Calculation Report

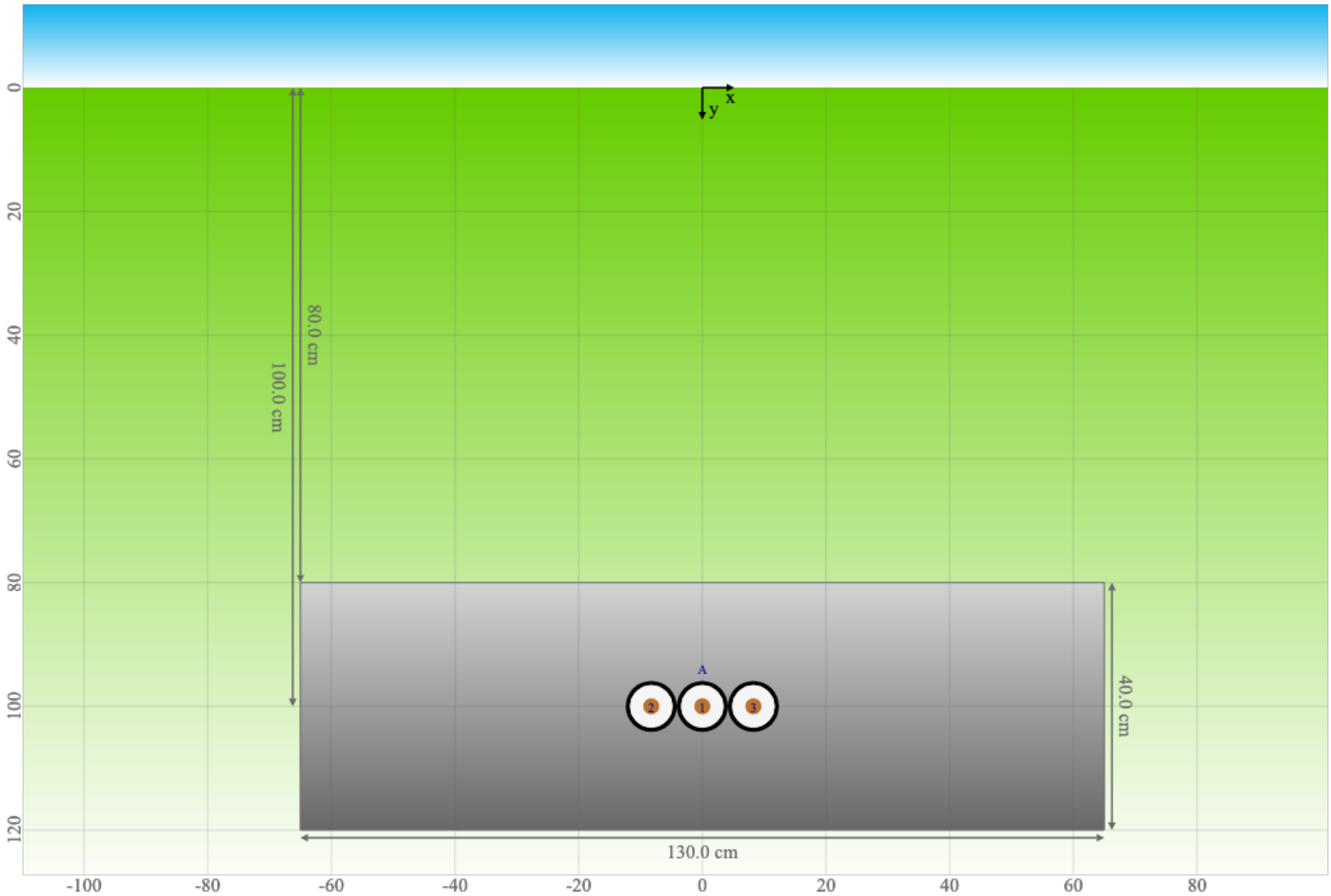
Title	Verification Phase 2 case 13
Project	Verification
Description	
Created	2020-05-17 11:54
Solver	2020-03-31 (bc60f)

Arrangement

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

Statistics

Number of iterations of the solver	N_{calc}	5
Sum of currents from all systems	I_{sum}	728.9 A
Sum of average conductor temperatures from all systems	θ_{sum}	87.6 °C
Number of overheated electrical systems		0
Sum of losses from all systems	W_{sum}	82.9 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	728.9	90.0 | 73.5	82.9

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

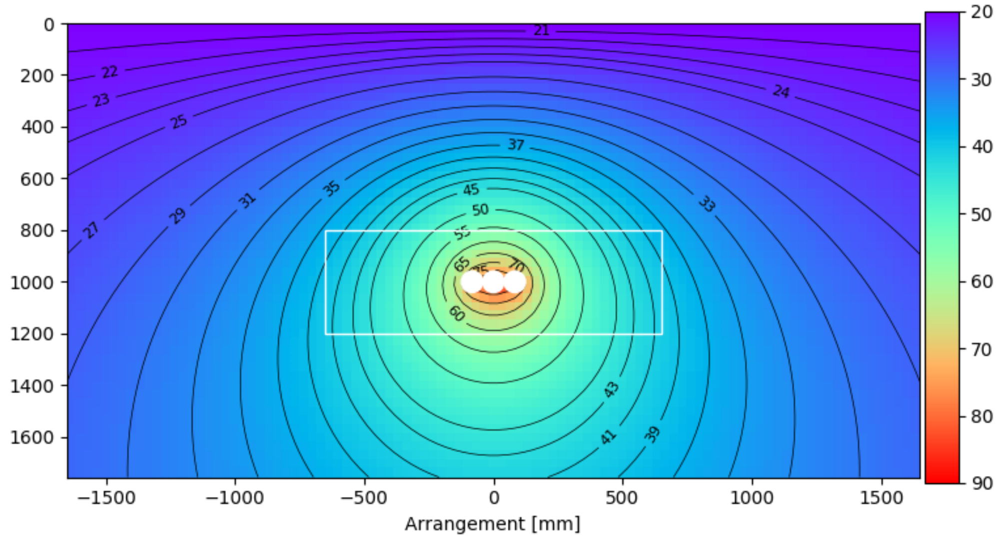
Backfill

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 [$^\circ$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	728.9 A

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

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}	1

Load

Continuous load	LF	1.0 p.u.

Temperatures

Temperature of conductor — θ_c — 1: 90.0 | 2: 86.1 | 3: 86.6 °C

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

Temperature of screen/sheath — θ_s — 1: 75.5 | 2: 71.8 | 3: 72.2 °C

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

External temperature of the object — θ_e — 1: 73.5 | 2: 70.0 | 3: 70.4 °C

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

Temperature rises

Temperature rise of conductor — $\Delta\theta_c$ — 1: 70.0 | 2: 66.1 | 3: 66.6 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 — $\Delta\theta_d$ — 1: 0.4 | 2: 0.5 | 3: 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

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

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

Losses

Ohmic

Conductor losses — W_c — 1: 26.061 | 2: 25.776 | 3: 25.810 W/m

$$I_c^2 R_c$$

Screen and sheath losses — W_s — 1: 3.005 | 2: 0.667 | 3: 0.944 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 — 1: 29.066 | 2: 26.443 | 3: 26.754 W/m

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

Dielectric

Dielectric losses $\frac{1000000 C_b U_o^2 \omega \tan\delta_i}{3}$	W_d	1: 0.207 | 2: 0.207 | 3: 0.207 W/m

Total

Total losses per phase $W_I + W_d + W_p$	W_t	1: 29.272 | 2: 26.649 | 3: 26.961 W/m
Total losses per object $W_t n_c$	W_{tot}	1: 29.272 | 2: 26.649 | 3: 26.961 W/m
Total losses of the system	W_{sys}	82.882 W/m

Arrangement

Center position of cable 1	x_1 / y_1	0.0 / 1000.0 mm
Center position of cable 2	x_2 / y_2	-82.6 / 1000.0 mm
Center position of cable 3	x_3 / y_3	82.6 / 1000.0 mm
Separation of conductors in a system	s_c	82.60 mm
Depth of laying of sources	L_c	1000.0 mm
Substitution coefficient u $\frac{2L_c}{D_e}$	u	24.231

Thermal Resistances

Internal thermal resistance for current losses $\frac{T_1}{n_c} + T_2(\lambda_1 + 1) + T_3(\lambda_1 + \lambda_2 + 1)$	T_i	1: 0.629 | 2: 0.623 | 3: 0.624 K.m/W
Internal thermal resistance for dielectric losses $\frac{T_1}{2n_c} + T_2 + T_3$	T_d	0.344 K.m/W
Thermal resistance to ambient $\rho_4 (0.475\, ln(2u) - 0.142)$	$T_{4\mu}$	1: 1.829 | 2: 1.875 | 3: 1.869 K.m/W
Correction of thermal resistance for backfill $\frac{G_b N_b (\rho_4 - \rho_b)}{2\pi}$	T_{4db}	1: 0.468 | 2: 0.514 | 3: 0.508 K.m/W
Number of loaded objects in backfill	N_b	1: 2.83 | 2: 3.11 | 3: 3.07
Mutual heating coefficient $\prod_{k=1}^{q} \frac{d_{\mathrm{pk1}}}{d_{\mathrm{pk2}}}$	F_{eq}	1: 587.273 | 2: 294.386 | 3: 294.386

Other characteristics

Earthing

Earthing of cable screen/sheath		Single side
Substitution coefficient λ_0 for eddy-currents $\frac{3d_e^2 m_0^2}{2s_c^2(m_0^2+1)}$ $\frac{0.375 d_e^2 m_0^2}{s_c^2(m_0^2+1)}$ $\frac{0.375 d_e^2 m_0^2}{s_c^2(m_0^2+1)}$	λ_0	1: 0.0284 | 2: 0.00727 | 3: 0.00725

Substitution coefficient Δ_1 for eddy-currents	Δ_1	1: 0.0014 | 2: -0.122 | 3: 0.245

$$0.86m_0^{3.08}\left(\frac{d_e}{2s_c}\right)^{1.4m_0+0.7}$$

$$-\frac{\sqrt{m_0}\left(\frac{d_e}{2s_c}\right)^{m_0+1}(0.74m_0+1.48)}{(m_0-0.3)^2+2}$$

$$4.7m_0^{0.7}\left(\frac{d_e}{2s_c}\right)^{0.16m_0+2}$$

Substitution coefficient Δ_2 for eddy-currents	Δ_2	1: 0 | 2: 0.000172 | 3: 0.000615

$$0$$

$$0.92m_0^{3.7}\left(\frac{d_e}{2s_c}\right)^{m_0+2}$$

$$21m_0^{3.3}\left(\frac{d_e}{2s_c}\right)^{1.47m_0+5.06}$$

Substitution coefficient m_0 for eddy-currents	m_0	1: 0.1592 | 2: 0.1612 | 3: 0.1609 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

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

Loss Factors

Loss factor of screen and sheath	λ_1	1: 0.115 | 2: 0.026 | 3: 0.037

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

Loss factor by circulating currents	λ_{1c}	0.000
Loss factor by eddy currents	λ_{1e}	1: 0.115 | 2: 0.026 | 3: 0.037

$$\lambda_{1es}$$

Loss factor for single point bonding	λ_{1es}	1: 0.115 | 2: 0.026 | 3: 0.037

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

Loss factor of armour	λ_2	0.000

Conductor resistance

AC resistance of conductor at operating temperature	R_c	1: 4.905e-02 | 2: 4.851e-02 | 3: 4.857e-02 Ω/km

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

DC resistance of conductor at operating temperature	R_{cDC}	1: 4.667e-02 | 2: 4.611e-02 | 3: 4.617e-02 Ω/km

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

Skin effect factor of conductor	y_s	1: 0.0367 | 2: 0.0375 | 3: 0.0374

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

Factor for skin effect on conductor	x_s	1: 1.6409 | 2: 1.6509 | 3: 1.6497

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

Proximity effect factor of conductors y_p 1: 0.0143 | 2: 0.0146 | 3: 0.0146

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

Factor for proximity effect of conductors x_p 1: 1.6409 | 2: 1.6509 | 3: 1.6497

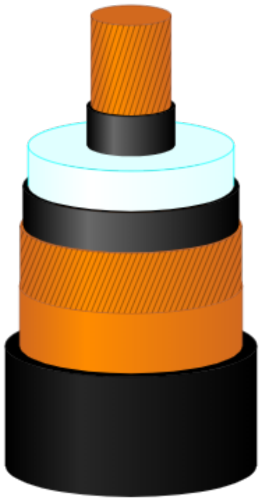
$$0.000894427190999916 \sqrt{\frac{f k_p \pi}{R_c}}$$

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

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