CIGRE B1 Themadag

Tutorial Track 1. Congestion

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For power system expertise

speaker

- Jos van Rossum
- Manager system engineering
- Prysmian, Delft

- Member of Cigre NC B1.
- Member of various Cigre working groups.

Origin of tutorial contents

- The work which will be presented, is developed within one of the CIGRE workgroups on current ratings. These are:
  - ✓ **B1.35 – A guide for underground cable rating calculations (TB 640)**
  - ✓ **B1.56 – Cable rating verification (TB 880)**
  - ✓ **B1.72 – Cable rating verification – application in complex situations (ongoing)**
  - ✓ **B1.45 – Thermal monitoring of cable circuits and grid operatior's use of dynamic rating systems (TB 756)**

Introduction to current ratings

Importance of current ratings

- Cables are installed to transmit power (voltage and current)
- Safeguarding the voltage withstand capabilities is extensively tested in high voltage laboratories
- Safeguarding the current rating is typically not done by testing, only by verification of calculations

Testing the current rating is rather difficult as:

- Rating depends on the cable installation
- Installation situation immediately after commissioning not equal to worst case installation situations
- Testing would require large current for a relative long period of time

Introduction to current ratings

Objective of workgroup B1.35

To be a guide for the user trying to calculate the cable rating of a new or existing power cable

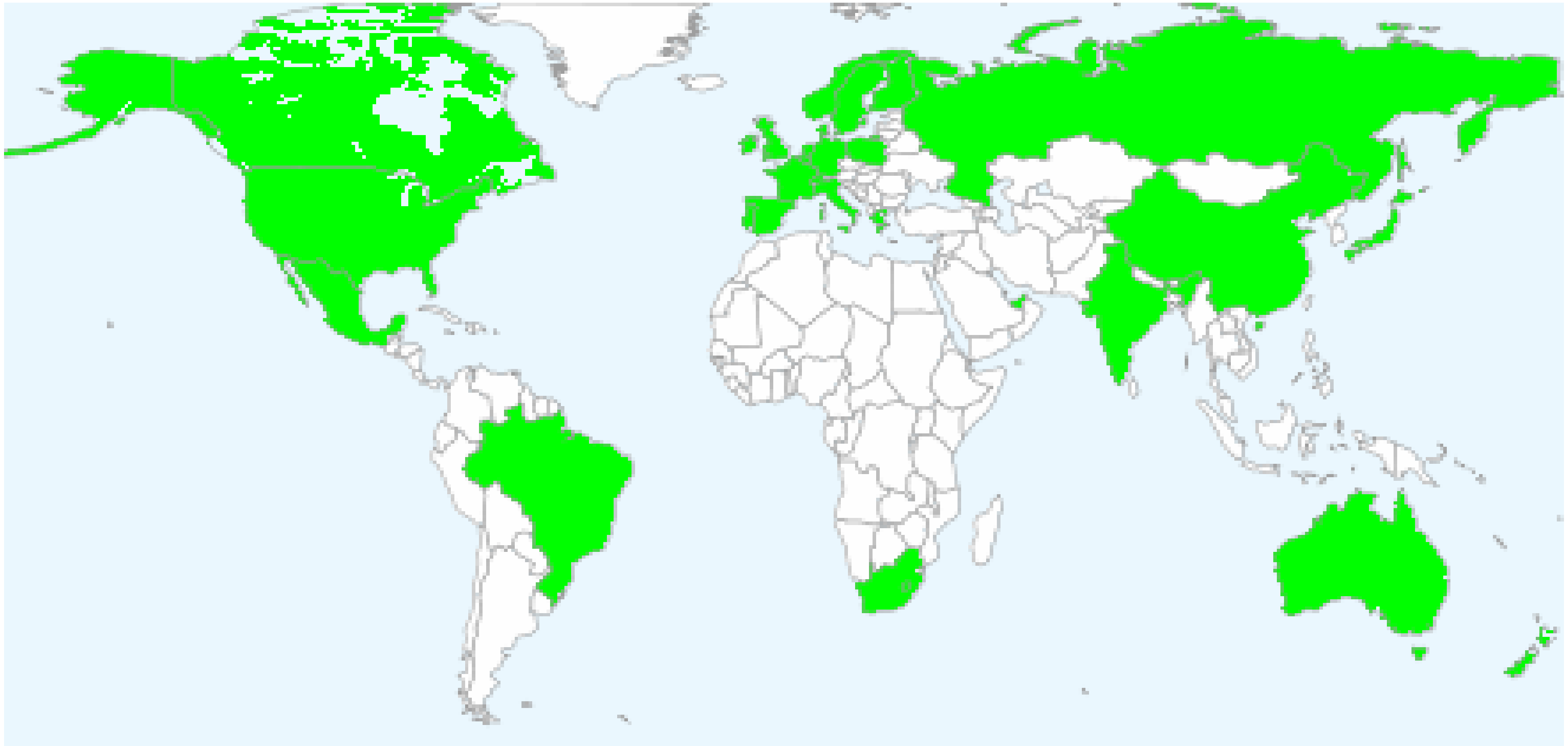
Goals:

- To collect experiences and information
- To discuss starting points for rating calculations
- To give guidance when calculating the rating, and standards do not give answers
- To discuss tools and techniques for rating calculations

Introduction to current ratings

Introduction to the questionnaire

Questionnaire was issued to learn how calculations are performed

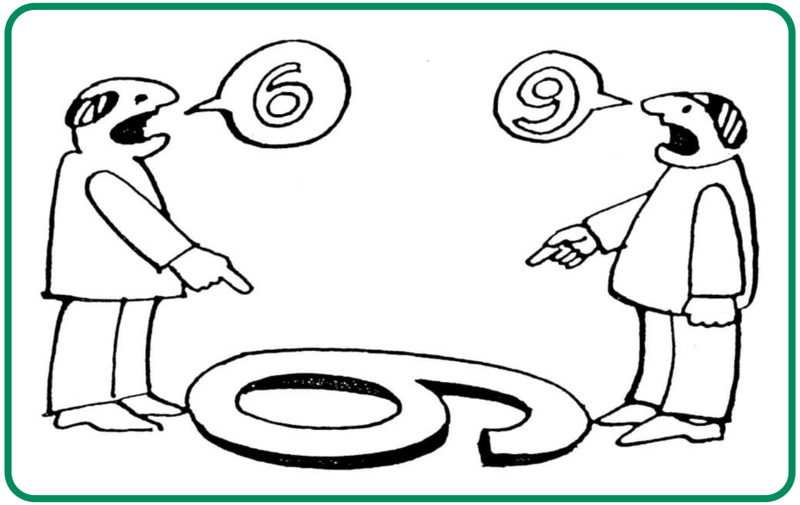


Using calculation methods and tools

Verification of tools

There is a clear need to verify calculation tools

- Calculations can be complex and difficult
- Caculation tools can be complex and less transparent
- Uncertainties and unknowns exist in application of the IEC standards, leading to various decisions to be made by the engineer when setting-up a calculation. Guidance is often missing, early in the calculation when initially interpreting the input data. And gaps are present in the applicable existing standards



- Different engineers making different choices, using different tools and different calculations, however submit a current rating of a power cable. As an overall result, the current rating may depend on the engineer and the tool used to make the calculation

Using calculation methods and tools

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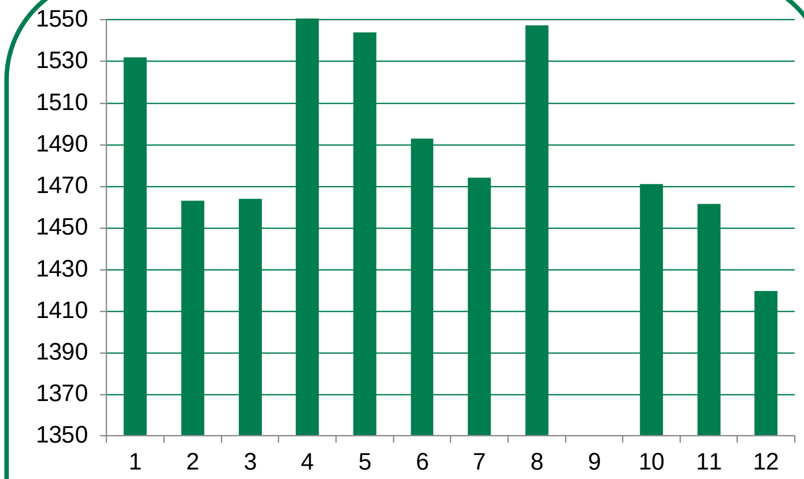

Current rating of same case according to different engineers

- Different engineers making different choices, using different tools and different calculations, however submit a current rating of a power cable. As an overall result, the current rating may depend on the engineer and the tool used to make the calculation

Verification of current rating calculation tools is very important!


Verification of Ratings
B1.56 and B1.72
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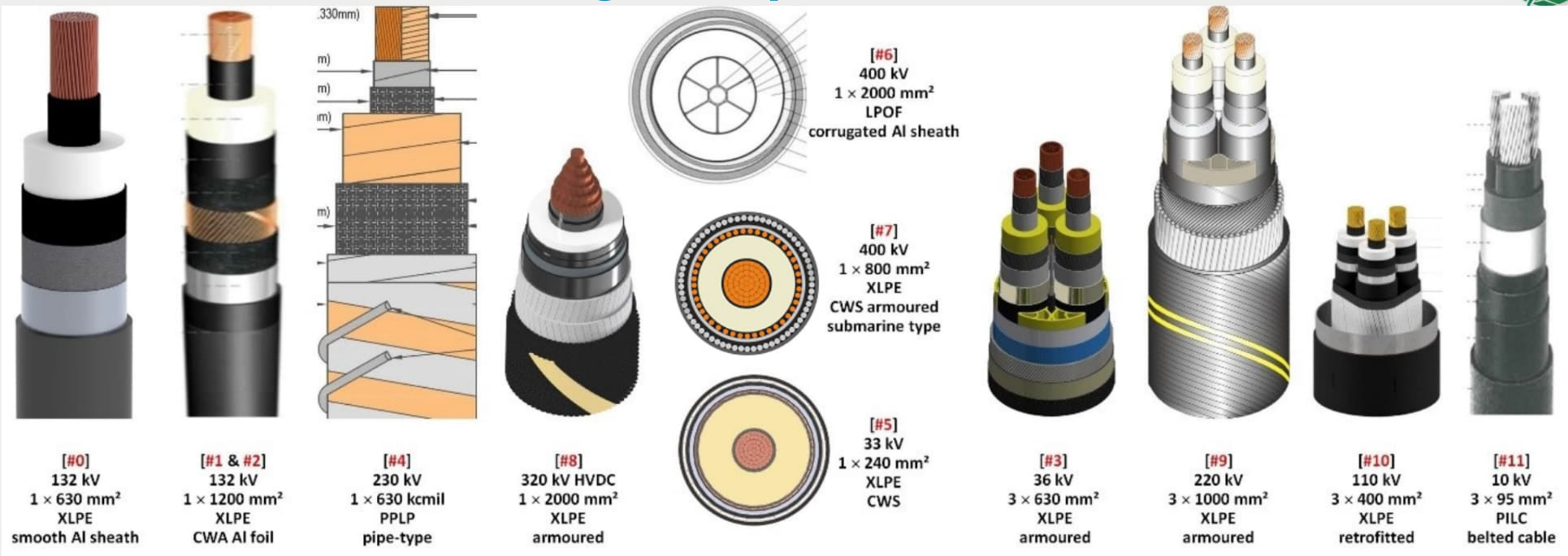
Background and Summary

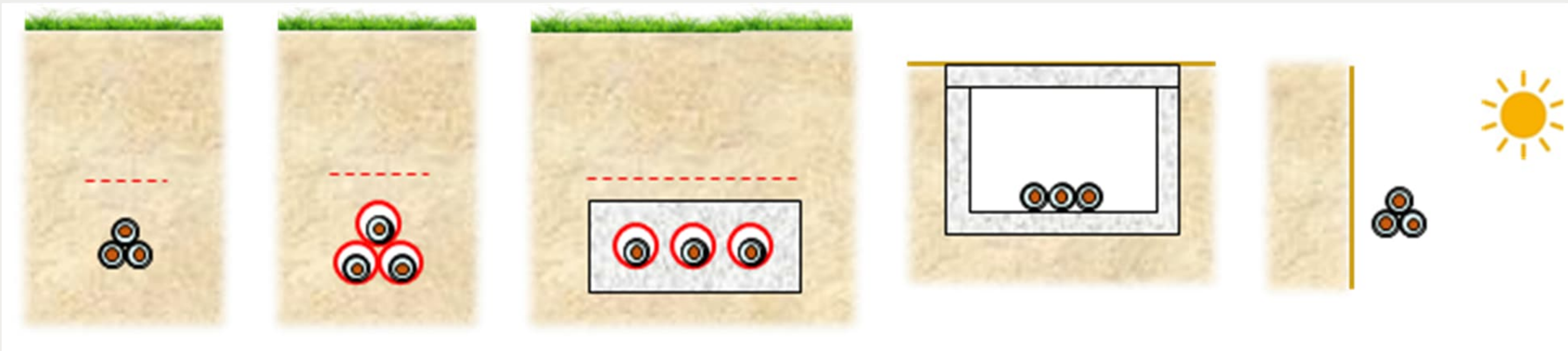
- The work of B1.35 was to catalog rating methodologies as has just been summarized earlier in this presentation; TB 640 does not provide actual calculations but instead describes starting points
- One of the outcomes of the earlier work was a need to provide detailed worked examples for various purposes:
  - ✓ **Range of examples that users may use for their own ampacity problems.**
  - ✓ **For users to verify their own calculations**
  - ✓ **Provide examples that users may use to test computer software (programs, spread sheets, etc.)**
- B1.56 and B1.72 were projects started to generate these examples.
  - ✓ **While there was some changes in representation, the members of these working groups were predominantly members of B1.35 along with some new members.**
- Cases were selected for B1.56 as being the most widely useful. B1.72 cases were considered more complex and extensions of the B1.56 cases

B1.56 and B1.72 Worked Example Contents

- B1.56
  - ✓ **WG TOR established November 2015**
  - ✓ **Cases:**
    - **0: 132kV cables (various configurations)**
    - 1: 132kV direct buried cable
    - 2: 30kV submarine cable array
    - 3: 230kV pipe-type cable
    - 4: 33kV land cable
    - 5: 400kV LPOF cable
    - 6: 400kV AC submarine cable
    - 7: 320kV HVDC submarine bi-pole
    - 8: 220kV 3-core submarine export cable
    - 9: 110kV
    - 10: 10kV 3-core PILC cable
- B1.72
  - ✓ **WG TOR established November 2018**
  - ✓ **First meeting in June 2019, and work is ongoing.**
  - ✓ **Cases:**
    - 11: Dynamic and cyclic ratings
    - 12-1: Multiple parallel circuits
      - (different constructions and load cycles)
    - 12-2: Multiple parallel circuits, MPB
    - 12-3: Multiple parallel circuits, SPB (matrix)
    - 12-4: One circuit, parallel external heat source
    - 13: Crossing cables external heat source
    - 14-1: Directional Drilling, 1ckt, common conduit
    - 14-2: Directional Drilling, 1ckt, inner ducts
    - 14-3: Multiple soil layers, conformal mapping

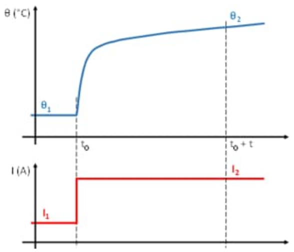
Case studies from Working Group B1.56





Case studies from Working Group B1.72

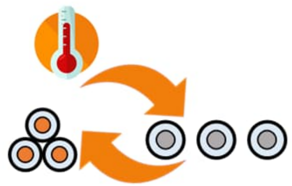
Case Study #11
Dynamic and cyclic ratings



IEC 60853-2

Variable loads: transient, emergency and load curve calculations.

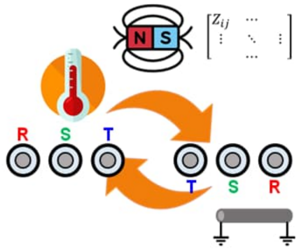
Case Study #12-1
Multiple circuits in parallel



IEC 60287-2-1

2 circuits in parallel with different cable types. Loss/load factor different for each circuit.

Case Study #12-2
Multiple circuits in parallel



IEC 60287-1-3

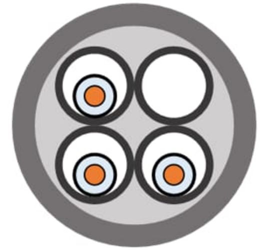
1 circuit, 2 cables per phase in parallel.

Case Study #14-1
Cables in HDD

IEC 60287-2-1

3 cables in 1 pipe (PE or PVC).

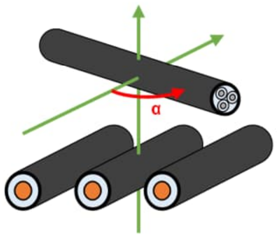
Case Study #14-2
Cables in HDD



IEC 60287-2-1

3 ducts in 1 pipe (PE or PVC), 1 cable per duct.

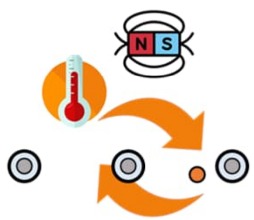
Case Study #13
Cable crossing, external heat source



IEC 60287-3-3

Cables of 2 circuits with crossing heat source (under a given angle).

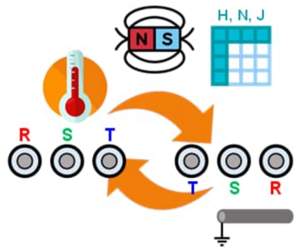
Case Study #12-4
Multiple circuits in parallel



IEC 60287-2-1

Cables with parallel heat source, being a current carrying Earth Continuity Conductor.

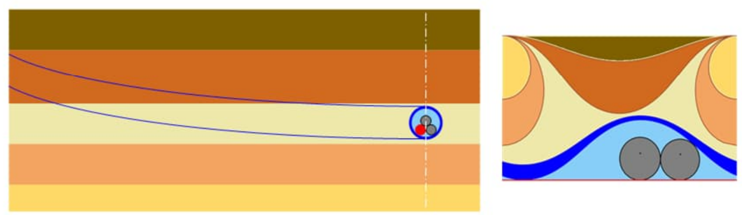
Case Study #12-3
Multiple circuits in parallel



IEC 60287-1-2

1 circuit, 2 cables per phase in parallel.

Case Study #14-3
Cables in HDD



IEC 60287-2-1, Electra 98-2

Inclined duct crossing soil layers with different properties, calculation of T4 by conformal mapping.

Using the Results of B1.56 and B1.72

- In preparing the cases, the working group often initially had discrepancies in calculation results
- As the cases were further developed and mutually verified, clarifications could be made as guidance points for users
- The examples provide very thorough calculations with all the intermediate steps and displaying results with at least 8-10 digits of precision
  - ✓ **This is far greater than the accuracy of information that is often available but was intended to provide users with better comparisons for verification purposes**
- The format of the reports is intended so that users can better make their own decisions when performing rating calculations

B1.56 / B1.72 “Guidance Points”

In developing the work for the example cases, over 49 informative points (TB880) of guidance were identified and summarized to assist users in their rating calculation efforts, especially when using a computerized tool.

- Examples:
  - ✓ **Rounding and accuracy – avoid rounding intermediate results (round final down to 1A for ratings up to 200A, down to 5A for ratings up to 500A, down to 10A > 500A)**
  - ✓ **Do not neglect eddy current losses or dielectric losses**
  - ✓ **When interpreting manufacturer’s data sheets, consider the diameters rather than thicknesses when modeling a cable**
  - ✓ **When performing other than hand calculations, avoid combining layers; preference is to model the thermal resistances of all layers including respective thermal resistivity values**
  - ✓ **Conductor resistance, in decreasing order of preference, should be based on (1) conductor standard resistance table (IEC 60228), (2) measured value, or (3) cross-sectional area, resistivity, and stranding lay factor**
  - ✓ **There are differences between the skin effect and proximity effect factors between CIGRE TB 272 and IEC 60287; the IEC standard values should be used unless they are not defined, in which case CIGRE TB values should be applied**

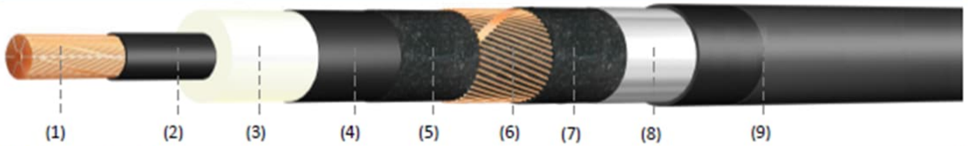
B1.56 / B1.72 “Guidance Points”

Guidance Point 46: Thermal resistance of cables in trefoil in air

Issue	Consideration of compensation for the close proximity for cables in touching trefoil formation in air.
Guidance	In case of cables in air in trefoil formation, factors which increase T_1 or T_3 (as given in Sections 4.2.4.3.2 and 4.2.4.3.3 of [4]) must not be taken into account.
Notes	If cables are in trefoil formation, the temperature distribution in individual power cables is disturbed. However, when the cables are installed in air, the air around the power cables will reduce the disturbance. The factors are calculated for buried touching cables in trefoil formation only.
Relation to IEC	This approach differs from the approach of IEC.

Example Case (B1.56) - details

Cable type	**: XLPE 76/132kV 1x1200 mm2 copper**	***Cable data sheet***
Standard	: IEC 60840	*12-Jan-2017*

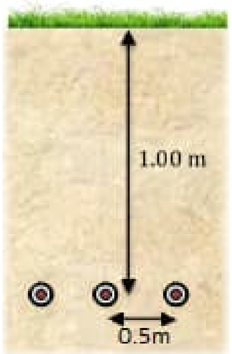


Cable construction		
Conductor	: (1)	Milliken compacted copper bare wires, bi-directional, water blocked
Conductorscreen	: (2)	semi-conducting tape + extruded semi-conducting compound
Insulation	: (3)	XLPE
Insulationscreen	: (4)	semi-conducting compound
Bedding	: (5)	semi-conducting swellable tape
Earthing screen	: (6)	copper round wires with counter helix of copper tape
Bedding	: (7)	semi-conducting swellable tape
Radial water	: (8)	aluminium laminate foil
Outer sheath	: (9)	black polyethylene jacket + extruded semi-conductive coating

Main dimensions and weight		Nominal thickness	Approx. Diameter
Conductor	:		43.1 mm
Conductorscreen	:		46.7 mm
Insulation	:	16.1 mm	80.5 mm
Insulationscreen	:		82.9 mm
Swelling tape	:		84.3 mm
Earthing screen	:	140 mm² 57x1.77 mm lay-length of 500 mm	87.8 mm
Swelling tape	:		88.4 mm
Aluminum foil (excluding glue)	:		88.8 mm
Outer sheath	:	3.6 mm	97 mm
Outer semi-conductive coating	:	0.5 mm	98 mm
Cable weight	:	appr. 18.4 kg/m	

Electrical data		
Rated voltages Uo/U (Um)	:	76/132 (145) kV
Conductor		
Maximum DC resistance at 20 °C	:	0.0151 Ω/km
Maximum temperature under normal conditions	:	90 °C
Maximum temperature under short circuit conditions	:	250 °C
Permissible short circuit current during 1 sec (adiabatic 90-250 °C)	:	>50 kA
Insulation		
Capacitance	:	0.25 µF/km
Charging current per core at Uo	:	6.0 A/km
Dielectric stress on conductor screen at Uo	:	6.2 kV/mm
Dielectric stress under insulation screen at Uo	:	3.7 kV/mm
Dielectric loss factor at Uo	:	$<10 \cdot 10^{-4}$
Earthing screen		
Maximum temperature in case of short circuit	:	180 °C
Permissible short circuit current (non-adiabatic 80-180 °C)	1s :	30.2 kA

- Depth of laying of the cable 1 m from earth surface to centre of the cable
- Flat formation configuration, phase spacing 500 mm
- Soil temperature 20 °C
- Soil thermal resistivity 1,0 K.m/W
- Sheaths are cross bonded, un-balanced, cables without transposition
- One circuit thermally independent



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Example Case (B1.56) - *continued*

5.1.3 Calculation of the conductor AC resistance at operating temperature

Table 5.1: Parameters needed to calculate the conductor AC resistance at operating temperature

Parameter	Symbol	unit	reference	Values
Conductor dc resistance @ 20ºC	R_o	$\frac{\Omega}{m}$	Cable data sheet	0,0151 x 10^{-3}
Conductor diameter	d_c	mm	Cable datasheet	43,1
Conductor material			Cable datasheet	Copper
Type of conductor			Cable datasheet	Milliken, bare wires, bi-directional
Skin effect coefficient	k_s	-	IEC60287-1-1 Table 2	0,8
Proximity effect coefficient	k_p	-	IEC60287-1-1 Table 2	0,37
Conductor temperature coefficient at 20ºC per Kelvin	α	-	IEC60287-1-1 Table 1	3,93 x 10^{-3}
Conductor operating temperature	θ	ºC	System design	90
Distance between conductor axes	s	mm	System design	98
System frequency	f	Hz	System design	50

Table 5.2: Sequential steps to calculate the conductor AC resistance at operating temperature

step	Parameter	Symbol	unit	Reference
1	Conductor DC resistance at operating temperature	R'	$\frac{\Omega}{m}$	IEC60287-1-1 clause 2.1.1
2	Argument of a Bessel function – skin effect	x_s	-	IEC60287-1-1 clause 2.1.2
3	Skin effect factor	y_s	-	IEC60287-1-1 clause 2.1.2
4	Argument of a Bessel function – proximity effect	x_p	-	IEC60287-1-1 clause 2.1.3
5	Proximity effect factor	y_p	-	IEC60287-1-1 clause 2.1.3
6	AC resistance of conductor	R	$\frac{\Omega}{m}$	IEC60287-1-1 clause 2.1

1. Conductor DC resistance at operating temperature R':

$$R' = R_o\,[1 + \alpha_{20}(\theta - 20)]\ \left(\frac{\Omega}{m}\right)$$

R_o	0,0151 x 10^{-3} Ω/m	R' = 1,9254010000 x 10^{-5} Ω/m
α_{20}	3,93 x 10^{-3}	
θ	90 ºC	

2. Argument of a Bessel function used to calculate skin effect x_s:

$$x_s^{\,2} = \frac{8\pi f}{R'} 10^{-7} k_s$$

f	50 Hz	$x_s^{\,2}$ = 5,2213001299
R'	1,925401 x 10^{-5} Ω/m	
k_s	0,8	

3. Skin effect factor y_s:

$$for\ 0 < x_s \le 2{,}8 \quad \rightarrow \quad y_s = \frac{x_s^{\,4}}{192 + 0{,}8 x_s^{\,4}}$$

Three equations are given for calculating y_s , use of these equations depends on the calculated value of x_s.

$x_s^{\,2}$	5,2213001299	y_s =0,1275058631

4. Argument of a Bessel function used to calculated proximity effect x_p:

$$x_p^{\,2} = \frac{8\pi f}{R'} 10^{-7} k_p$$

f	50 Hz	$x_p^{\,2}$ = 2,4148513101
R'	1,925401 x 10^{-5} Ω/m	
k_p	0,37	

5. Proximity effect factor y_p:

$$y_p = \frac{x_p^{\,4}}{192 + 0{,}8 x_p^{\,4}} \left(\frac{d_c}{s}\right)^2 \left[0{,}312 \left(\frac{d_c}{s}\right)^2 + \frac{1{,}18}{\frac{x_p^{\,4}}{192 + 0{,}8 x_p^{\,4}} + 0{,}27}\right]$$

$x_p^{\,2}$	2,4148513101	y_p = 0,0229311323
d_c	43,1 mm	
s	98 mm	

6. AC resistance of conductor R:

$$R = R'(1 + y_s + y_p)\ \left(\frac{\Omega}{m}\right)$$

R'	1,925401 x 10^{-5} Ω/m	R = 2,2150525415 x10^{-5} Ω/m
y_s	0,1275058631	
y_p	0,0229311323	

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Example Case (B1.56) – *continued*

5.1.4 Dielectric losses

Table 5.3: Parameters needed to calculate the dielectric loss per unit length per phase

Parameter	Symbol	unit	Reference	values
External diameter of the insulation	D_i	mm	Cable data sheet	80,5
External diameter of the conductor, incl. screen	d_{sc}	mm	Cable datasheet	46,7
Relative permittivity of the insulation	ϵ	-	IEC60287-1-1 Table 3	2,5
Loss factor of the insulation	$tan\delta$	-	IEC60287-1-1 Table 3, note 1	10 x 10^{-4}
Voltage to earth	U_o	V	System design	132kV / √3
System frequency	f	Hz	System design	50
Note 1: always assume unfilled XLPE unless specified otherwise				

Table 5.4: Sequential steps to calculate the dielectric loss per unit length per phase

step	Parameter	Symbol	unit	Reference
1	Capacitance	C	$\frac{F}{m}$	IEC60287-1-1 clause 2.2
2	Angular frequency of system	ω	-	IEC60287-1-1 clause 2.2
3	Dielectric loss per unit length in each phase	W_d	W/m	IEC60287-1-1 clause 2.2, note 1
Note 1: according to IEC60287-1-1 Table 3, the dielectric losses may be omitted in the calculation.				

1. Capacitance C (for circular conductors):

$$C = \frac{\varepsilon}{18\ln\left(\frac{D_i}{d_{sc}}\right)} 10^{-9} \left(\frac{F}{m}\right)$$

ε	2,5	C = 2,5506991358 x10^{-10} F/m
D_i	80,5 mm	
d_{sc}	46,7 mm	

2. Angular frequency of system:

$$\omega = 2\pi f \left(\frac{rad}{s}\right)$$

f	50 HZ	ω = 314,159265359 rad/s

3. Dielectric loss per unit length in each phase:

$$W_d = \omega C U_o^2 tan\delta \quad (W/m)$$

C	2,5506991358 x10^{-10} F/m	W_d = 0,4654100053 W/m
ω	314,159265359 rad/s	
U_o	132kV/√3 = 7,6210235533 x10^{4} V	
$tan\delta$	10 x 10^{-4}	

Example Case (B1.56) - *continued*

5.1.5 Loss factor for screen and laminated foil

See flow charts in Section 2.12 for details.

Table 5.5: Parameters needed to calculate the loss factor for screen and laminated foil

Parameter	Symbol	unit	Reference	Data
AC resistance of screen at 20°C	$R_{so_{sc}}$	$\frac{\Omega}{m}$	Cable datasheet, note 1	-
AC resistance of laminated foil at 20°C	$R_{so_{fl}}$	$\frac{\Omega}{m}$	Cable datasheet, note 2	-
External Diameter of screen	D_{sc}	mm	Cable data sheet	87,8
External Diameter over laminated foil	D_{fl}	mm	Cable data sheet	88,8
Diameter of one copper wire of the copper wires screen	d_{cw}	mm	Cable data sheet	1,77
Number of copper wires in the copper wires screen	n_{cws}	-	Cable data sheet	57
Length of lay of copper wires screen	lay	mm	Cable data sheet	500
Thickness of the laminated foil	t_{fl}	mm	Cable data sheet	0,2
Screen resistivity at 20°C	ρ_{sc}	Ωm	IEC60287-1-1 Table 1	$1{,}7241 \times 10^{-8}$
Laminated foil resistivity at 20°C	ρ_{fl}	Ωm	IEC60287-1-1 Table 1	$2{,}84 \times 10^{-8}$
Copper wires screen temperature coefficient at 20°C per Kelvin	α_{sc}	-	IEC60287-1-1 Table 1	$3{,}93 \times 10^{-3}$
Laminated foil temperature coefficient at 20°C per Kelvin	α_{fl}	-	IEC60287-1-1 Table 1	$4{,}03 \times 10^{-3}$
Distance between conductor axes of the electrical section being considered	s	mm	System design	98
System frequency	f	Hz	System design	50
AC resistance of conductor at operating temp.	R	$\frac{\Omega}{m}$	Calculated	$2{,}2150525415 \times 10^{-5}$
Dielectric loss per unit length in each phase	W_d	W/m	Calculated	0,4654100053
Thermal resistance between conductor and metallic screen	T_1	K.m/W	Calculated	0,3789088974
Thermal resistance between metallic screen and laminated foil	T_2	K.m/W	Calculated	0,0121371405
Note 1: if not given, to be calculated based on the cross section of the copper wires screen Note 2: if not given, to be calculated based on the cross section of the laminated foil				

Table 5.6: Sequential steps to calculate the loss factor for screen and laminated foil

step	Parameter	Symbol	unit	Reference
1	AC Resistance of screen at 20°C	$R_{so_{sc}}$	$\frac{\Omega}{m}$	-
2	AC Resistance of laminated foil at 20°C	$R_{so_{fl}}$	$\frac{\Omega}{m}$	-
3	Maximum operating temperature of the cable copper wires screen, to be determined iterative	θ_{sc}	°C	IEC60287-1-1 clause 2.3
4	Maximum operating temperature of the cable laminated foil, to be determined iterative	θ_{fl}	°C	IEC60287-1-1 clause 2.4
5	Resistance of screen at operating temperature	$R_{s_{sc}}$	$\frac{\Omega}{m}$	IEC60287-1-1 clause 2.3
6	Resistance of laminated foil at operating temperature	$R_{s_{fl}}$	$\frac{\Omega}{m}$	IEC60287-1-1 clause 2.3
7	Resistance of screen and laminated foil at operating temperature	R_s	$\frac{\Omega}{m}$	
8	Reactance per unit length of screen and laminated foil	X	$\frac{\Omega}{m}$	IEC60287-1-1 clause 2.3.1
9	Loss factor circulating losses for screen and laminated foil	λ'_{1com}	-	IEC60287-1-1 clause 2.3.1
10	Split loss factor in screen loss factor and laminated foil loss factor	λ'_1 λ'_2		See note 3
11	Loss factor for eddy current losses	λ''_1 λ''_2	-	IEC60287-1-1 clause 2.3.6.1 and note 3
12	Effect factor for Milliken conductors, for eddy current losses in laminated foil only	F	-	IEC60287-1-1 clause 2.3.5
13	Add circulating losses and eddy current losses to find λ_1 and λ_2	λ_1 λ_2		See note 3.
Note 3: to make a clear distinguish, λ_1 refers to the copper wires screen losses ratio and λ_2 refers to the aluminum laminated foil losses ratio.				

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Example Case (B1.56) - *continued*

1. Resistance of screen at 20ºC:
   Cross section of the copper wires screen, based on the wire diameter and the number of wires:

$$A_{cws} = n_{cws} \cdot \frac{1}{4} \cdot \pi \cdot d_{cw}^2 \cdot 10^{-6} \quad (m^2)$$

n_{cws}	57	A_{cws} = 140,252171265 x 10^{-6} m²
d_{cw}	1,77 mm	

AC Resistance of the screen at 20ºC per unit length is:

$$R'_{so_{sc}} = \frac{\rho_{sc}}{A_{cws}} \quad \left(\frac{\Omega}{m}\right)$$

ρ_{sc}	1,7241 x 10^{-8} Ω·m	$R'_{so_{sc}}$ = 1,2292810367 x 10^{-4} $\frac{\Omega}{m}$
A_{cws}	140,252171265 x 10^{-6} m²	

Correction of the AC resistance of the screen, taken into account lay-length:

$$R_{so_{sc}} = R'_{so_{sc}} \sqrt{1 + \left(\frac{\pi(D_{sc} - d_{cw})}{lay}\right)^2} \quad \left(\frac{\Omega}{m}\right)$$

$R'_{so_{sc}}$	1,2292810367 x 10^{-4} $\frac{\Omega}{m}$	$R_{so_{sc}}$ = 1,3975243485 x 10^{-4} Ω/m
D_{sc}	87,8 mm	
d_{cw}	1,77 mm	
lay	500 mm	

2. Resistance of laminated foil at 20ºC:
   AC Resistance of the laminated foil at 20ºC per unit length is:

$$R_{so_{fl}} = \frac{\rho_{fl}}{t_{fl} \cdot \pi (D_{fl} - t_{fl})} \quad \left(\frac{\Omega}{m}\right)$$

ρ_{fl}	2,84 x 10^{-8} Ω·m	$R_{so_{fl}}$ = 5,1015805686 x 10^{-4} Ω/m
t_{fl}	0,2 x 10^{-3} m	
D_{fl}	88,8 x10^{-3} m	

3. The operating temperature θ_{sc} (ºC) of the screen is given by:

$$\theta_{sc} = \theta - (I^2 R + 0{,}5 W_d) T_1 \quad (oC)$$

θ	90 ºC	θ_{sc} = 81,6982082654 ºC
I	989,2540243946 A	
R	2,2150525415 x10^{-5} Ω/m	
W_d	0,4654100053 W/m	
T_1	0,3789088974	

Note: θ_{sc} is the operating temperature of the cable screen (ºC). Since the temperature of the screen is a function of the current I, an iterative method must be used here.

4. The operating temperature θ_{fl} (ºC) of the laminated foil is given by:

$$\theta_{fl} = \theta - \{(I^2 R + 0{,}5 W_d) T_1 + [I^2 R (1 + \lambda_1) + W_d] n T_2\} \quad (oC)$$

θ	90 ºC	θ_{fl} = 81,2745199508 ºC
I	989,2540243946 A	
R	2,2150525415 x10^{-5} Ω/m	
W_d	0,4654100053 W/m	
T_1	0,3789088974 K.m/W	
λ_1	0,5889174287	
T_2	0,0121371405 K.m/W	
n	1	

Note: θ_{fl} is the operating temperature of the laminated foil (ºC). Since the temperature of the laminated foil is a function of the current I, an iterative method must be used here.

5. Copper wires screen AC resistance at operating temperature θ_{sc}:

$$R_{s_{sc}} = R_{so_{sc}}[1 + \alpha_{sc}(\theta_{sc} - 20)] \quad \left(\frac{\Omega}{m}\right)$$

$R_{so_{sc}}$	1,3975243485 x 10^{-4} Ω/m	$R_{s_{sc}}$ = 1,7363876094 x10^{-4} Ω/m
α_{sc}	3,93 x 10^{-3}	
θ_{sc}	81,6982082654 ºC	

6. Laminated foil AC resistance at operating temperature θ_{fl}:

$$R_{s_{fl}} = R_{so_{fl}}[1 + \alpha_{fl}(\theta_{fl} - 20)] \quad \left(\frac{\Omega}{m}\right)$$

$R_{so_{fl}}$	5,1015805686 x 10^{-4} Ω/m	$R_{s_{fl}}$ = 6,3613460770 x10^{-4} Ω/m
α_{fl}	4,03 x 10^{-3}	
θ_{fl}	81,2745199508 ºC	

7. Resistance of screen and laminated foil at operating temperature R_s:

$$R_s = \frac{R_{s_{sc}} \cdot R_{s_{fl}}}{R_{s_{sc}} + R_{s_{fl}}} \quad \left(\frac{\Omega}{m}\right)$$

$R_{s_{sc}}$	1,7363876094 x10^{-4} Ω/m	R_s = 1,3640560353 x10^{-4} Ω/m
$R_{s_{fl}}$	6,3613460770 x10^{-4} Ω/m	

8. Calculation of the reactance X per unit length of the screen:
   Mean diameter of screen and laminated foil:

$$d = \sqrt{\frac{(D_{sc} - d_{cw})^2 + (D_{fl} - t_{fl})^2}{2}} \quad (mm)$$

D_{sc}	87,84 mm	d = 87,3441609382 mm
d_{cw}	1,77 mm	
D_{fl}	88,8 mm	
t_{fl}	0,2 mm	

$$X = 2\omega 10^{-7} \ln\left(\frac{2s}{d}\right) \quad \left(\frac{\Omega}{m}\right)$$

ω	$2\pi f$ =314,159265359 rad/s	X = 5,0784377532 x 10^{-5} Ω/m
s	98 mm	
d	87,3441609382 mm	

9. Loss factor λ'_{1com} for circulating losses in screen and laminated foil:

$$\lambda'_{1com} = \left(\frac{R_s}{R} \frac{1}{1 + \left(\frac{R_s}{X}\right)^2}\right)$$

R_s	1,3640560353 x10^{-4} Ω/m	λ'_{1com} = 0,7496678287
R	2,2150525415 x10^{-5} Ω/m	
X	5,0784377532 x 10^{-5} Ω/m	

10. Split loss factor in screen loss factor and laminated foil loss factor:

$$\lambda'_1 = \lambda'_{1com}\left(\frac{R_{s_{fl}}}{R_{s_{sc}} + R_{s_{fl}}}\right)$$

$$\lambda'_2 = \lambda'_{1com}\left(\frac{R_{s_{sc}}}{R_{s_{sc}} + R_{s_{fl}}}\right)$$

λ'_{1com}	0,7496678287	λ'_1 = 0,5889174287 λ'_2 = 0,1607504
$R_{s_{sc}}$	1,7363876094 x10^{-4} Ω/m	
$R_{s_{fl}}$	6,3613460770 x10^{-4} Ω/m	

Example Case (B1.56) - *continued*

11. Loss factor λ_2'' for eddy current losses

As per IEC60287-1-1, clause 2.3.6.1, Note 3, the eddy-current losses are considered negligible for a wire screen, thus $\lambda_1''=0$. The eddy current losses for the laminated foil are determined hereunder:

$$m=\frac{\omega}{R_{sfl}}10^{-7}$$

ω	314,159265359 rad/s	$m = 0{,}0493856586$
R_{sfl}	6,3613460770 x10^{-4} Ω/m	

$$d_{fl}=D_{fl}-t_{fl}\quad(mm)$$

D_{fl}	88,8 mm	d_{fl} = 88,6 mm
t_{fl}	0,2 mm	

$$\lambda_0=3\left(\frac{m^2}{1+m^2}\right)\left(\frac{d_{fl}}{2s}\right)^2$$

m	0,0493856586	
d_{fl}	88,6 mm	λ_0 = 1,4914899275 x10^{-3}
s	98 mm	

$$\Delta_1=(1{,}14m^{2{,}45}+0{,}33)\left(\frac{d_{fl}}{2s}\right)^{(0{,}92m+1{,}66)}$$

$$\Delta_2=0$$

m	0,0493856586	$\Delta_1 = 0{,}0853858722$ $\Delta_2 = 0$
d_{fl}	88,6 mm	
s	98 mm	

$$\beta_1=\sqrt{\frac{4\pi\omega}{10^7\rho_{fl}\cdot[1+\alpha_{fl}(\theta_{fl}-20)]}}$$

ω	314,159265359	
ρ_{fl}	2,84 x10^{-8} Ω·m	$\beta_1 = 105{,}584109554$
α_{fl}	4,03 x 10^{-3}	
θ_{fl}	81,2745199508 °C	

$$g_s=1+\left(\frac{t_{fl}}{D_{fl}}\right)^{1{,}74}(\beta_1D_{fl}10^{-3}-1{,}6)$$

D_{fl}	88,8 mm	
t_{fl}	0,2 mm	$g_s = 1{,}0001924432$
β_1	105,584109554	

$$\lambda_2''=\frac{R_{sfl}}{R}\left[g_s\lambda_0(1+\Delta_1+\Delta_2)+\frac{(\beta_1t_{fl})^4}{12\times10^{12}}\right]$$

R_{sfl}	6,361346077 x10^{-4} Ω/m	
R	2,2150525415 x10^{-5} Ω/m	
g_s	1,0001924432	
λ_0	1,4914899275 x10^{-3}	$\lambda_2'' = 0{,}0465004862$
Δ_1	0,0853858722	
Δ_2	0	
β_1	105,584109554	
t_{fl}	0,2 mm	

12. Effect factor for Milliken conductors:

$$M=N=\frac{R_{sfl}}{X}$$

R_{sfl}	6,361346077 x10^{-4} Ω/m	$M = 12{,}5261869615$ $N = 12{,}5261869615$
X	5,0784377532 x 10^{-5} Ω/m	

$$F=\frac{4M^2N^2+(M+N)^2}{4(M^2+1)(N^2+1)}$$

M	12,5261869615	$F = 0{,}9936670927$
N	12,5261869615	

13. Add circulating losses and eddy current losses to find λ_1 and λ_2:

Copper wires screen losses ratio:

$$\lambda_1=\lambda_1'+F\cdot\lambda_1''$$

λ_1'	0,5889174287	
λ_1''	0	$\lambda_1 = 0{,}5889174287$
F	0,9936670927	

Aluminimum laminated foil losses ratio:

$$\lambda_2=\lambda_2'+F\cdot\lambda_2''$$

λ_2'	0,1607504	
λ_2''	0,0465004862	$\lambda_2 = 0{,}2069564029$
F	0,9936670927	

5.1.6 Thermal resistance T1 between conductor and screen

Note that in the following section, sc denotes semi-conducting material.

Table 5.7: Parameters needed to calculate the thermal resistance between conductor and screen

Parameter	Symbol	Unit	reference	Value
diameter of conductor	d_c	mm	Cable datasheet	43,1
External diameter of sc conductor screen	d_{sc}	mm	Cable datasheet	46,7
External diameter of insulation	D_i	mm	Cable data sheet	80,5
External diameter of sc insulation screen	D_{si}	mm	Cable data sheet	82,9
External diameter of sc- water blocking tape(s) under the copper wires screen	D_{uwb}	mm	Cable data sheet	84,3
Thermal resistivity of sc screen	ρ_{sc}	K.m/W	note 1	2,5
Thermal resistivity of insulation	ρ_i	K.m/W	IEC60287-2-1 Table 1	3,5
Thermal resistivity of water blocking tape	ρ_{wb}	K.m/W	note 2	12
Note 1: in this case: 2,5 K.m/W Note 2: in this case: 12 K.m/W unless more accurate values are available				

Table 5.8: Sequential steps to calculate the thermal resistance between conductor and screen

step	parameter	Symbol	unit	Reference
1	Thermal resistance of sc conductor screen	$T_{1\ csc}$	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.2.1
2	Thermal resistance of insulation	T_{1_i}	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.2.1
3	Thermal resistance of sc insulation screen	$T_{1_{isc}}$	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.2.1
4	Thermal resistance of sc water blocking tape under the copper wires screen	$T_{1_{uwht}}$	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.2.1
5	Thermal resistance between conductor and screen	T_1	$K.\frac{m}{W}$	-
6	Include correction factor	-	-	IEC60287-2-1 clause 4.2.4.3.2

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Example Case (B1.56) - *continued*

1. Thermal resistance of sc conductor screen:

$$T_{1\_csc} = \frac{\rho_{sc}}{2\pi}\ln\left(\frac{d_{sc}}{d_c}\right) \quad \left(K.\frac{m}{W}\right)$$

ρ_{sc}	2,5 K.m/W	$T_{1\ csc}$ = 0,0319189884 K.m/W
d_{sc}	46,7mm	
d_c	43,1mm	

2. Thermal resistance of insulation:

$$T_{1_i} = \frac{\rho_i}{2\pi}\ln\left(\frac{D_i}{D_{sc}}\right) \quad \left(K.\frac{m}{W}\right)$$

ρ_i	3,5 K.m/W	T_{1_i} = 0,3033167853 K.m/W
D_i	80,5 mm	
D_{sc}	46,7 mm	

3. Thermal resistance of sc insulation screen:

$$T_{1_{isc}} = \frac{\rho_{sc}}{2\pi}\ln\left(\frac{D_{si}}{D_i}\right) \quad \left(K.\frac{m}{W}\right)$$

ρ_{sc}	2,5 K.m/W	$T_{1_{isc}}$ = 0,0116890861 K.m/W
D_{si}	82,9 mm	
D_i	80,5 mm	

4. Thermal resistance of sc water blocking tape under the copper wires screen:

$$T_{1_{uwbt}} = \frac{\rho_{wb}}{2\pi}\ln\left(\frac{D_{si}}{D_i}\right) \left(K.\frac{m}{W}\right)$$

ρ_{wb}	12 K.m/W	$T_{1_{uwbt}}$ = 0,0319840375 K.m/W
D_{bst}	84,3 mm	
D_{si}	82,9 mm	

5. Thermal resistance between conductor and screen:

$$T_1 = T_{1\_csc} + T_{1_i} + T_{1_{isc}} + T_{1_{uwbt}} \quad \left(K.\frac{m}{W}\right)$$

$T_{1\ csc}$	0,0319189884 K.m/W	T_1 = 0,3789088974 K.m/W
T_{1_i}	0,3033167853 K.m/W	
$T_{1_{isc}}$	0,0116890861 K.m/W	
$T_{1_{uwbt}}$	0,0319840375 K.m/W	

6. Correction factor:
   Although the copper wires screen covering is less than 50%, see IEC60287-1-1 clause 4.2.4.3.3, the aluminum foil is considered here as a metallic sheath and therefore no correction factor is applied for T_1.

5.1.7 Thermal resistance T2 between screen and laminated foil

Table 5.9: Parameters needed to calculate the thermal resistance between conductor and screen'

Parameter	Symbol	unit	reference	Value
External diameter of copper wires screen	D_{sc}	mm	Cable data sheet note 1	87,84
External diameter of sc- water blocking tape(s) over the copper wires screen	D_{owt}	mm	Cable data sheet	88,4
Thermal resistivity of water blocking tape	ρ_{wb}	K.m/W	note 2	12 K.m/W
Note 1: the indicated external diameter on the datasheet is 87,8 mm but this is a rounded number. Based on the copper wire diameter in the copper wires screen, the actual diameter is 84,3mm + 2x1,77mm = 87,84 mm and this value is used in the calculations. Note 2: in this case: 12 K.m/W, unless more accurate values are available				

Table 5.10: Sequential steps to calculate the thermal resistance between screen and laminated foil'

step	parameter	Symbol	unit	Reference
1	Thermal resistance of sc water blocking tape over the copper wires screen	$T_{2_{owbt}}$	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.2.1

1. Thermal resistance of sc water blocking tape over the copper wires screen:

$T_2 = \frac{\rho_{wb}}{2\pi} ln\left(\frac{D_{owt}}{D_{sc}}\right) \quad \left(K.\frac{m}{W}\right) \rho_{wb}$	12 K.m/W	T_2 = 0,0121371405 K.m/W
D_{owt}	88,4 mm	
D_{sc}	87,84 mm	

5.1.8 Thermal resistance T3 of outer covering

Table 5.11 'Parameters needed to calculate the thermal resistance T3 of the outer covering'

Parameter	Symbol	unit	reference	Value
External diameter of the aluminum foil	D_{fl}	mm	Cable data sheet	88,8
External diameter of outer covering without semi conductive layer	D_{e_1}	mm	Cable data sheet	97,0
External diameter semi conductive layer over outer covering	D_{e_2}	mm	Cable data sheet	98,0
Thermal resistivity of outer covering	ρ_{Ti}	K.m/W	IEC60287-2-1 table 1	3,5 K.m/W
Thermal resistivity of semi conductive layer over outer covering	ρ_{Tcs}	K.m/W	Note 1	2,5 K.m/W
Note 1: in this case: 2.5 K.m/W				

Table 5.12 'Sequential steps to calculate the thermal resistance T3 of the outer covering'

step	parameter	Symbol	unit	Reference
1	Thermal resistance of outer covering	$T_{3_{oc}}$	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.4.1
2	Thermal resistance of semi conductive layer over outer covering	$T_{3_{sc}}$	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.1.4.1
3	Thermal resistance outer covering	T_3	$K.\frac{m}{W}$	
4	Include correction factor	-	-	IEC60287-2-1 clause 4.2.4.3.2

1. Thermal resistance of outer covering:

$$T_{3_{oc}} = \frac{\rho_{Ti}}{2\pi} ln\left(\frac{D_{e_1}}{D_{fl}}\right) \quad \left(K.\frac{m}{W}\right)$$

ρ_{Ti}	3,5 K.m/W	$T_{3_{oc}}$ = 0,0492003872 K.m/W
D_{e_1}	97,0 mm	
D_{fl}	88,8 mm	

2. Thermal resistance of semi conductive layer over outer covering:

$$T_{3_{sc}} = \frac{\rho_{Tcs}}{2\pi} ln\left(\frac{D_{e_2}}{D_{e_1}}\right) \quad \left(K.\frac{m}{w}\right)$$

ρ_{Tsc}	2,5 K.m/W	$T_{3_{sc}}$ = 4,0809317511 x10^{-3} K.m/W
D_{e_1}	97,0 mm	
D_{e_2}	98,0 mm	

3. Thermal resistance outer covering:

$$T_3 = T_{3_{oc}} + T_{3_{sc}} \quad \left(K.\frac{m}{W}\right)$$

$T_{3_{oc}}$	0,0492003872 K.m/W	T_3 = 0,0532813189 K.m/W
$T_{3_{sc}}$	4,0809317511 x10^{-3} K.m/W	

4. Correction factor:
   multiply T_3 with 1.6

factor	1,6	$1.6 * T_3$ = 0,0852501103 K.m/W

Example Case (B1.56) - *continued*

5.1.9 External thermal resistance T4

Table 5.13 'Parameters needed to calculate the external thermal resistance T_4'

Parameter	Symbol	unit	reference	Value
External diameter of one cable	D_{e_2}	mm	Cable data sheet	98
Distance from the surface of the ground to the cable axis	L	mm	System design, note 1	1000
Thermal resistivity of the soil	ρ_T	K.m/W	System design	1,0 K.m/W
Note 1: L is measured to the centre of the trefoil group				

Table 5.14 'Sequential steps to calculate the external thermal resistance T_4'

step	Parameter	Symbol	unit	Reference
1	External thermal resistance	T_4	$K.\frac{m}{W}$	IEC60287-2-1 clause 4.2.4.3.2

1. External thermal resistance:

$$u = \frac{2L}{D_{e_2}}$$

L	1000 mm	$u = 20{,}4081632653$
D_{e_2}	98 mm	

$$T_4 = \frac{1{,}5}{\pi}\rho_T[\ln(2u) - 0{,}630] \quad \left(K.\frac{m}{W}\right)$$

ρ_T	1,0 K.m/W	$T_4 = 1{,}4701534385$ K.m/W
u	20,4081632653	

5.1.10 Permissible current rating

Table 5.15 'Parameters needed to calculate the continuous current carrying capacity'

Parameter	Symbol	unit	reference	Values
Conductor operating temperature	θ	°C	System design	90
Ambient temperature	θ_a	°C	System design	20
Number of conductors in cable	n	-	Cable data sheet	1
AC resistance of conductor at operating temperature	R	Ω/m	Calculated	2,2150525415 x10^{-5}
Ratio of the total losses in metallic screen	λ_1	-	Calculated	0,5889174287
Ratio of the total losses in metallic foil	λ_2	-	Calculated	0,2069564029
Dielectric losses	W_d	W/m	Calculated	0,4654100053
Thermal resistance between conductor and metallic screen	T_1	K.m/W	Calculated	0,3789088974
Thermal resistance between metallic screen and metallic foil	T_2	K.m/W	Calculated	0,0121371405
Thermal resistance of external serving	$1{,}6 \cdot T_3$	K.m/W	Calculated	0,0852501103
Thermal resistance of surrounding medium	T_4	K.m/W	Calculated	1,4701534385

Table 5.16 'Sequential steps to calculate the continuous current rating capacity'

step	Parameter	Symbol	unit	Reference
1	Conductor temperature rise above ambient	$\Delta\theta$	K	IEC60287-1-1 clause 1.4.1.1
2	Permissible current rating	I	A	IEC60287-1-1 clause 1.4.1.1

1. Conductor temperature rise above ambient:

$$\Delta\theta = \theta - \theta_a$$

θ	90 °C	$\Delta\theta = 70$ K
θ_a	20 °C	

2. Permissible current rating:

$$I = \left[\frac{\Delta\theta - W_d\,[0{,}5 \cdot T_1 + n(T_2 + 1{,}6 \cdot T_3 + T_4)]}{R \cdot T_1 + nR(1+\lambda_1)T_2 + nR(1+\lambda_1+\lambda_2)(1{,}6 \cdot T_3 + T_4)}\right]^{0{,}5}$$

$\Delta\theta$	70 K	$I = 989{,}2540243946$ A
W_d	0,4654100053 K.m/W	
T_1	0,3789088974 K.m/W	
T_2	0,0121371405 K.m/W	
$1{,}6 \cdot T_3$	0,0852501103 K.m/W	
T_4	1,4701534385 K.m/W	
R	2,2150525415 x10^{-5} Ω/m	
n	1	
λ_1	0,5889174287	
λ_2	0,2069564029	

5.1.11 Calculation of losses

Conductor losses:

$$P_c = RI^2 \text{ (W/m)}$$

R	2,2150525415 x10^{-5} Ω/m	$P_c = 21{,}6770252575$ W/m
I	$I = 989{,}2540243946$ A	

Copper wires screen losses:

$$P_{screen} = \lambda_1 RI^2 \text{ (W/m)}$$

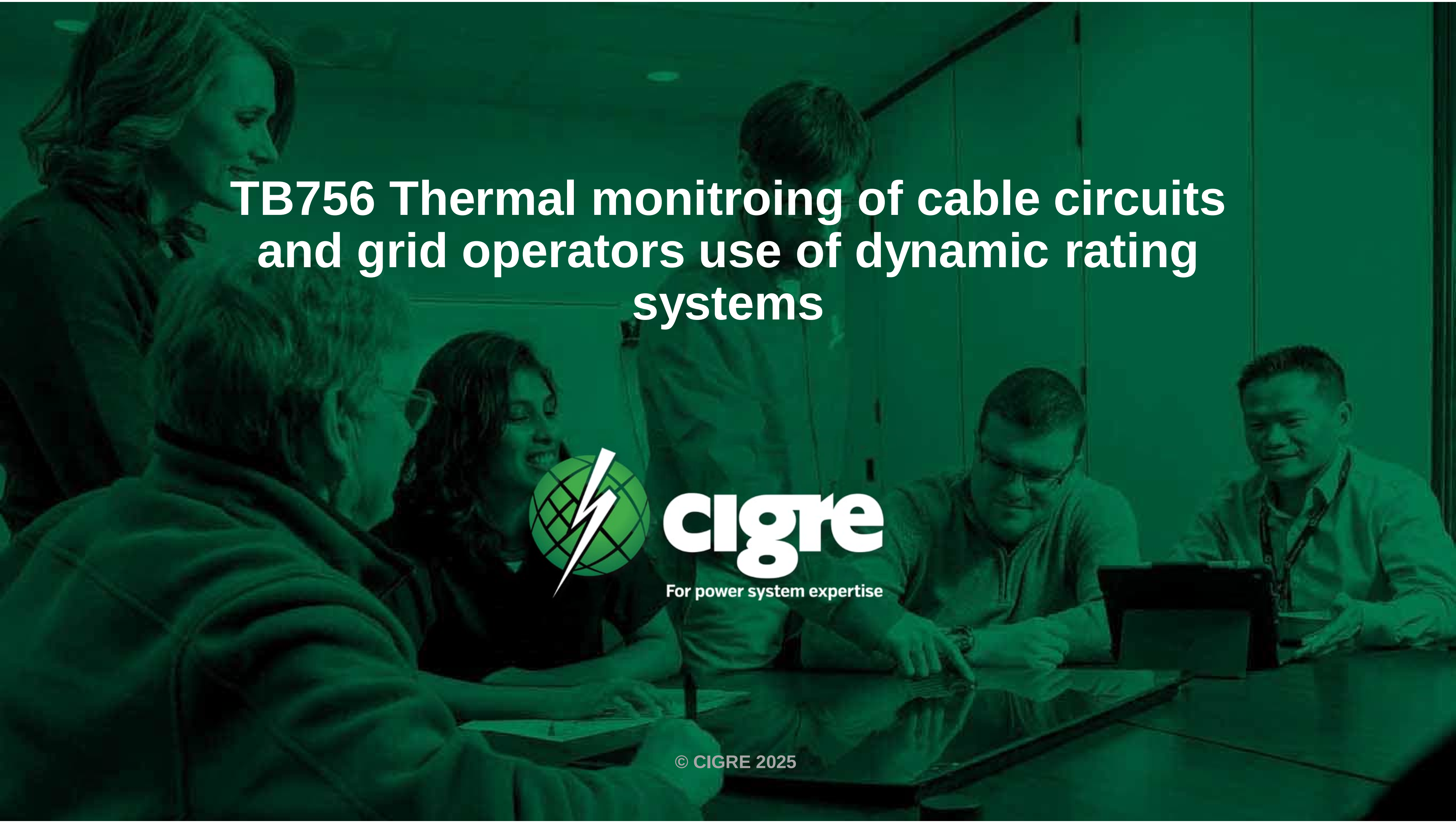
R	2,2150525415 x10^{-5} Ω/m	$P_{screen} = 12{,}7659779776 \frac{W}{m}$
I	$I = 989{,}2540243946$ A	
λ_1	0,5889174287	

Aluminum laminated foil losses:

$$P_{foil} = \lambda_2 RI^2 \text{ (W/m)}$$

R	2,2150525415 x10^{-5} Ω/m	$P_{foil} = 4{,}4861991725 \frac{W}{m}$
I	$I = 989{,}2540243946$ A	
λ_2	0,2069564029	

TB756 Thermal monitroing of cable circuits and grid operators use of dynamic rating systems



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DTS and RTTR Application for Cable Monitoring

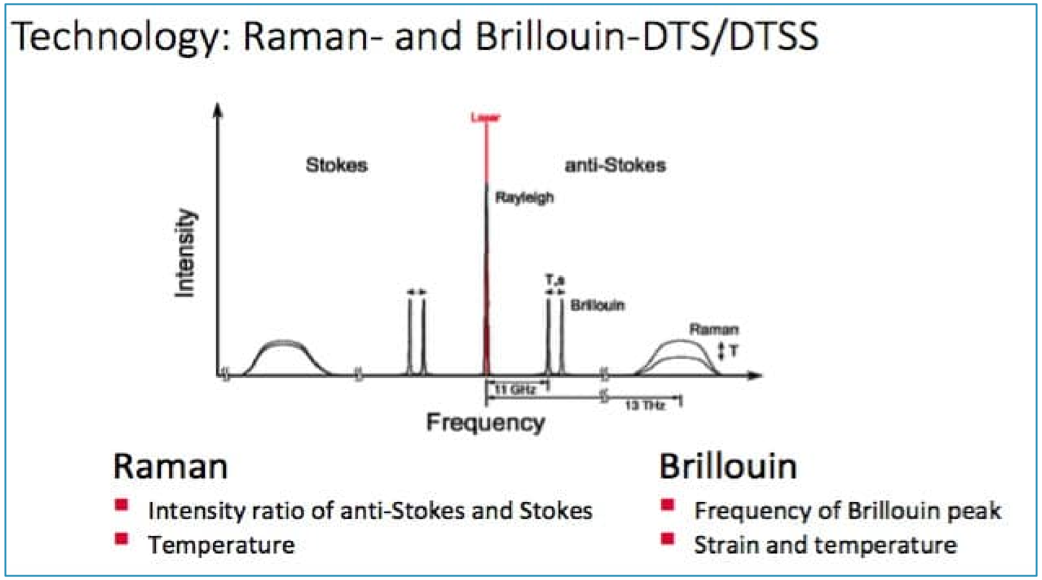
- Lack of proper information about (old) circuit
- The need to establish operating power transfer limits
- The need to verify thermal models
- Confirmation of the calculated circuit ratings with “as-installed” condition

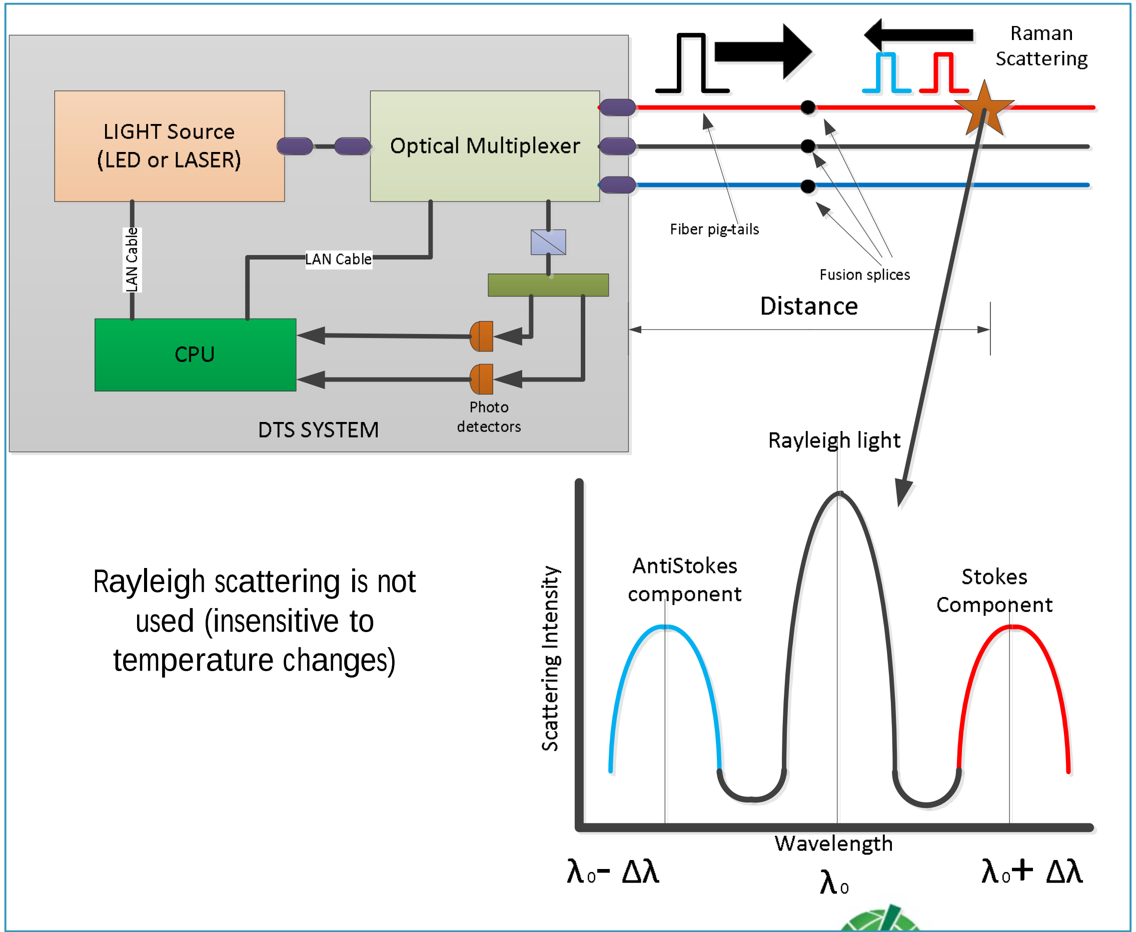
- RTTR – converts temperature into predicted current carrying capacity
- DTS/RTTR – accuracy heavily dependent on fibre position

Thermal monitoring

DTS systems – how does it work?

- Raman – intensity of reflection (most common)
- Brillouin – frequency change

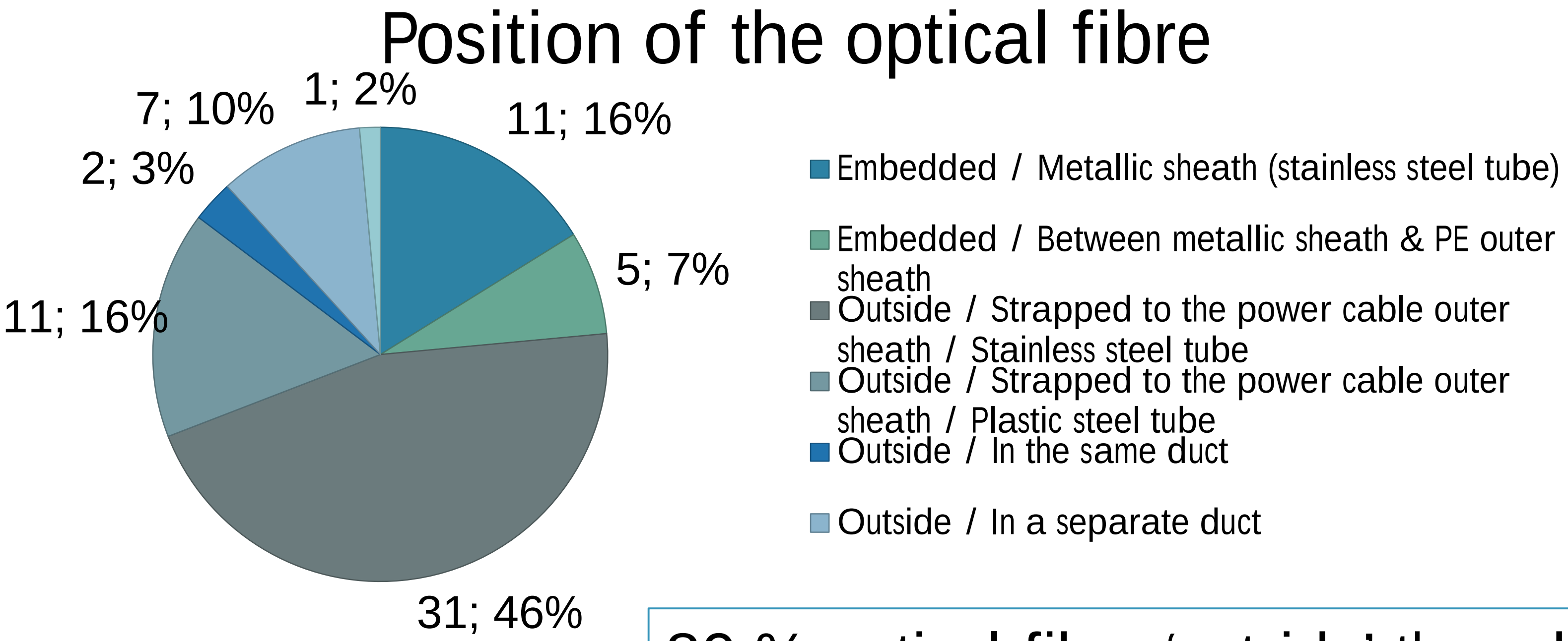




Thermal monitoring

DTS systems - Questionnaire - Temperature monitoring with glass fibre (+5 years)

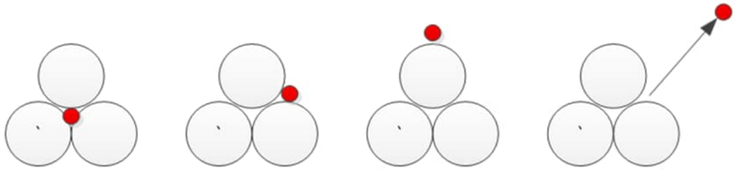
Reported position of the glass fibre in the cable system (19 respondents, 68 projects):



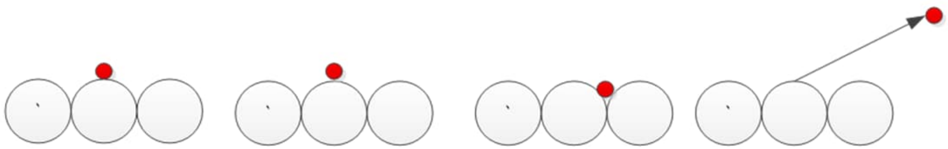
80 % optical fibre ‘outside’ the cable

DTS Systems

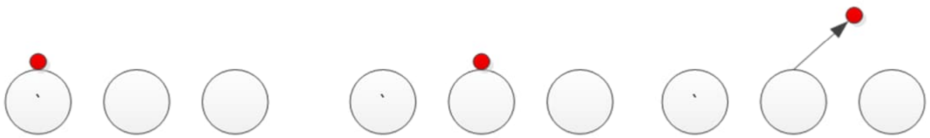
- Fibre position vs. distance to conductor vs. temperature systematic error
- Heat transfer introduce time delays and errors into the measurement



Possible location of DTS fibre in a Trefoil configuration
The farther the cable is from cable conductor the less accurate will be the rating



Possible location of DTS fibre in a flat cable configuration
The farther the DTS cable is from cable conductor the less accurate will be the rating

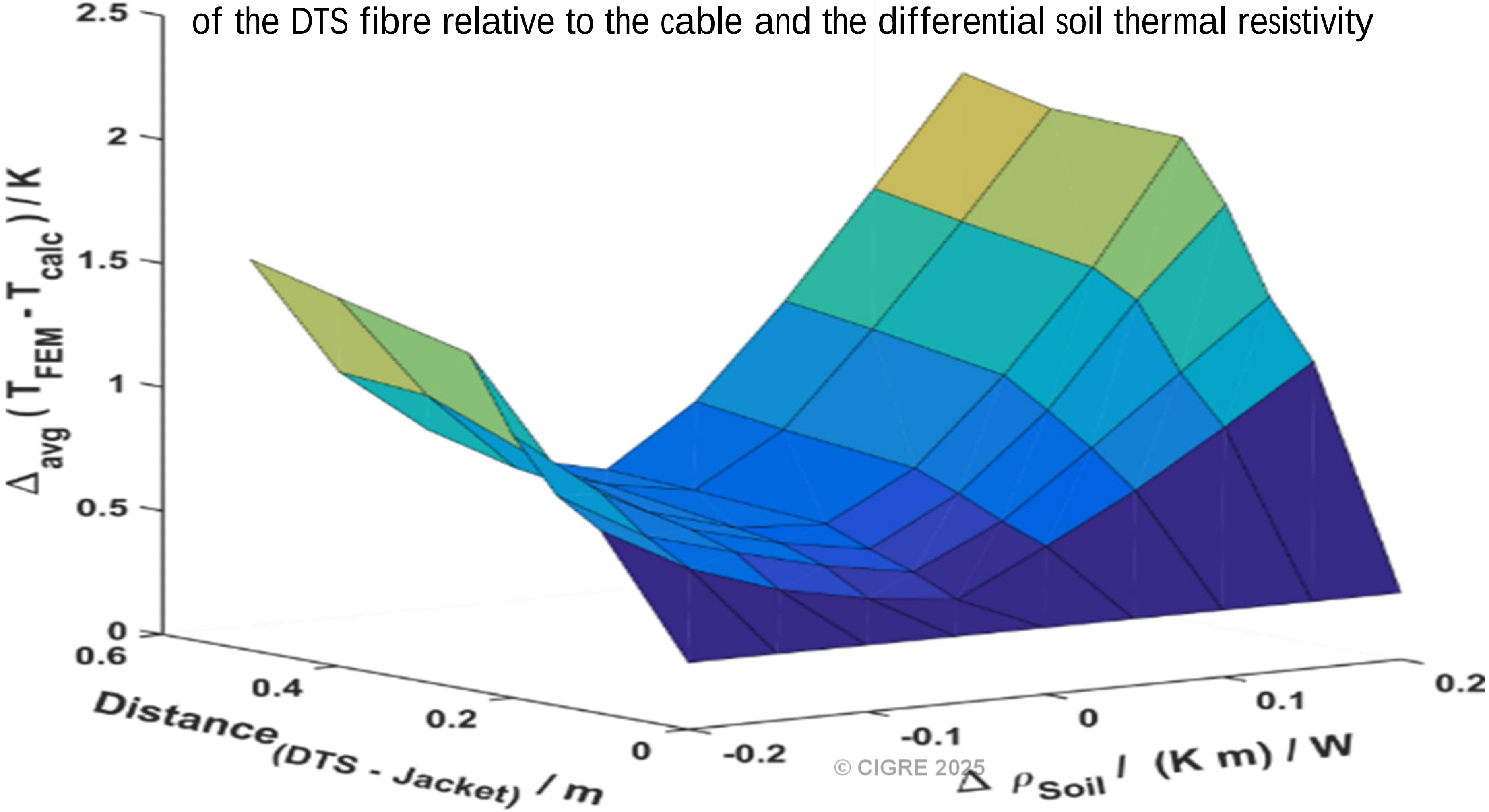


Possible locations for the DTS fibre in a cable configuration where the phases are farther apart. The farther the DTS cable is from cable conductor the less accurate will be the rating

Cables in pipes where the DTS fiber position can change, affect temperature measurements and impact rating

DTS Systems

The graph shows the error in predicted and measured temperatures as a function of position of the DTS fibre relative to the cable and the differential soil thermal resistivity



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Optical Fibre Systems

Two main fibre types used for thermal monitoring are Multi Mode (MM) and Single Mode (SM).

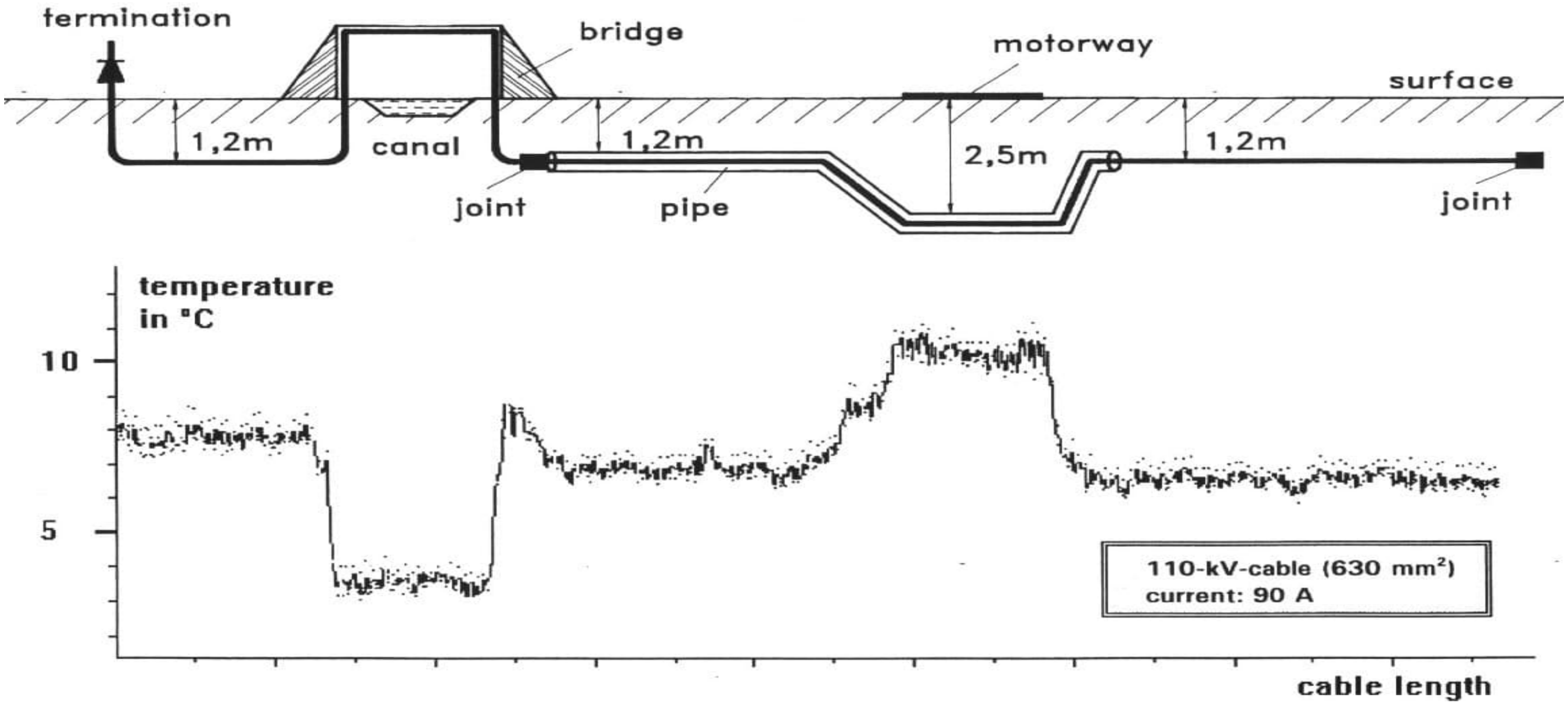
- MM fibre has a bigger core than SM fibre and allows for more optical power to be launched into the fibre.
- MM bringing higher temperature resolution.

- SM fibre has lower backscattering losses and therefore longer distances can be measured.

Thermal monitoring

DTS systems – how does it work?

- DTS trace of a 110 kV cable carrying about 90 A in winter
- Cable at the canal is cooler and under the motorway is at higher temperature



Thermal monitoring

DRS / RTTR systems

DRS: Dynamic rating systems

RTTR: Real time dynamic rating systems

This is a software package which calculates, taking into account the thermal model for the cable system, the corresponding conductor temperature over the cable route.

The RTTR gives valuable information about the (over)load capability of the cable system

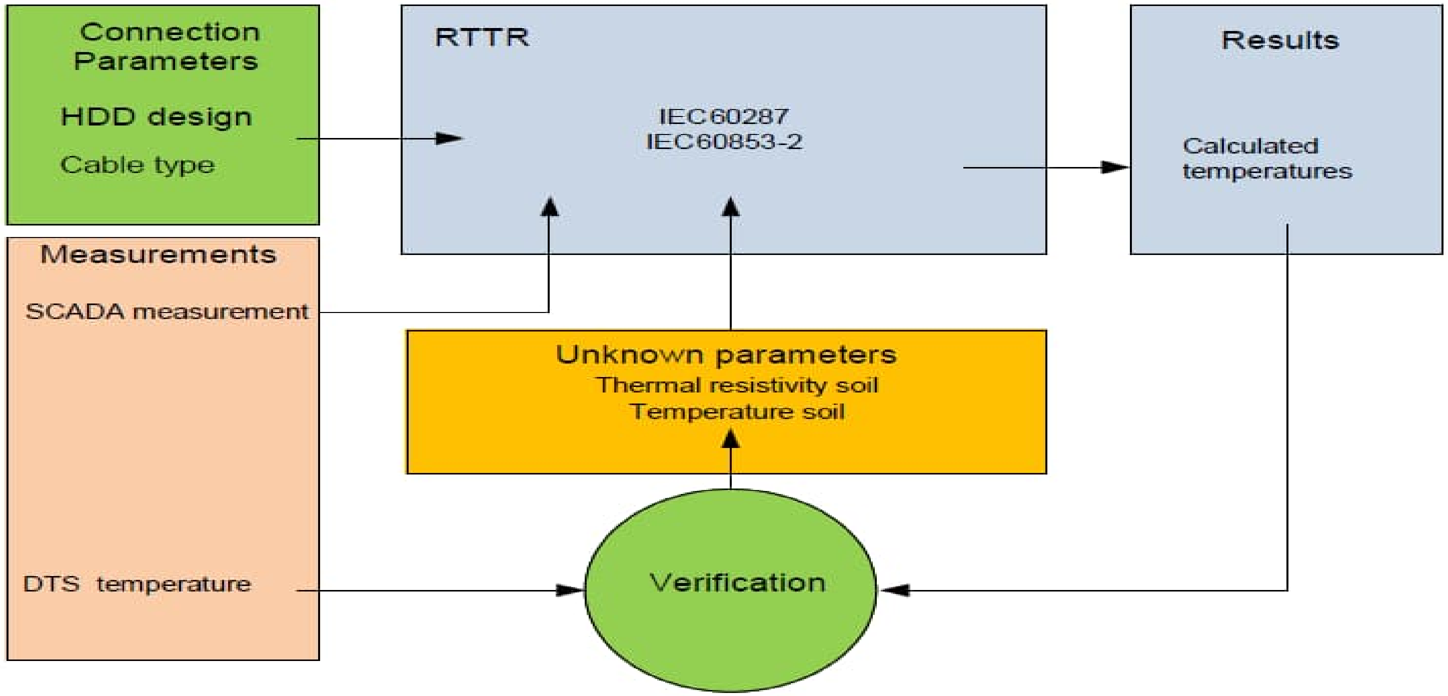
Thermal monitoring

DRS / RTTR systems - RTTR systems

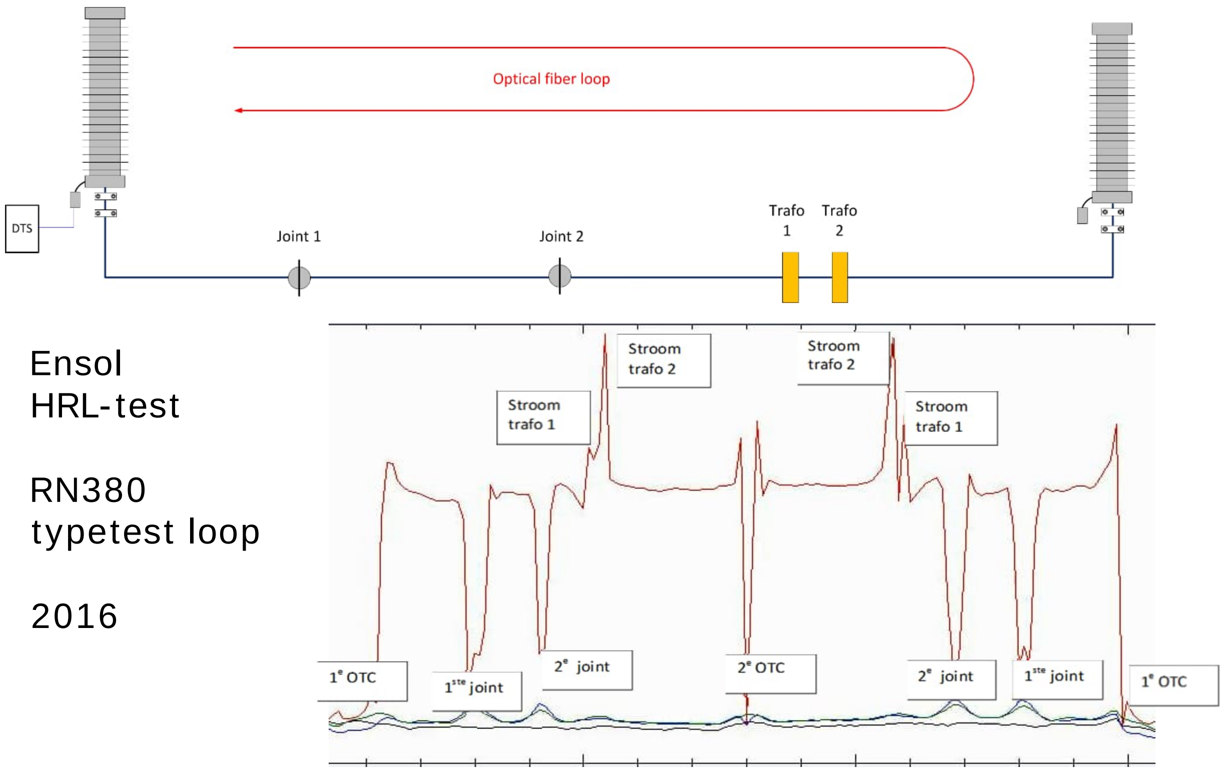
- Using prevailing DTS, soil temperature data and thermal resistivity of soil

Interesting for:

- Asset Manager: Investment Planning
- System Operator: real time power transfer limits / overload scenarios



Integrated optical fibers



Ensol
HRL-test

RN380
typetest loop

2016

Thermal monitoring

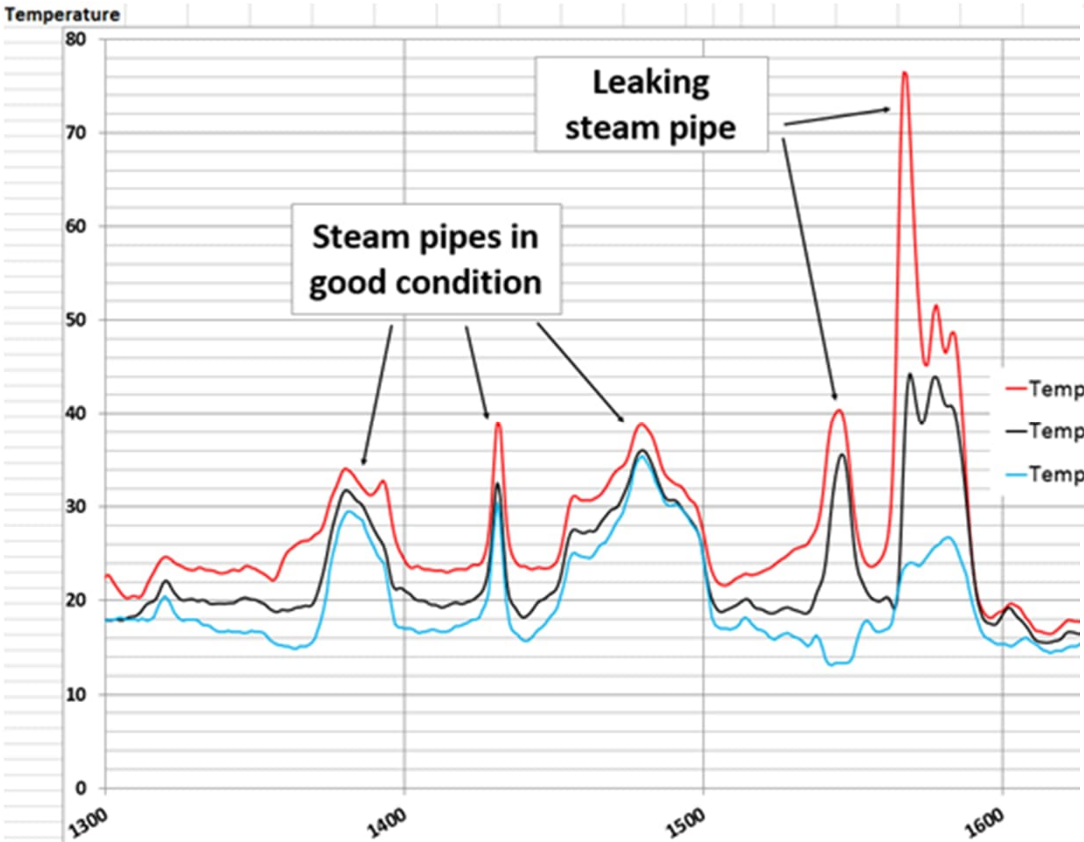
User Experience and Case Studies

- The use of DTS requires specific guidelines especially if not reviewed by a cable specialist for specific interpretation
- Two issues are frequently encountered:
    1. Users are swamped by data and interpretation, as analysis is very labour intensive and therefore clear directives are not given
    2. Equipment is isolated or not used, as results are not analysed or there are underlying problems with the trace calibration
- To implement the effective use of DTS, previous (positive) experience with using and installing is valuable
- Previous DTS problem solving, installation experience and depth of knowledge of other systems is invaluable in approaching new system specification, installation and operation/use
- Analysis and interpretation of the DTS output has to be budgeted, costed, and measured against the business/investment case

→ This is even more important and critical for RTTR systems

Thermal monitoring

User Experience and Case Studies - Case Study - the leaking steam pipe



Before commissioning of the cable circuit:

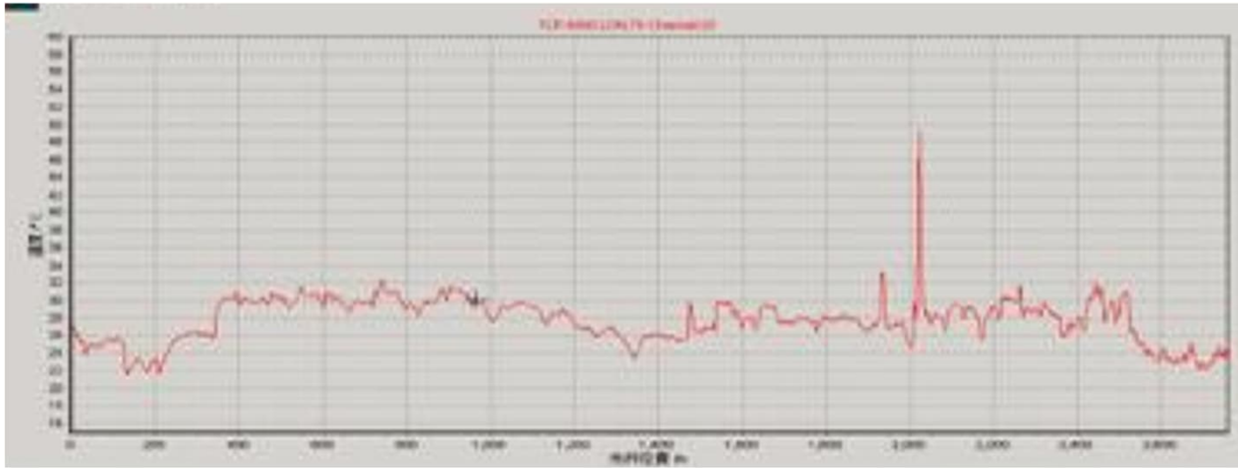
- A severe and unexpected hot spot
  - ❑ 76°C at 1570 m, instead of 40°C expected

After taking into operations:

- The lifetime of the link would have been drastically reduced
- unplanned outage and repair costs would have incurred
- Temperature monitoring during the next 3 years:
  - no other unexpected hotspots
  - the cable circuit is still in good thermal condition.

Thermal monitoring

User Experience and Case Studies - Case Study - failing cross bonding system



- Abnormality discovered during periodically perform DTS measurements
- Circuit already in DTS database / easy set-up and measurement
- 3 hours of DTS measuring
- Unexpected temperature peak: 48 °C
- Water inside the cross-bonding box: ~ 80 °C
- Cross-bonding box is repaired


Concluding remarks
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Concluding remarks

- The current rating is very important for users of power cables, as – together with the voltage level – it defines how much power can be transported. It is both important for new and for existing cable systems. Remember that the current rating is not physically tested
- The current rating depends strongly on the cable system design and on the properties of the cable environment
- As rating evaluation studies come with limited accuracy, there is need for margin in the current rating. This margin is proposed to be discussed and agreed between parties in any cable project
- The most important starting points seem often to be assumed rather than measured or investigated. This leads to large uncertainties
- Engineers calculating the current rating have to make influential choices when deriving starting points and when making calculations

Concluding remarks

- Generations of engineers have developed their own spreadsheets or tools or buy commercial dedicated software applications. Today, these spreadsheets and softwares arrive at different results for the same problems
- To reduce these problems, CIGRE has performed activities that – on top of the IEC standards for current ratings – help the user to calculate the current rating and to verify a calculation tool or software, which is recommended
- Further, to help unleash the potential of dynamic rating systems / real time thermal rating systems, CIGRE provides insights in the details and prospects of thermal monitoring

For power system expertise

Reference work

The following resources are relevant

- TB 640 – A guide for rating calculations of insulated cables
- TB 756 – Thermal monitoring of cable circuits and grid operators' use of dynamic rating systems
- TB 714 – Long term performance of soil and backfill systems
- TB 880 – Power cable rating examples for calculation tool verification (B1.56)

In development:

- Power cable rating examples for calculation tool verification in complex situations (B1.72)
- TB 908 – Evaluation of losses in armoured three core power cables (B1.64)

…all to be used in addition to the IEC standards – IEC 60287 and IEC 60853

Questions and answers

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