180 A
Conductor current	I_c	1187.38 A

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

Conductor root mean square current	$I_{c,LF}$	1062.03 A

$\sqrt{LF}I_c$

Operating voltage	U_o	230 kV
Angular frequency	ω	377 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	60 Hz
Cyclic load with Load factor	LF	0.8 p.u.
Loss factor daily load variation	μ	0.688 p.u.

$k_{LF}LF + (1 - k_{LF})\,LF^2$

Characteristic diameter daily load	D_x	205.1 mm

$60000K_x\sqrt{\frac{\tau}{3600}\delta_{soil}}$

Factor for fictitious diameter by Neher	K_x	1.02
Transient load period	τ	24 hours
Load loss coefficient	k_{LF}	0.3 p.u.

Arrangement

Arrangement		individual
Position cable 1	$x_1\vert y_1$	0.0 | 1193.8 mm
Separation of conductors in a system	s_c	79.96 mm
Mean distance between the phases	a_m	79.959 mm
Geometric mean distance between phases of the same system	GMD	0.02095 m

GMR_{cc}

Depth of laying of sources	L_c	1193.8 mm
Depth of laying	L_{cm}	1.194 m
Outer diameter	D_o	0.2231 m
Substitution coefficient u	u	10.7001

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

Geometric constant of circle buried	g_u	21.3533

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

Geometric constant of circle characteristic diameter g_x 23.2338 p.u.

$$\frac{2L_c}{D_x} + \sqrt{\left(\frac{2L_c}{D_x}\right)^2 - 1}$$

Temperature

Temperature conductor θ_c 85 °C

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

Temperature screen/sheath θ_s 71.56 °C

Temperature screen θ_{sc} 71.56 °C

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

Mean temperature medium in the steel pipe θ_{spf} 68.15 °C

$$\frac{\theta_{sc}}{2} + \frac{\theta_{sp}}{2}$$

Temperature steel pipe θ_{sp} 64.73 °C

$$\theta_c - T_1\left(W_c + \frac{W_d}{2}\right) - n_{ph}T_2\left(W_c\left(1 + \lambda_1 + \lambda_2\right) + W_d\right)$$

External temperature object θ_e 63.34 °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 $\Delta\theta_c$ 60 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 $\Delta\theta_d$ 5.6128 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 30.26 W/m

$$I_c^{\,2}R_c$$

Screen/sheath losses (phase) W_s 0.085 W/m

$$\lambda_1 W_c$$

Steel pipe losses (phase) W_{sp} 11.514 W/m

$$\lambda_3 W_c$$

Duct losses W_{duct} 0 W/m

Ohmic losses (phase) W_I 41.859 W/m

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

Dielectric

Dielectric losses (phase) $\omega C_b \left(1000 \frac{U_o}{\sqrt{3}}\right)^2 \tan\delta_i$	W_d	3.418 W/m

Total

Total losses (phase) $W_I + W_d$	W_t	45.277 W/m
Total losses (object) $n_{ph} W_t$	W_{tot}	135.831 W/m
Total losses (system)	W_{sys}	135.831 W/m

Thermal resistance

Thermal resistance ambient $T_{4ss}\left(\mu + \frac{(1-\mu) T_{4d}}{T_{4ss}}\right)$	$T_{4\mu}$	0.2727 K.m/W
Thermal resistance steady-state $T_{4iii} + T_{4db}$	T_{4ss}	0.3996 K.m/W
Thermal resistance daily load cycle $\frac{\rho_b}{2\pi} \ln\left(\frac{D_x}{Do_d}\right)$	T_{4d}	-0.0074 K.m/W
Thermal resistance backfill correction Neher $\frac{\mu(\rho_4 - \rho_b)}{2\pi} G_b$	T_{4c}	0.0906 K.m/W
Mutual heating coefficient	F_{mh}	1

Backfill

Thermal resistance backfill correction $\frac{N_b(\rho_4 - \rho_b)}{2\pi} G_b$	T_{4db}	0.1317 K.m/W
Number of loaded objects in backfill	N_b	1
Thermal resistance ambient $\frac{\rho_4}{2\pi}(\ln(g_u) + \ln(F_{mh}))$	T_{4iii}	0.268 K.m/W
Thermal resistance steel pipe filling @ 68.1 °C $\frac{U_{spf}}{1 + 0.1(V_{spf} + Y_{spf}\theta_{spf}) D_{eq}}$	T_2	0.0675 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}	0.2219 K.m/W
Internal thermal resistance for dielectric losses $\frac{T_1}{2n_c} + T_2 + T_3$	T_d	0.14777 K.m/W

Other characteristics

Earthing

earthing screen/sheath	both-side bonding

Variation of spacing		No variation

Loss factor

Loss factor shield (screen/sheath) $\lambda_{11}+\lambda_{12}$	λ_1	0.0028
Loss factor shield, circulating currents $\frac{1.5\frac{R_e}{R_c}}{1+\left(\frac{R_e}{X_e}\right)^2}$	λ_{11}	0.0028
Loss factor shield, eddy currents	λ_{12}	0
Electrical resistance shield/armour	R_e	1.1038e2 Ω/km
Loss factor armour	λ_2	0
Loss factor steel pipe pipe-type cable $10^{-5}\frac{0.00438s_c+0.00226Di_{sp}}{R_c}\left(\frac{f}{60}\right)^2\sqrt{\frac{60}{f}}$	λ_3	0.3805

Drying-out of soil

Characteristic diameter drying zone	D_{dry}	0.223 m
Depth characteristic diameter drying zone	L_{dry}	1.194 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	2.1463e-5 Ω/m → 0.0215 Ω
Electrical resistance DC conductor $R_{c20}\left(1+\alpha_c\left(\theta_c-20\right)\right)$	R_{cDC}	1.8035e-5 Ω/m → 0.018 Ω
Skin effect factor conductor $\frac{{x_s}^4}{192+0.8{x_s}^4}$	y_s	0.0653
Factor for skin effect on conductor $\sqrt{10^{-7}\frac{8\pi f}{R_{cDC}}k_s}$	x_s	1.90713
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	0.06142
Factor for proximity effect of conductors $\sqrt{10^{-7}\frac{8\pi f}{R_{cDC}}k_p}$	x_p	1.75889
Electrical resistance screen $R_{sc}\left(1+\alpha_{sc}\left(\theta_{sc}-20\right)\right)$	R_{sc}	1.5285e0 Ω/m → 1528.4707 Ω
Electrical resistance skid wires	R_{sw}	1.1898e-1 Ω/m → 118.9759 Ω

Electrical resistance shield $\frac{1}{\frac{1}{R_{sc}}+\frac{1}{R_{sw}}}$	R_s	1.1038e-1 Ω/m → 110.3837 Ω
Reduction factor $\frac{R_s}{\sqrt{{R_s}^2+{X_s}^2}}$	RF	1
Electrical resistance steel pipe $R_{sp}\left(1+\alpha_{sp}\left(\theta_{sp}-20\right)\right)$	R_{sp}	3.9064e-5 Ω/m → 0.0391 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	13.019 | 8.524 kV/mm
Radius to point x in insulation	r_x	24.079 | 36.779 mm
Line-to-ground voltage $\frac{1000U_o}{\sqrt{3}}$	U_e	132790.56 V
Capacitance insulation $\frac{1}{2\pi\epsilon_0}\frac{10^{-9}}{18}C_b$	C_b	3.672e-10 F/m → 0.3672 μF
Capacitive load current $U_e\omega C_b$	I_C	1.838e-2 A/m → 18.3842 A
Charging capacity $n_{ph}{U_e}^2\omega C_b$	P_C	7323.7363 var/m → 7323.7363 kvar
Capacitive earth short-circuit current $3U_e\omega C_E$	I_{Ce}	5.515e-2 A/m

Reactance

Self reactance conductor $\omega\frac{\mu_0}{2\pi}\ln\left(\frac{D_E}{GMR_c}\right)$	X_a	8.184e-4 Ω/m → 0.8184 Ω
Self reactance screen/sheath $\omega\frac{\mu_0}{2\pi}\ln\left(\frac{2.3s_c}{d_s}\right)$	X_e	6.679e-5 Ω/m → 0.0668 Ω

Induced current (approximate)

Induced circulating current shield $\max\left(I_c\sqrt{\frac{\lambda_{11,sb}R_c}{R_s}}\right)$	I_s	0.880+0.000j A
Loss factor shield, circulating currents	$\lambda_{11,sb}$	0.0028+0.0000j
Induced circulating current pipe $I_c\sqrt{\frac{\lambda_3 R_c}{R_{sp}}}$	I_{sp}	542.892 A

Load, Voltage drop

Apparent power generator-side $\sqrt{3}U_oI_c$	S_G	473.02 MVA

Voltage drop $\sqrt{3}\,(R_c\cos\varphi + \omega L_m \sin\varphi)$	V_{drop}	0.037 V/(A.km) → 44.1 V = 0.02%
Inductance (mean) $\frac{\mu_0}{2\pi}\ln\left(\frac{GMD}{GMR_c}\right)$	L_m	3.058e-8+0.000e0j H/m → 0.0306 mH

Telegrapher equation

Surge impedance $\sqrt{\frac{Z_1}{Y_1}}$	Z_C	48.3068-2.0360j Ω
Propagation constant $\sqrt{Z_1 Y_1}$	γ_C	2.819e-7+6.688e-6j

Impedance valid up to 100 Hz without earth return

Positive sequence admittance $G + j\omega C_b$	Y_1	0.000e0+1.384e-7j S/m → 0.0000+0.0001j S
Positive sequence impedance $R_1 + jX_1$	Z_1	2.723e-5+3.225e-4j Ω/m → 0.0272+0.3225j Ω
Positive sequence reactance $1.15\omega\frac{\mu_0}{2\pi}\ln\left(\frac{S_{sp}}{GMR_{sp}}\right)$	X_1	3.225e-4 Ω/m → 0.3225 Ω

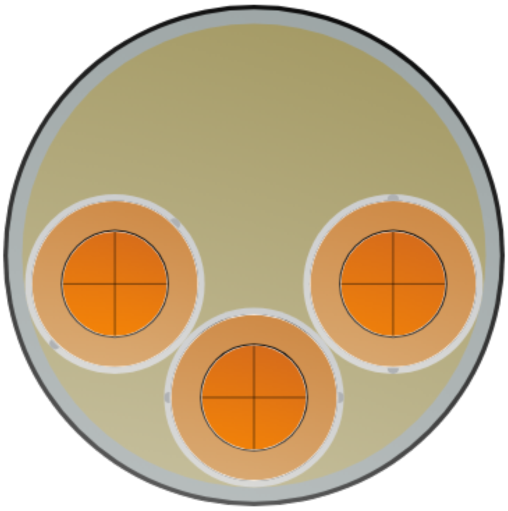
Cable datasheet

Title	CIGRE TB 880 Case 3 230kV HPFF cable SI (#16304)
Description	SI units

Info! Electric stress is higher than recommended in Cigre ELT-151 ($U_n \geq 220$ kV).
Info! PPLP was developed for EHV cables U_n >330 kV.
Cable is used in following systems: B
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 2500 kcmil (1270 mm^2)
Conductor material	M_c	Copper, round Milliken
External diameter conductor	d_c	46.33 mm
Radius conductor $\frac{d_c}{2}$	r_c	23.165 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	41.238 mm
Separation of conductors in a system D_{sw}	s_c	79.96 mm

Insulation

Insulation material	M_i	Polypropylene laminated paper (PPLP)
Thickness conductor tape	t_{ct}	0.25 mm
Thickness conductor shield	t_{cs}	0.66 mm
Thickness insulation	t_{ins}	12.7 mm
Thickness insulation screen	t_{is}	0.36 mm
Thickness insulation $t_{ct} + t_{cs} + t_{ins} + t_{is}$	t_i	13.97 mm
Thickness of insulation between conductors $2t_i$	t_{i1}	27.94 mm
Thickness of insulation between conductor and metallic sheath $t_i + t_{scb} + t_{scs} + t_f$	t_{i2}	14.57 mm
Material of conductor tapes		Semiconducting tapes

Screen bedding

Screen bedding material		Water-blocking tapes, semi-conducting
Thickness screen bedding	t_{scb}	0.05 mm

Screen

Type		Tapes
Screen material	M_{sc}	Stainless steel
Diameter over screen	t_{sc}	0.127 mm
Thickness skid wires	t_{sw}	2.54 mm
Number of wires skid wires	n_{sw}	2

Steel pipe

Steel pipe filling medium	M_{spf}	Dielectric oil
Thickness steel pipe	t_{sp}	6.35 mm

Jacket

Jacket material	M_j	High density polyethylene (HDPE, ST7)
Thickness jacket	t_j	2.03 mm

Overall

External diameter object	D_e	223.139 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}	76.972 kg/m

Electrical

Conductor

Electrical resistance DC conductor 20°C	R_{c20}	1.4365e-5 Ω/m
Standard DC resistance of conductor	R_{co}	0.0144 Ω/km
Coating of wires		plain
Insulation of wires		bare bi-directional wires
Skin effect coefficient	k_s	0.435

Proximity effect coefficient	k_p	0.37
Geometric mean radius conductor bundle $\left(GMR_c\left(\frac{s_c}{1000}\right)^{n_c}\right)^{\frac{1}{n_c}}$	GMR_{cc}	0.02095 mm
Geometric mean radius conductor $K_{GMR} r_{z1}$	GMR_c	0.01798 m
Factor geometric mean radius	K_{GMR}	0.776
Constant relating to conductor formation	K_{BICC}	0.051
Number of wires conductor	n_{cw}	127
Diameter of wires conductor (average)	d_{cw}	3.568 mm

Insulation

Capacitance, with approximation (CIGRE TB 880) $\frac{1}{2\pi\epsilon_0}\frac{10^{-9}}{18}C_b$	C_b	3.672e-10 F/m
Capacitance (exact) $\frac{2\pi\epsilon_0\epsilon_i}{\ln\left(\frac{r_{osc}}{r_{isc}}\right)}$	C_b	3.677e-10 F/m
Capacitance to earth C_b	C_E	3.672e-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}	24.079 mm
Radius over capacitive insulation layers $\frac{D_{ins}}{2}$	r_{osc}	36.779 mm
Velocity of propagation $\frac{1}{1000\sqrt{\mu_0\epsilon_0\epsilon_i}}$	v_{prop}	179160.3 km/s

Screen + Sheath

Electrical resistance screen $10^6\frac{F_{lay,sc}\rho_{sc}}{A_{sc}}$	R_{sc}	1.5285e0 Ω/m
Electrical resistance skid wires $10^6\frac{\rho_{sw}}{A_{sw}}$	R_{sw}	3.4537e-02 Ω/m
Electrical resistance skid wires, CIGRE TB 880 $F_{lay,sw}R_{sw}$	R_{sw}	1.1898e-01 Ω/m
Electrical resistance of screen and skid wires $\frac{1}{\frac{1}{R_{sc}}+\frac{1}{R_{sw}}}$	R_s	1.1038e-1 Ω/m
Effective length per unit lay length screen wires $\sqrt{1+\left(\frac{\pi d_{sc}}{L_{lay,sc}}\right)^2}$	$F_{lay,sc}$	12.3264
Length of lay screen wires	$L_{lay,sc}$	19.05 mm

Effective length per unit lay length skid wires	$F_{lay,sw}$	3.4449
$\sqrt{1+\left(\frac{\pi D_{sw}}{L_{lay,sw}}\right)^2}$		
Length of lay skid wires	$L_{lay,sw}$	76.2 mm
Electrical resistance screen/sheath 20°C	R_{so}	1.528e3 Ω/km

Steel pipe

Electrical resistance steel pipe	R_{sp}	3.2519e-5 Ω/m
$10^6 \frac{\rho_{sp}}{A_{sp}}$		
Geometric mean radius steel pipe	GMR_{sp}	0.02862 m
$e^{-\left(\frac{1}{4}\right)}\sqrt{\frac{A_{sp}}{\pi}}\frac{1}{1000}$		

Radius

Radius conductor	r_{z1}	0.02316 m
Radius shield (inner)	r_{z2}	0.03712 m
Radius shield (outer)	r_{z3}	0.03738 m
Radius screen (inner)	$r_{z2,sc}$	0.03712 m
Radius screen (outer)	$r_{z3,sc}$	0.03738 m
Radius outersheath	r_{z6}	0.11157 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	2.8
Loss factor insulation material	$\tan\delta_i$	0.0014
Thermal resistivity insulation material	ρ_i	5.5 K.m/W
Volumetric heat capacity insulation material	σ_i	2.00e6 J/(K.m^3)
Density insulation material	ζ_i	0.9 g/cm^3
Max. temperature conductor	θ_{cmax}	70 °C
Max. temperature conductor, emergency overload	θ_{cmaxeo}	80 °C
Max. temperature conductor, short-circuit	θ_{cmaxsc}	130 °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}	6 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

Screen

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

Skid wires

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

Steel pipe

Specific electrical resistivity steel pipe material	ρ_{sp}	1.380e-7 Ω.m
Temperature coefficient steel pipe material	α_{sp}	4.50e-3 1/K
Reciprocal of temperature coefficient steel pipe material	β_{sp}	2.022e2 K
Volumetric heat capacity steel pipe material	σ_{sp}	3.80e6 J/(K.m^3)
Thermal conductivity steel pipe material	k_{sp}	36.1 W/(m.K)
Density steel pipe material	ζ_{sp}	7.85 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_1	0.4203 K.m/W

$$\frac{\rho_i}{2\pi}\ln\left(1+\frac{2t_1}{d_c}\right)$$

Thermal resistance between sheath and pipe	T_2	0.0841 K.m/W

$$T_{spf} + T_{ab}$$

Thermal resistance jacket	T_3	0.0102 K.m/W

$$\frac{\rho_j}{2\pi}\ln\left(\frac{D_j}{D_j - 2t_3}\right)$$

Thickness conductor—sheath	t_1	14.27 mm

$$\frac{D_{sc}}{2} - \frac{d_c}{2} + t_{scs}$$

Thickness sheath—armour $t_{shj} + t_{ab} + t_f$	t_2	0.55 mm
Thickness armour—surface $t_j + t_{jj}$	t_3	2.03 mm

Cable elements

Thermal resistance, transient $T_1 + T_2 + T_3$	T_{tot}	0.5146 K.m/W
Thermal resistance insulation $T_{ct} + T_{cs} + T_{ins} + T_{is}$	T_i	0.39609 K.m/W
Thermal resistance conductor tape $\frac{\rho_{ct}}{2\pi} \ln\left(\frac{d_c + 2t_{ct}}{d_c}\right)$	T_{ct}	0.01041 K.m/W
Thermal resistance conductor shield $\frac{\rho_{cs}}{2\pi} \ln\left(\frac{D_{cs}}{D_{cs} - 2t_{cs}}\right)$	T_{cs}	0.01106 K.m/W
Thermal resistance insulation $\frac{\rho_i}{2\pi} \ln\left(\frac{D_{ins}}{D_{ins} - 2t_{ins}}\right)$	T_{ins}	0.37079 K.m/W
Thermal resistance insulation screen $\frac{\rho_{is}}{2\pi} \ln\left(\frac{D_{ins} + 2t_{is}}{D_{ins}}\right)$	T_{is}	0.00383 K.m/W
Thermal resistance screen bedding $\frac{\rho_{scb}}{2\pi} \ln\left(\frac{D_{scb}}{D_i}\right)$	T_{scb}	0.00131 K.m/W
Thermal resistance steel pipe filling @ 50.0 °C $\frac{U_{spf}}{1 + 0.1\left(V_{spf} + Y_{spf}\theta_{spf}\right) D_{eq}}$	T_{spf}	0.0841 K.m/W
Constant U pipe-type cable	U_{spf}	0.26
Constant V pipe-type cables	V_{spf}	0
Constant Y pipe-type cables	Y_{spf}	0.0026
Equivalent diameter of a group of round objects $2.15 D_{sc}$	D_{eq}	160.99 mm
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	0.01024 K.m/W

Dimensions

Diameter

External diameter conductor	d_c	46.33 mm
Diameter over conductor shield $d_c + 2\left(t_{ct} + t_{cs}\right)$	D_{cs}	48.158 mm
Diameter over insulation $d_c + 2\left(t_{ct} + t_{cs} + t_{ins}\right)$	D_{ins}	73.558 mm
Diameter over insulation incl. insulation screen $d_c + 2\left(t_{ct} + t_{cs} + t_{ins} + t_{is}\right)$	D_i	74.27 mm
Diameter over insulation screen $d_c + 2t_i$	D_{is}	74.27 mm

Diameter over screen bedding $d_c + t_{i1} + 2t_{scb}$	D_{scb}	74.371 mm
Mean diameter screen $D_{scb} + t_{sc}$	d_{sc}	74.498 mm
Diameter over screen $D_{scb} + 2n_{scw}t_{sc}$	D_{sc}	74.879 mm
Equivalent diameter of screen and sheath $\sqrt{\frac{\left(\frac{D_{ins}+D_{sc}}{2}\right)^2 + \left(\frac{D_{sc}+D_{sw}}{2}\right)^2}{2}}$	d_s	75.836 mm
Diameter over skid wires $D_{sc} + 2t_{sw}$	D_{sw}	79.959 mm
Diameter over core cable	D_{core}	74.879 mm
Diameter over filler $F_x D_{sh} + 2t_f$	D_f	162.435 mm
Inner diameter steel pipe	Di_{sp}	206.375 mm
Outer diameter steel pipe $Di_{sp} + 2t_{sp}$	Do_{sp}	219.075 mm
Diameter over jacket $Do_{sp} + 2t_j$	D_j	223.139 mm

Area

		values are per phase
Cross-sectional area conductor	A_c	1270 mm^2
Cross-sectional area insulation $\frac{\pi}{4}\left({D_{is}}^2 - {d_c}^2\right)$	A_i	2646.4 mm^2
Cross-sectional area screen bedding $\pi t_{scb}\left(D_{scb} - t_{scb}\right)$	A_{scb}	11.9 mm^2
Cross-sectional area screen $n_{scw}t_{sc}w_{sc}$	A_{sc}	5.65 mm^2
Cross-sectional area skid wires $n_{sw}\frac{\pi}{2}{t_{sw}}^2$	A_{sw}	20.3 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	1411.5 mm^2