Calculation Report

Title	Verification Phase 2 case 04
Project	Verification
Description	
Created	2020-05-17 11:55
Solver	2020-03-31 (bc60f)

Arrangement

Arrangement type		**buried**
Activated options		None
Active systems		A

Statistics

Number of iterations of the solver	N_{calc}	6
Sum of currents from all systems	I_{sum}	690.8 A
Sum of average conductor temperatures from all systems	θ_{sum}	90.0 °C
Number of overheated electrical systems		0
Sum of losses from all systems	W_{sum}	75.2 W/m
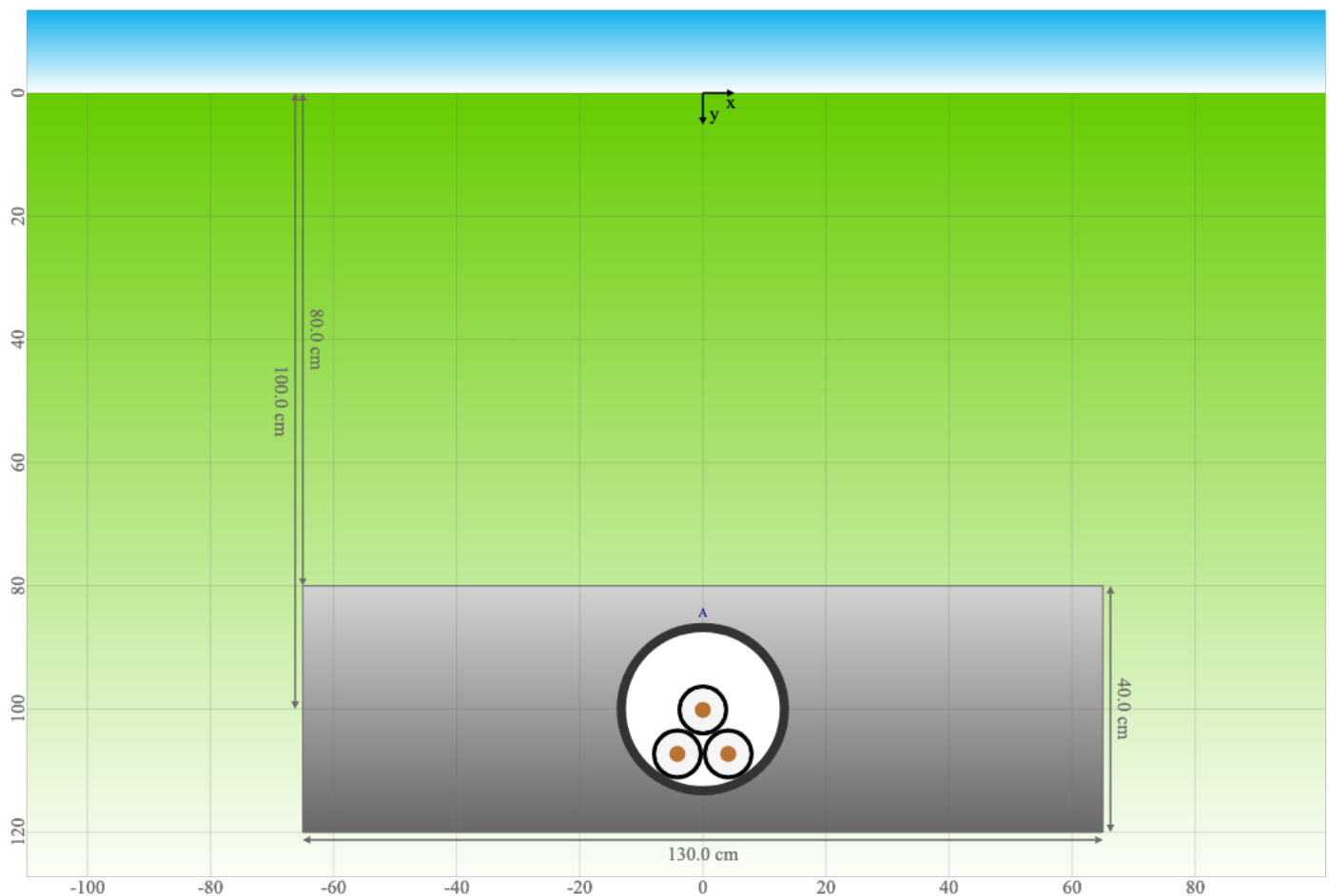
Systems

Following systems are active in the arrangement:

System	Object	Current I_c [A]	max Temp. θ_c | θ_e [°C]	Losses W_{sys} [W/m]
System A	Verification Phase 2 case 01	690.8	90.0 | 75.3	75.2

Objects

**Following objects are used:**

Verification Phase 2 case 01

Ambient

Ambient temperature	θ_a	20.0 °C
Thermal resistivity of soil	ρ_4	1.5 K.m/W
Ratio thermal resistivity dry/moist soil	v_4	1.000

Backfill

Calculation method	acc. El-Kady et al (1985)

Backfill Area 1

Thermal resistivity backfill	ρ_b	0.8 K.m/W
Horizontal center of backfill	x_b	0.0 mm
Vertical center of backfill	L_b	1000.0 mm
Height of the backfill	h_b	400.0 mm
Width of the backfill	w_b	1300.0 mm
Geometric factor for backfill	G_b	1.4835

Approximate steady-state temperature field [°C] with 1.267 K.m/W
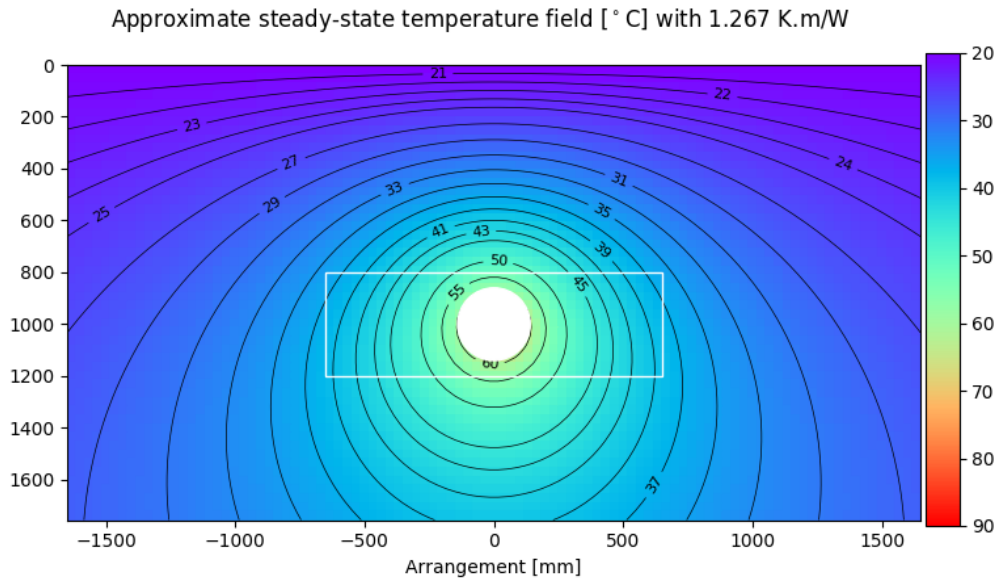
System A (High voltage cable)

Ampacity

Name of cable		Verification Phase 2 case 01
Conductor current	I_c	690.8 A

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

Operating voltage	U_o	110.0 kV
System frequency	f	50.0 Hz
Number of sources in system	N_c	3
Number of conductors combined	n_{cc}	3

$N_c n_c$

Load

Continuous load	LF	1.0 p.u.

Temperatures

Temperature of conductor	θ_c	90.0 °C

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

Temperature of screen/sheath	θ_s	77.0 °C

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

External temperature of the object	θ_e	75.3 °C

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

Duct

Mean temperature of the medium in the duct	θ_{dm}	68.9 °C

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

Temperature of duct inner wall	θ_{di}	62.6 °C

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

Temperature of duct outer wall	θ_{de}	57.8 °C

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

Temperature rises

Temperature rise of conductor	$\Delta\theta_c$	70.0 K

$$W_I n_{cc} (T_{4i} + T_{4ii} + T_{4\mu} v_4) + W_d n_{cc} (T_{4i} + T_{4ii} + T_{4ss} v_4) + W_p n_{cc} \left(\frac{T_{4ii}}{2} + T_{4\mu} v_4\right) + n_c (T_d W_d + T_i W_c)$$

Temperature rise by dielectric losses	$\Delta\theta_d$	0.5 K

$W_d (T_d n_c + n_{cc} (T_{4i} + T_{4ii} + T_{4ss} v_4))$

Temperature rise by other buried objects	$\Delta\theta_p$	0.0 K

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

Critical soil temperature rise	$\Delta\theta_x$	0.0 K

Losses

Ohmic

Conductor losses	W_c	23.409 W/m

$I_c^2 R_c$

Screen and sheath losses	W_s	1.447 W/m

$W_c \lambda_1$

Losses in pipe	W_p	0.000 W/m

$W_c \lambda_3$

Ohmic losses per phase	W_I	24.856 W/m

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

Dielectric

Dielectric losses	W_d	0.207 W/m

$$\frac{1000000 C_b U_o^2 \omega \tan\delta_i}{3}$$

Total

Total losses per phase	W_t	25.063 W/m

$W_I + W_d + W_p$

Total losses per object	W_{tot}	25.063 W/m

$W_t n_c$

Total losses of the system	W_{sys}	75.188 W/m

Arrangement

Material of duct pipe	M_d	Plastic duct made of PE (Polyethylene)
Inside / outside diameter of duct	Di_d/Do_d	250.0 | 280.0 mm
Thermal resistivity of duct material	ρ_d	3.500 K.m/W
Specific heat capacity of duct material	σ_d	2400000.0 J/K.m^3
Absorption coefficient of solar radiation	σ_{sun}	0.4
Center position of duct 1	x_1 / y_1	0.0 / 1000.0 mm
Separation of conductors in a system	s_c	82.54 mm
Depth of laying of sources	L_c	1000.0 mm
Substitution coefficient u	u	7.143

$$\frac{2L_c}{Do_d}$$

Thermal Resistances

Internal thermal resistance for current losses	T_i	0.625 K.m/W

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

Internal thermal resistance for dielectric losses	T_d	0.344 K.m/W

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

Thermal resistance to ambient	$T_{4\mu}$	0.503 K.m/W

$$\frac{\rho_4 \, ln \left(F_{eq} \left(u + \sqrt{u^2 - 1} \right) \right)}{2\pi}$$

Thermal resistance of medium in the duct	T_{4i}	0.169 K.m/W

$$\frac{U_d}{D_{eq} \left(0.1 V_d + 0.1 Y_d \theta_{dm} \right) + 1}$$

Thermal resistance of the duct wall	T_{4ii}	0.063 K.m/W

$$\frac{\rho_d \, ln\left(\frac{Do_d}{Di_d}\right)}{2\pi}$$

Correction of thermal resistance for backfill	T_{4db}	0.165 K.m/W

$$\frac{G_b N_b \left(\rho_4 - \rho_b\right)}{2\pi}$$

Number of loaded objects in backfill	N_b	1.00
Mutual heating coefficient	F_{eq}	1.000

Other characteristics

Earthing

Earthing of cable screen/sheath		Single side
Substitution coefficient λ_0 for eddy-currents	λ_0	0.0141

$$\frac{3d_e^2 m_0^2}{4s_c^2 \left(m_0^2 + 1\right)}$$

Substitution coefficient Δ_1 for eddy-currents	Δ_1	0.0771

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

Substitution coefficient Δ_2 for eddy-currents	Δ_2	0
Substitution coefficient m_0 for eddy-currents	m_0	0.1585 Hz.m/Ω

$$\frac{1.0 \cdot 10^{-7}\omega}{R_e}$$

Substitution coefficient β_1 for eddy-currents	β_1	151.3208

$$0.000632455532033676\sqrt{\frac{\omega\pi}{\rho_{sh}}}$$

Substitution coefficient g_s for eddy-currents	g_s	1.0071

$$\left(\frac{t_{sc} + t_{scs} + t_{sh}}{D_s}\right)^{1.74} \left(0.001 D_s \beta_1 - 1.6\right) + 1$$

Loss Factors

Loss factor of screen and sheath	λ_1	0.062

$$\lambda_{1c} + \lambda_{1e}$$

Loss factor by circulating currents	λ_{1c}	0.000
Loss factor by eddy currents	λ_{1e}	0.062

$$\lambda_{1es}$$

Loss factor for single point bonding	λ_{1es}	0.062

$$\frac{R_e \left(8.33333333333333 \cdot 10^{-14}\beta_1^4 t_{sh}^4 + g_s\lambda_0 \left(\Delta_1 + \Delta_2 + 1\right)\right)}{R_c}$$

Loss factor of armour	λ_2	0.000

Conductor resistance

AC resistance of conductor at operating temperature	R_c	4.905e-02 Ω/km

$$R_{cDC} \left(y_p + y_s + 1\right)$$

DC resistance of conductor at operating temperature	R_{cDC}	4.667e-02 Ω/km

$$R_{co} \left(\alpha_c \left(\theta_c - 20\right) + 1\right)$$

Skin effect factor of conductor	y_s	0.0367

$$\frac{x_s^4}{0.8x_s^4 + 192}$$

Factor for skin effect on conductor $\qquad\qquad x_s \qquad$ 1.6409

$$0.000894427190999916\sqrt{\frac{fk_s\pi}{R_c}}$$

Proximity effect factor of conductors $\qquad\qquad y_p \qquad$ 0.0143

$$\frac{d_c^2 x_p^4 \left(\frac{0.312 d_c^2}{s_c^2} + \frac{1.18}{\frac{x_p^4}{0.8 x_p^4 + 192} + 0.27} \right)}{s_c^2 \left(0.8 x_p^4 + 192 \right)}$$

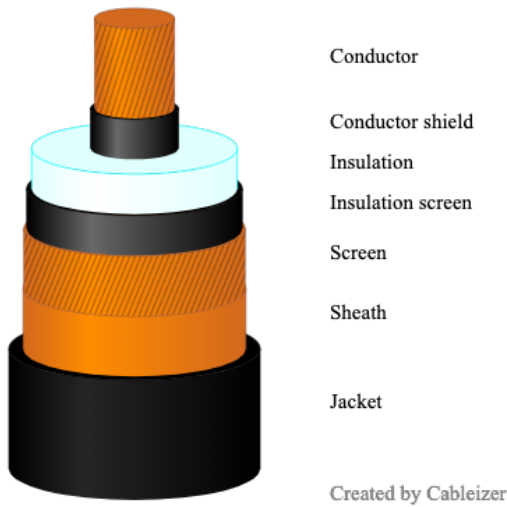Factor for proximity effect of conductors $\qquad\qquad x_p \qquad$ 1.6409

$$0.000894427190999916\sqrt{\frac{fk_p\pi}{R_c}}$$

Cable: Verification Phase 2 case 01

Cable is used in following systems: A

General Data

Manufacturer		none
Description		Cableizer Testkabel
Rated line-to-line voltage	U_n	110.0 kV
Base voltage for tests	U_0	64.0 kV
Highest voltage for equipment	U_m	123.0 kV
System frequency	f	50.0 Hz

Conductor

Conductor shield

Insulation

Insulation screen

Screen

Sheath

Jacket

Created by Cableizer

Conductor

Number of conductors in object	n_c	1
Cross-sectional area of conductor	A_c	500.0 mm^2
Material of conductor	M_c	Copper
Construction of conductor	c_{constr}	Round, stranded
Coating of wires	R_{co}	plain
Skin effect coefficient	k_s	1.0
Proximity effect coefficient	k_p	1.0
DC resistance of conductor at 20°C	R_{co}	3.66e-05 Ω/m
Electrical resistivity of conductor material	ρ_c	1.7241e-08 Ω.m
Temperature coefficient of conductor material	α_c	0.00393 1/K
Specific heat capacity of conductor material	σ_c	3450000.0 J/K.m^3
External diameter of conductor	d_c	26.2 mm
Thickness of s.c. tape wrapped around conductor	t_{ct}	0 mm

Insulation

Material of insulation	M_i	Crosslinked polyethylene (XLPE)
Thickness of conductor shield	t_{cs}	1.3 mm
Thickness of insulation	t_{ins}	19.4 mm
Thickness of insulation screen	t_{is}	1.6 mm
Thickness of insulation between conductors	t	44.6000 mm

$$2t_{cs} + 2t_{ct} + 2t_{ins} + 2t_{is}$$

Max. conductor temperature	θ_{cmax}	90.0 °C
Max. emergency overload conductor temperature	θ_{cmaxeo}	130.0 °C
Max. short-circuit conductor temperature	θ_{cmaxsc}	250.0 °C
Relative permittivity of insulation	ϵ_i	2.5000
Loss factor of insulation	$\tan\delta_i$	0.0010
Thermal resistivity of insulation	ρ_i	3.5 K.m/W
Specific heat capacity of insulation material	σ_i	2400000.0 J/K.m^3
Capacitance of insulation	C_b	0.1630 μF/km

$$\frac{2\epsilon_0\epsilon_i\pi}{ln\left(\frac{r_I}{r_F}\right)}$$

Vacuum permittivity	ϵ_0	8.85419e-12 F/m
Radius below the insulation	r_F	14.40 mm

$$r_c + t_{cs} + t_{ct}$$

Radius of the insulation	r_I	33.80 mm

$$r_F + t_{ins}$$

Screen

Type of screen		Round wires
Material of screen	M_{sc}	Copper
Diameter of screen wires	t_{sc}	0.92 mm
Number of screen wires	n_{sw}	74
Cross-sectional area of screen	A_{sc}	49.2 mm^2

$$\frac{n_{sw}\pi t_{sc}^2}{4}$$

Electrical resistance of screen	R_{sc}	0.3505 Ω/km

$$\frac{1000000\rho_{sc}}{A_{sc}}$$

Specific electrical resistivity of screen material	ρ_{sc}	1.7241e-08 Ω.m
Temperature coefficient of screen material	α_{sc}	0.00393 1/K
Specific heat capacity of screen material	σ_{sc}	3450000.0 J/K.m^3

Sheath

Material of sheath	M_{sh}	Copper
Thickness of the sheath	t_{sh}	0.25 mm
Corrugated sheath		No
Mean diameter of sheath	d_{sh}	72.89 mm

$$D_{it} + \Delta d_{sh} + t_{sh}$$

Mean external diameter of the sheath	D_s	73.14 mm

$$D_{oc} - \Delta d_{sh}$$

Cross-sectional area of sheath	A_{sh}	57.2 mm^2

$$d_{sh}\pi t_{sh}$$

Electrical resistance of sheath	R_{sh}	0.3012 Ω/km

$$\frac{1000000\rho_{sh}}{A_{sh}}$$

Specific electrical resistivity of sheath material	ρ_{sh}	1.7241e-08 Ω.m
Temperature coefficient of sheath material	α_{sh}	0.00393 1/K
Specific heat capacity of sheath material	σ_{sh}	3450000.0 J/K.m^3

Jacket

Material of jacket	M_j	Polyethylene (LD/MDPE, ST3)
Thickness of jacket	t_j	4.70 mm
External diameter of object	D_e	82.54 mm

$$D_{a_2} + 2t_j + 2t_{jj}$$

Thermal resistivity of jacket material	ρ_j	3.5 K.m/W
Specific heat capacity of jacket material	σ_j	2400000.0 J/K.m^3

Internal thermal resistances

Thermal resistance between one conductor and sheath	T_1	0.554 K.m/W

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

Thermal resistance between sheath and armour	T_2	0.000 K.m/W

$$T_{2_1} + T_{2_2}$$

Thermal resistance between sheath and 1st armour layer	T_{2_1}	0.000 K.m/W
Thermal resistance of material between armour layers	T_{2_2}	0.000 K.m/W
Thermal resistance of jacket	T_3	0.067 K.m/W

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

Thickness of insulation to sheath	t_1	22.300 mm

$$\frac{\Delta d_{sh}}{2} + \frac{t}{2} + t_{scb} + t_{scs}$$

Thickness of bedding under armour	t_2	0.000 mm

$$\frac{\Delta d_{sh}}{2} + t_{ab_1}$$

Thickness of serving over armour	t_3	4.700 mm

$$t_j + t_{jj}$$

Mechanical

Mass of object	m	9.93 kg/m
Heat energy content	H_c	187.54 MJ/m
Heat energy content	H_c	52.10 kWh/m
Embodied energy		745.43 MJ/kg
Embodied carbon		17.09 kgCO2/kg
Factor of permissible pull	f_{ppc}	60.0 N/mm^2
Permissible pull force on cable	F_{ppc}	3000.0 daN

$$\frac{A_c f_{ppc} n_c}{10}$$