

## Calculation Report

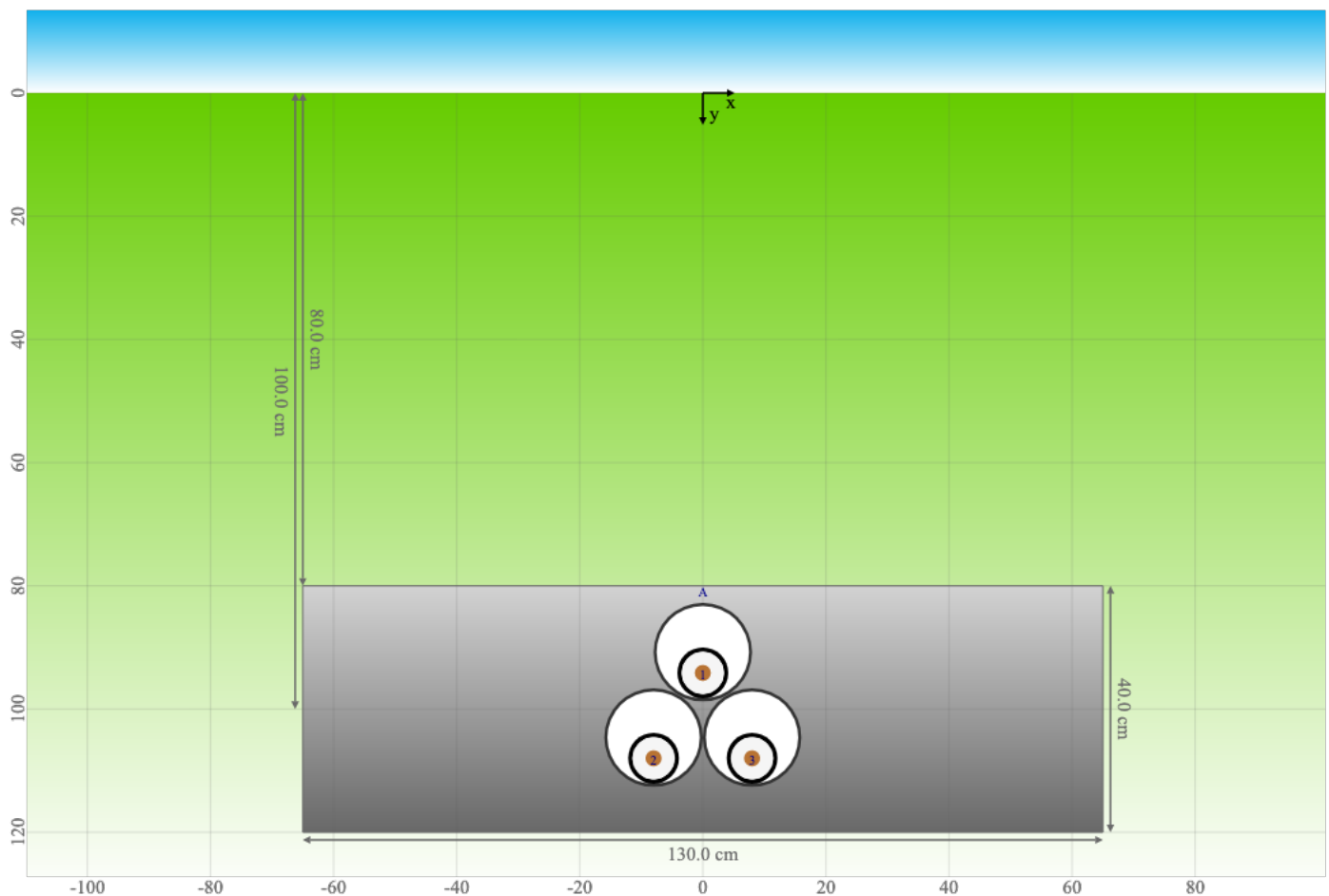
**Title** Verification Phase 2 case 06  
**Project** Verification  
**Description**  
**Created** 2020-05-17 11:55  
**Solver** 2020-03-31 (bc60f)

### Arrangement

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

### Statistics

Number of iterations of the solver  $N_{calc}$  5  
 Sum of currents from all systems  $I_{sum}$  746.9 A  
 Sum of average conductor temperatures from all systems  $\theta_{sum}$  90.0 °C  
 Number of overheated electrical systems 0  
 Sum of losses from all systems  $W_{sum}$  83.2 W/m



### Systems

Following systems are active in the arrangement:

System	Object	Current $I_c$ [A]	max Temp. $\theta_c$   $\theta_e$ [°C]	Losses $W_{sys}$ [W/m]
System A	Verification Phase 2 case 01	746.9	90.0   73.1	83.2

**Objects**

Following objects are used:

[Verification Phase 2 case 01](#)

**Ambient**

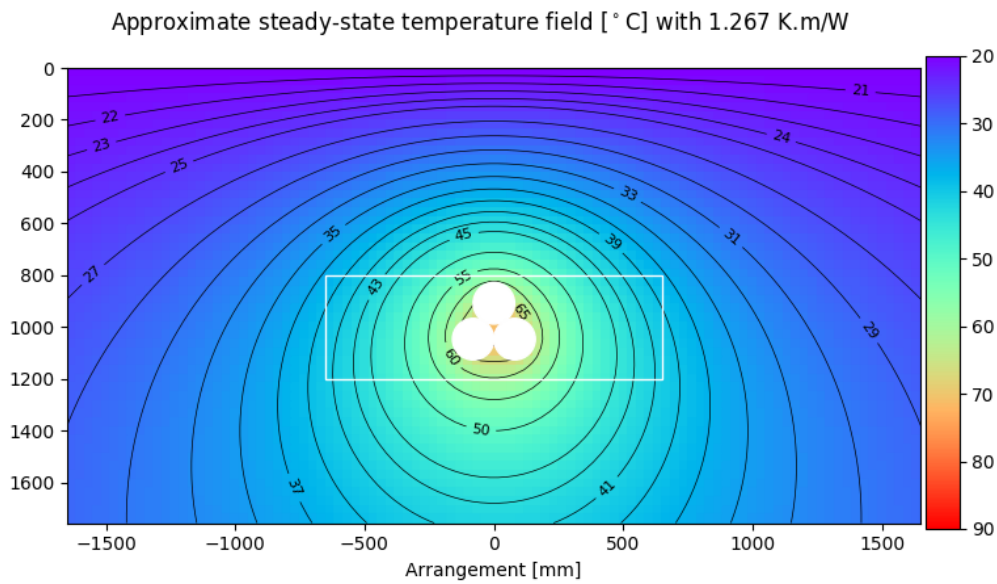
Ambient temperature	$\theta_a$	20.0 °C
Thermal resistivity of soil	$\rho_4$	1.5 K.m/W
Ratio thermal resistivity dry/moist soil	$v_4$	1.000

**Backfill**

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

**Backfill Area 1**

Thermal resistivity backfill	$\rho_b$	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



**System A (High voltage cable)****Ampacity**Name of cable Verification Phase 2 case 01Conductor current  $I_c$  746.9 A

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

Operating voltage  $U_o$  110.0 kVSystem frequency  $f$  50.0 HzNumber of sources in system  $N_c$  3Number of conductors combined  $n_{cc}$  1**Load**Continuous load  $LF$  1.0 p.u.**Temperatures**Temperature of conductor  $\theta_c$  90.0 °C

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

Temperature of screen/sheath  $\theta_s$  74.9 °C

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

External temperature of the object  $\theta_e$  73.1 °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  $\theta_{dm}$  68.5 °C

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

Temperature of duct inner wall  $\theta_{di}$  63.9 °C

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

Temperature of duct outer wall  $\theta_{de}$  62.9 °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  $W_c$  27.084 W/m

$$I_c^2 R_c$$

Screen and sheath losses	$W_s$	0.430 W/m
$W_c \lambda_1$		
Losses in pipe	$W_p$	0.000 W/m
$W_c \lambda_3$		
Ohmic losses per phase	$W_I$	27.514 W/m
$W_c (\lambda_1 + \lambda_2 + 1)$		

### 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	$W_t$	27.721 W/m
$W_I + W_d + W_p$		
Total losses per object	$W_{tot}$	27.721 W/m
$W_t n_c$		
Total losses of the system	$W_{sys}$	83.162 W/m

### Arrangement

Material of duct pipe	$M_d$	Plastic duct made of PE (Polyethylene)
Inside / outside diameter of duct	$Di_d / Do_d$	150.0   160.0 mm
Thermal resistivity of duct material	$\rho_d$	3.500 K.m/W
Specific heat capacity of duct material	$\sigma_d$	2400000.0 J/K.m <sup>3</sup>
Absorption coefficient of solar radiation	$\sigma_{sun}$	0.4
Center position of duct 1	$x_1 / y_1$	0.0 / 907.6 mm
Center position of duct 2	$x_2 / y_2$	-80.0 / 1046.2 mm
Center position of duct 3	$x_3 / y_3$	80.0 / 1046.2 mm
Separation of conductors in a system	$s_c$	160.00 mm
Depth of laying of sources	$L_c$	1000.0 mm
Substitution coefficient u	$u$	12.500
$\frac{2L_c}{Do_d}$		

### Thermal Resistances

Internal thermal resistance for current losses	$T_i$	0.622 K.m/W
$\frac{T_1}{n_c} + T_2 (\lambda_1 + 1) + T_3 (\lambda_1 + \lambda_2 + 1)$		
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	$T_{4\mu}$	1.549 K.m/W
$\frac{\rho_4 (2 \ln(u) + \ln(2u))}{2\pi}$		
Thermal resistance of medium in the duct	$T_{4i}$	0.330 K.m/W
$\frac{U_d}{D_{eq} (0.1V_d + 0.1Y_d \theta_{dm}) + 1}$		
Thermal resistance of the duct wall	$T_{4ii}$	0.036 K.m/W
$\frac{\rho_d \ln\left(\frac{Do_d}{Di_d}\right)}{2\pi}$		

Correction of thermal resistance for backfill	$T_{4db}$	0.496 K.m/W
$\frac{G_b N_b (\rho_4 - \rho_b)}{2\pi}$		
Number of loaded objects in backfill	$N_b$	3.00
Mutual heating coefficient	$F_{eq}$	1: 149.307   2: 160.262   3: 160.262
$\prod_{k=1}^q \frac{d_{pk1}}{d_{pk2}}$		

## Other characteristics

### Earthing

Earthing of cable screen/sheath		Single side
Substitution coefficient $\lambda_0$ for eddy-currents	$\lambda_0$	0.0038
$\frac{3d_e^2 m_0^2}{4s_c^2 (m_0^2 + 1)}$		
Substitution coefficient $\Delta_1$ for eddy-currents	$\Delta_1$	0.0233
$\left(\frac{d_e}{2s_c}\right)^{0.92m_0+1.66} (1.14m_0^{2.45} + 0.33)$		
Substitution coefficient $\Delta_2$ for eddy-currents	$\Delta_2$	0
Substitution coefficient $m_0$ for eddy-currents	$m_0$	0.1595 Hz.m/Ω
$\frac{1.0 \cdot 10^{-7} \omega}{R_e}$		
Substitution coefficient $\beta_1$ for eddy-currents	$\beta_1$	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	$\lambda_1$	0.016
$\lambda_{1c} + \lambda_{1e}$		
Loss factor by circulating currents	$\lambda_{1c}$	0.000
Loss factor by eddy currents	$\lambda_{1e}$	0.016
$\lambda_{1es}$		
Loss factor for single point bonding	$\lambda_{1es}$	0.016
$\frac{R_e (8.33333333333333 \cdot 10^{-14} \beta_1^4 t_{sh}^4 + g_s \lambda_0 (\Delta_1 + \Delta_2 + 1))}{R_c}$		
Loss factor of armour	$\lambda_2$	0.000

### Conductor resistance

AC resistance of conductor at operating temperature	$R_c$	4.856e-02 Ω/km
$R_{cDC} (y_p + y_s + 1)$		
DC resistance of conductor at operating temperature	$R_{cDC}$	4.667e-02 Ω/km
$R_{co} (\alpha_c (\theta_c - 20) + 1)$		
Skin effect factor of conductor	$y_s$	0.0367
$\frac{x_s^4}{0.8x_s^4 + 192}$		

Factor for skin effect on conductor  $x_s$  1.6409

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

Proximity effect factor of conductors  $y_p$  0.0038

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

Factor for proximity effect of conductors  $x_p$  1.6409

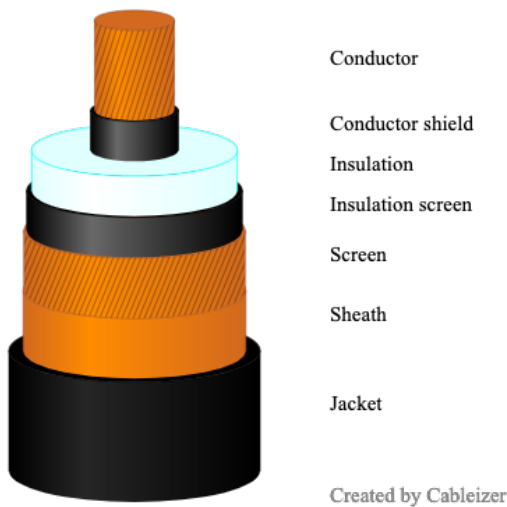
$$0.000894427190999916 \sqrt{\frac{fk_p \pi}{R_c}}$$

## 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

Number of conductors in object	$n_c$	1
Cross-sectional area of conductor	$A_c$	500.0 mm <sup>2</sup>
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	$\rho_c$	1.7241e-08 Ω.m
Temperature coefficient of conductor material	$\alpha_c$	0.00393 1/K
Specific heat capacity of conductor material	$\sigma_c$	3450000.0 J/K.m <sup>3</sup>
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	$\theta_{cmax}$	90.0 °C
Max. emergency overload conductor temperature	$\theta_{cmaxeo}$	130.0 °C
Max. short-circuit conductor temperature	$\theta_{cmaxsc}$	250.0 °C
Relative permittivity of insulation	$\epsilon_i$	2.5000
Loss factor of insulation	$\tan\delta_i$	0.0010
Thermal resistivity of insulation	$\rho_i$	3.5 K.m/W
Specific heat capacity of insulation material	$\sigma_i$	2400000.0 J/K.m <sup>3</sup>
Capacitance of insulation	$C_b$	0.1630 $\mu$ F/km
$\frac{2\epsilon_0\epsilon_i\pi}{\ln\left(\frac{r_L}{r_F}\right)}$		
Vacuum permittivity	$\epsilon_0$	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 <sup>2</sup>
$\frac{n_{sw}\pi t_{sc}^2}{4}$		
Electrical resistance of screen	$R_{sc}$	0.3505 $\Omega$ /km
$\frac{1000000\rho_{sc}}{A_{sc}}$		
Specific electrical resistivity of screen material	$\rho_{sc}$	1.7241e-08 $\Omega$ .m
Temperature coefficient of screen material	$\alpha_{sc}$	0.00393 1/K
Specific heat capacity of screen material	$\sigma_{sc}$	3450000.0 J/K.m <sup>3</sup>

## 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 <sup>2</sup>
$d_{sh}\pi t_{sh}$		
Electrical resistance of sheath	$R_{sh}$	0.3012 $\Omega$ /km
$\frac{1000000\rho_{sh}}{A_{sh}}$		



Specific electrical resistivity of sheath material	$\rho_{sh}$	1.7241e-08 $\Omega \cdot m$
Temperature coefficient of sheath material	$\alpha_{sh}$	0.00393 1/K
Specific heat capacity of sheath material	$\sigma_{sh}$	3450000.0 J/K.m <sup>3</sup>

### 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	$\rho_j$	3.5 K.m/W
Specific heat capacity of jacket material	$\sigma_j$	2400000.0 J/K.m <sup>3</sup>

### 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 kgCO <sub>2</sub> /kg
Factor of permissible pull	$f_{ppc}$	60.0 N/mm <sup>2</sup>
Permissible pull force on cable	$F_{ppc}$	3000.0 daN
$\frac{A_c f_{ppc} n_c}{10}$		