DYNAMIC RATING CALCULATIONS
VERIFICATION OF GRØFT DESIGN® WITH THE IEC 60853-2 AND ENGINEERING PRACTICE

Technical documentation

Grøft Design® has been verified against IEC 60853-2 [1] for calculating the cyclic and emergency current rating of power cables. The results obtained with the Grøft Design® comply with the IEC standard. Furthermore, Grøft Design® software correlates well with analytical models incorporating the IEC [1, 2] standards and the principle of superposition for multi-step load [3]. The dynamic rating calculations in Grøft Design® were studied with reference to Distribute Temperature Sensing (DTS) measurements performed on a real-life cable installation. The good agreement of the results indicates that the Grøft Design® models may be correlated with real installations and forecast the cable performance for steady, variable and emergency loading.

GRØFT DESIGN®

Grøft Design® (GRØFT) is software for thermal and electromagnetic analysis of power cable installations. GRØFT is based on the Finite Element Analysis (FEA) and utilizes COMSOL Multiphysics® as the analysis engine. Therefore, modelling of complex power cable installations and environments is much more comprehensive in comparison to the solutions incorporating only the analytical approach. GRØFT has been verified against the CIGRÉ Technical Brochure (TB) 880.

The software is available through a user-friendly web application. It has a built-in library of standardized cables and components, and a build in component designer where users can add their own cables and components. In the Designer, users can make several geometrical adjustments, both for cables and trenches, far beyond the scope of the IEC standards. Since GRØFT is web-based, the projects may be easily shared with other users in the project.

To meet the need for maximizing the utilization of the power grid, GRØFT has introduced a module enabling the calculation of dynamic current rating for complex cable arrangements and variable loading patterns. For time-varying load defined by the user, the software provides a transient electro-thermal result. Among others, the following functionalities are featured:

- Modelling of steady-state, transient, cyclic or daily cycle loads,
- Modelling of the load patterns directly in the software or uploaded as xlsx. or csv. data,
- Creating of multiple scenarios for individual sections,
- Transient analysis considering the load factor,
- Analysis of emergency loads up to the specified maximum temperature,
- Modelling of multiple-zone trenches and thermal layers with drying-out effect,
- Constant or time-variable temperature on the ground surface,
- Analysis of multiple parallel circuits with different variable or steady-state load,
- Calculation of cable installations buried at great depths,
- Material properties compliant with the IEC standards, modifiable by the user,
- User-friendly interface facilitating the setup of analyses and boundary conditions,
- Interactive visualization of the results and extensive report generation options.

Grøft Design is developed by REN AS [1] through several research projects together with SINTEF Energy, industry partners and the Research Council of Norway. In 2024 the INCA[2] research project started. It will run over three years and develop better transient current rating models and link these with Distribute Temperature Sensing (DTS) measurements and Real-Time Monitoring.

[1] Norwegian company owned by over 50 distribution operators, which develops guidelines and tools to ensure best practices in the design, installation, operation and maintenance of the electrical grid.
[2] Read more about INCA here.

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1. INTRODUCTION

In the verification report of Grøft Design® (GRØFT) with the Technical Brochure (TB) 880 [4], the software was proven to reproduce, with a high accuracy, the current ratings of power cables for steady-state operation calculated with the theoretical models based on the IEC 60287 [2]. However, no corresponding guidance or verification covering dynamic and cycling rating has been yet released by CIGRE[3].

As for now, the rating of the power cables with variable load relies on the IEC 60853-2 [1] and the IEC 60287 [2], which cover only limited cable installations and operating conditions, as discussed in verification report of GRØFT Design with TB 880 [5]. Furthermore, the following limitations were recognized with reference to the application of the IEC 60853-2 standard:

- The IEC standard assumes the emergency step-change in the load which starts from a stationary temperature and from the preceding stationary loading, which will not always be the case,
- The emergency rating cannot be fully combined with cyclic rating calculations resembling daily or weekly load cycles,
- The thermal resistance of the cable environment $\mathrm{T_4}$ calculated with an exponential integral formula for the infinite time does not correspond the empirical formula for the thermal resistance $\mathrm{T_4}$ for cables in trefoil defined in IEC 60287,
- For calculation of the transient temperature response $\theta_e(t)$ (see equation 4-36 [1]) the total losses in the cable are assumed the same for all the cables, which would not be the case, especially for the separated, solid-bonded cables with unbalanced losses in sheath, i.e. in a flat formation,
- For most practical cases it is required to combine the standard with the application of mathematical algorithms and numerical methods, which are not specified by the standard.

2. SCOPE OF THE STUDY

The Grøft Design® software was verified with the IEC 60853-2 standard for the transient current rating calculations. For the purpose of this work a Visual Basic for Applications (VBA) tool based on the IEC standards [1, 2] and performing the algorithms on the analytical formulas was developed. Due to the limitation of the IEC 60853-2 standard for the analysis of more complex loading patterns, apart from the single emergency step-load or 24-hour cycle, the IEC formulas had to be supplemented with the *principle of the superposition* [3] which enabled the analysis of the cable temperature response to the multiple-step load. The results obtained with GRØFT were compared with the analytical models. Furthermore, a case study considering real-life cable installation was analyzed. The data gathered from field-measurements (Distribute Temperature Sensing) was compared with a simulation carried out in the GRØFT software.

[3] The Technical Brochures issued by CIGRE Working Group (WG) B1.72 "Power rating verification – additional cases" and "Update of IEC 60853 within CIGRE" are in progress as of today.

3. REFERENCE INSTALLATION

The TB 880 [4] case #0 132 kV cable was used as the basis for analyses presented in this report (see Table 1). Two geometrical setups of the cable were considered – cables directly buried in trefoil (LAYOUT 1) and flat formation (LAYOUT 2), as presented in Figure 1. Cables are solid-bonded. The depth of the installation is 1.0 m. Spacing of phases for LAYOUT 2 is 0.4 m. The isothermal condition of 20 °C was applied on the ground surface[4]. The thermal resistance of the soil is $\rho_{T_4} = 1.0\ K.m/W$. The diffusivity of the soil is $\delta_{T_4} = 0.5 \cdot 10^{-6}\ m^2/s$.

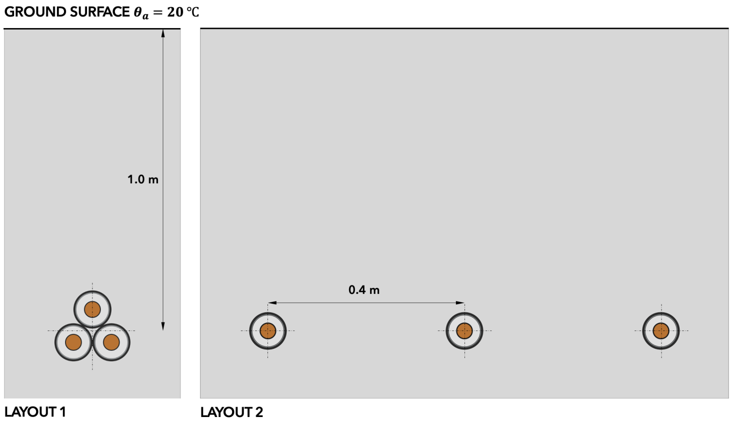
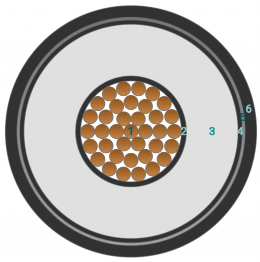


Figure 1 Geometrical representation of the cable installations - LAYOUT 1 and LAYOUT 2

Table 1 Parameters of TB880 case #0 132 kV cable

No	Description	Nominal Diameter (mm)	Thermal Resistivity (K.m/W)	Volumetric specific heat (J/K.m³·10⁶)
1	Copper stranded conductor	30.3	n/a	3.45
2	Inner semi-conducting layer	33.3	2.5	2.4
3	XLPE insulation	64.3	3.5	2.4
4	Outer semi-conducting layer	66.9	2.5	2.4
5	Aluminum sheath	68.5	n/a	2.5
6	HDPE oversheath	75.5	3.5	2.4



For LAYOUT 1 the rated current for a steady state operation, i.e. for max temperature of the conductor $\theta_{max} = 90$ °C, is established in GRØFT at $I_{R_{G1}} = 809\ A$ and with the analytical model at $I_{R_{A1}} = 803.2\ A$. The slight discrepancy between GRØFT and the analytical model is due to the generalization of the multiplication factor f_φ applied for the calculation of the thermal resistance T_3 according to the IEC [6]. This is discussed in detail in verification report of GRØFT Design with TB 880 [5].

For LAYOUT 2 the current rating for a steady state operation is established in GRØFT at $I_{R_{G2}} = 660\ A$ and with the analytical model at $I_{R_{G2}} = 663.46\ A$, which is a marginal difference.

[4] In GRØFT the temperature on the ground surface may be defined as time-varying.

Furthermore, for LAYOUT 1 as the thermal resistance of the cable environment T_4 was calculated with the exponential integral (1) according to IEC 60853-2 [1] instead of the empirical formula (2) found in the IEC 60287 [2], the current rating for a steady state operation was established at $I_{R_{G1(2)}} = 792.67\ A$ (see reference standards [1, 6] for definitions in equations (1) and (2))

$$T_4(t \to \infty) = \frac{\rho_{T4}}{4\pi} \left\{ \begin{array}{c} \left[-Ei\left(-\frac{D_e^2}{16\delta t}\right) - \left(-Ei\left(-\frac{{L_A}^2}{\delta t}\right)\right)\right] + \left[-Ei\left(-\frac{{d_{(BA)}}^2}{4\delta t}\right) - \left(-Ei\left(-\frac{{d'_{(BA)}}^2}{4\delta t}\right)\right)\right] \\ + \left[-Ei\left(-\frac{{d_{(CA)}}^2}{4\delta t}\right) - \left(-Ei\left(-\frac{{d'_{(CA)}}^2}{4\delta t}\right)\right)\right] \end{array} \right\} \tag{1}$$

$$T_4 = \frac{1.5}{\pi} \rho_{T4} \left(ln\left(u_2 + \sqrt{{u_2}^2 - 1}\right) - 0.63 \right) \tag{2}$$

In the comparisons of the GRØFT models with the analytical models presented in this report, the rated currents found individually for these models were used as the reference.

4. TEMPERATURE RESPONSE TO A CURRENT STEP

The emergency loading starts from the initial steady-state (1), i.e. the current load $0.6 \cdot I_{R_G}$ (for the GRØFT model) or $0.6 \cdot I_{R_A}$ (for the analytical model) and steady temperature $\theta_{(1)}$. From that initial state a step-load $1.2 \cdot I_{R_G}$ or $1.2 \cdot I_{R_A}$ are applied up to the point (2) for the time duration $t_{1-2} = 72h$. The comparison of the IEC calculation with GRØFT are presented in Figure *2* for LAYOUT 1 and LAYOUT 2.

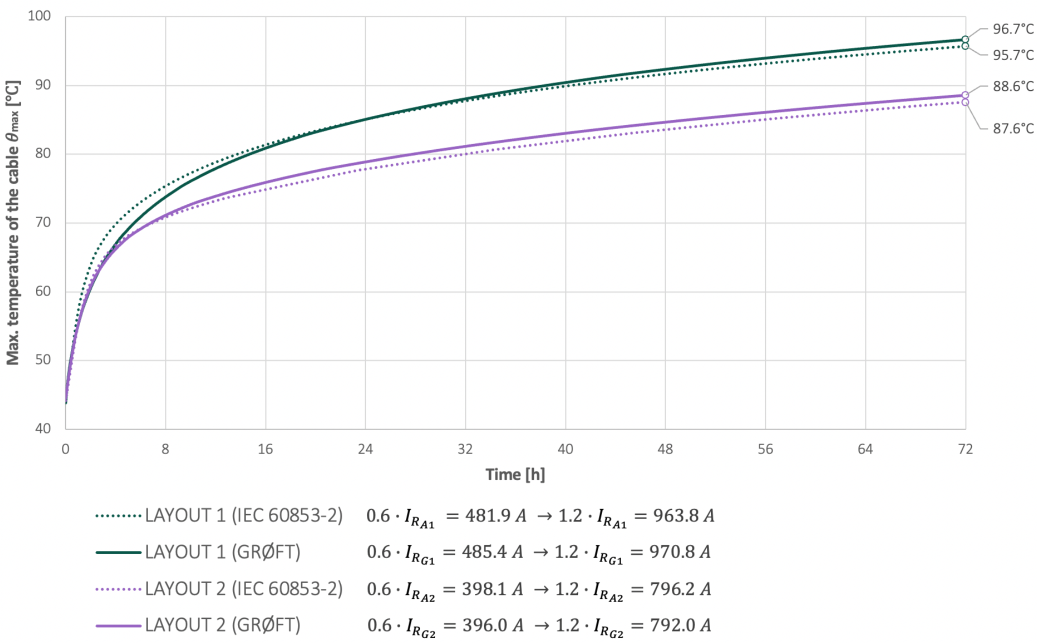


Figure 2 Comparison of the thermal response for LAYOUT 1 and LAYOUT 2 for a step-load. For LAYOUT 2 the temperature of the warmest phase is displayed

The GRØFT model correlates well with the analytical model for the single step-load, both for LAYOUT 1 and 2.

5. TEMPERATURE RESPONSE TO A MULTI-STEP LOAD

The temperature responses of the GRØFT and the analytical models were compared for a multi-step load presented in Table **2**. The temperature responses for LAYOUT 1 are presented in Figure 3 and for LAYOUT 2 in Figure 4.

Table 2 Multi-step load

STEP	% of the rated current	Duration [h]
0	0.6	∞
1	1	72
2	1.1	24
3	0.5	72
4	1.2	12
5	0.9	24
6	0.6	72
7	1.0	24
8	1.2	12
9	0.9	72
10	0.6	16

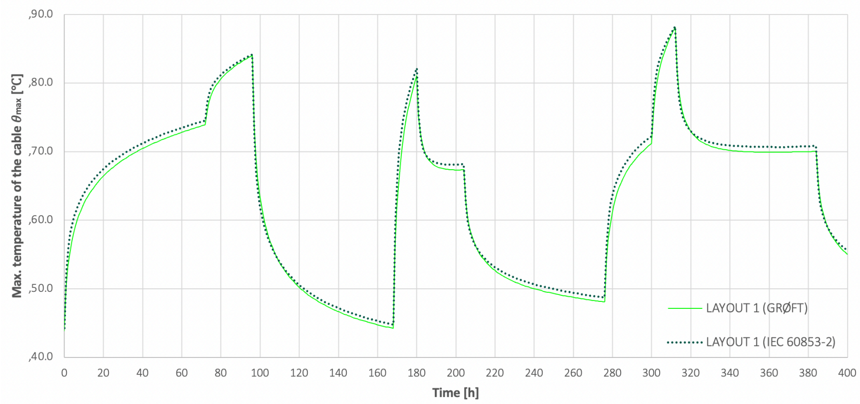


Figure 3 Comparison of the thermal response for LAYOUT 1 and LAYOUT 2 for a multi-step load

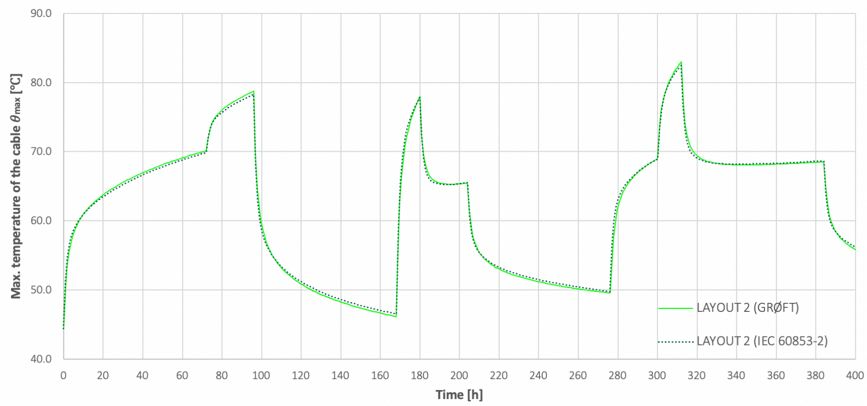


Figure 4 Comparison of the thermal response for LAYOUT 1 and LAYOUT 2 for a multi-step load. Max difference between GRØFT and IEC results is 0.64 °C

<u>The GRØFT model correlates very well with the analytical model for the multi-step load, both for LAYOUT 1 and 2. Max. difference between GRØFT and IEC results is 0.81 °C for LAYOUT 1 and 0.65 °C for LAYOUT 2.</u>

6. 24H CYCLIC LOADING AND LOAD FACTOR

The method introduced by Goldenberg (IEC) [1] is incorporated in GRØFT if the rated current I_R and daily load factor lf for a cable circuit are specified for cyclic rating only. The method was found a satisfactory approximation in comparison to the full daily-cycle analysis. However, if a daily load profile is given by the user, the full cycle analysis will be simulated in the software instead.

For a daily load cycle defined with load factor lf, losses in cable vary according to a load-loss factor μ, [7], specified as:

$$\mu = p \cdot lf + (1 - p) \cdot lf^2 \tag{3}$$

Where:

p	-	Weighting factor (0.2 for distribution network and 0.3 for transmission network)[5]
μ	-	Load-loss factor
lf	-	Load factor

The loss-load factor μ of the daily current cycle is determined by decomposing the cycle into hourly rectangular pulses (4). Based on μ and the rated current I_R, which is the maximum of the 24-hour cycle, the average current I_{ave} is found (5):

$$\mu = \frac{1}{24}\sum_{i=1}^{24}\frac{I_i^2}{I_R^2} \tag{4}$$

$$I_{ave} = \sqrt{\mu I_R^2} \tag{5}$$

Where:

I_R	-	Sustained (100% load factor) rated current for the conductor to attain, but not exceed, the standard maximum permissible temperature
I_{ave}	-	Daily load cycle averaged load current [3]

Upon the application of the continuous current I_{ave}, a thermal state of the cable and the soil are found. This state approximates a thermal average for which the transient thermal response of the cable and the soil oscillates. According to IEC [1], in order to find the maximum temperature of the cable, it is sufficient to consider the load cycle over a period of only 6h from the averaged state as the reference. The period of 6h correspond to the fraction of the cycle before the maximum temperature of the cable will be reached. Location of that period must be made by an individual assessment based on the given loading curve (see Figure 5 and Figure 6 for reference). In GRØFT, if only the rated current I_R and loss-load factor μ are given, an approximation of a linear increase of the current load from I_{ave} to I_R for a 6h period is made. This method was found a satisfactory approximation for both, single and multiple circuit cable trenches.

Calculations which are performed in GRØFT resemble, but differ slightly from the analytical approach found in the IEC [1]. The IEC introduces the factor M, (6), by which the steady-state rated current I_R (for which the maximum permissible temperature of the cable is obtain) may be multiplied to obtain the peak value of the daily cyclic load for which the same permissible temperature of the cable is obtained. For this method the period of 6h from a cycle of known shape, which correspond to the fraction of the daily cycle before the maximum temperature of the cable will be reached, must be chosen.

$$M = \frac{1}{\sqrt{\sum_{j=0}^{5} Y_j\left[\frac{\theta_R(j+1)}{\theta_R(\infty)} - \frac{\theta_R(j)}{\theta_R(\infty)}\right] + \mu\left[1 - \frac{\theta_R(6)}{\theta_R(\infty)}\right]}} \tag{6}$$

Where:

$\theta_R(j)$	-	Temperature rise over ambient at given time j and load I_j (excluding the temperature rise due to the dielectric losses), $\theta_R(0) = 0$
Y_j	-	ordinate ${I_j}^2/{I_R}^2$

[5] The factor account for a diversity of load, that is higher at lower voltages [7]

EXAMPLE 1: Based on the daily cycle load specified in Table 3 for LAYOUT 1 (IEC), the loss-load factor μ, load factor lf and average current I_{ave} are found. Furthermore, the factor M is determined for this configuration and the maximum permisible peak current $I_{R\,(IEC)}$ of the same daily cycle load is found analytically. The cycle load of the same characteristic, i.e. the same load ratio I_i/I_R for each time-step i, is applied for the analyses carried out in GRØFT and the peak current $I_{R\,(GRØFT)}$ is found (the full 24h cycle is simulated).

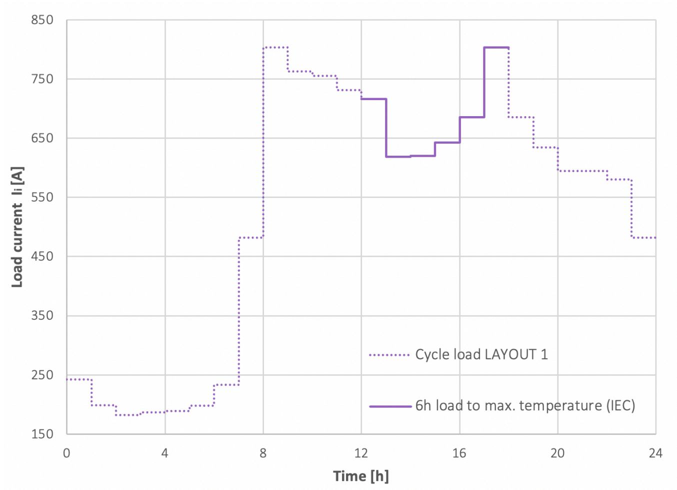


Figure 5 Daily cycle load for LAYOUT 1

Table 3 Example a daily cycle load for LAYOUT 1

Time	Load ratio	Load RMS			
$t\,[h]$	I_i/I_R	$I_{G1_i}\,[A]$	Y_i		
24.00-01.00	0.302	242.6	0.09		
01.00-02.00	0.247	198.4	0.06		
02.00-03.00	0.227	182.3	0.05		
03.00-04.00	0.232	186.3	0.05		
04.00-05.00	0.235	188.8	0.06		
05.00-06.00	0.246	197.6	0.06		
06.00-07.00	0.29	232.9	0.08		
07.00-08.00	0.6	481.9	0.36		
08.00-09.00	1	803.2	1.00		
09.00-10.00	0.95	763.0	0.90		
10.00-11.00	0.94	755.0	0.88	$\theta_R(I_j)$	j
11.00-12.00	0.91	730.9	0.83	22.16	6
12.00-13.00	0.892	716.5	0.80	20.23	5
13.00-14.00	0.77	618.5	0.59	14.11	4
14.00-15.00	0.772	620.1	0.60	12.94	3
15.00-16.00	0.8	642.6	0.64	11.89	2
16.00-17.00	0.853	685.1	0.73	9.23	1
17.00-18.00	1	803.2	1.00	0	0
18.00-19.00	0.853	685.1	0.73		
19.00-20.00	0.79	634.5	0.62		
20.00-21.00	0.74	594.4	0.55		
21.00-22.00	0.74	594.4	0.55		
22.00-23.00	0.722	579.9	0.52		
23.00-24.00	0.6	481.9	0.36		

$I_R\,[A]$	803.2
μ	0.505
$I_{ave}\,[A]$	570.59
lf	0.65
M	1.29
$I_{R(IEC)}\,[A]$	1038.53
$I_{R(GRØFT)}\,[A]$	1032.1

EXAMPLE 2: The same analysis as for the EXAMPLE 1 is performed for LAYOUT 2 based on the daily cycle load as specified in Table 4.

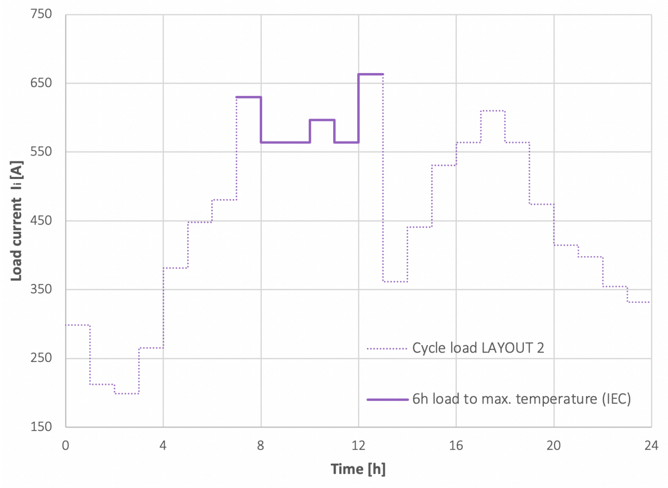


Figure 6 Daily cycle load for LAYOUT 2

Table 4 Example a daily cycle load for LAYOUT 2

Time	Load ratio	Load RMS			
$t\ [h]$	I_i/I_R	$I_{G1_i}\ [A]$	Y_i		
24.00-01.00	0.45	298.4	0.20		
01.00-02.00	0.32	212.2	0.10		
02.00-03.00	0.3	199.0	0.09		
03.00-04.00	0.4	265.3	0.16		
04.00-05.00	0.575	381.3	0.33		
05.00-06.00	0.675	447.7	0.46	$\theta_R(I_j)$	j
06.00-07.00	0.725	480.8	0.53	13.00	6
07.00-08.00	0.95	630.0	0.90	20.03	5
08.00-09.00	0.85	563.7	0.72	15.18	4
09.00-10.00	0.85	563.7	0.72	13.95	3
10.00-11.00	0.9	596.9	0.81	13.36	2
11.00-12.00	0.85	563.7	0.72	8.11	1
12.00-13.00	1	663.2	1.00	0	0
13.00-14.00	0.545	361.4	0.30		
14.00-15.00	0.665	441.0	0.44		
15.00-16.00	0.8	530.6	0.64		
16.00-17.00	0.85	563.7	0.72		
17.00-18.00	0.92	610.1	0.85		
18.00-19.00	0.85	563.7	0.72		
19.00-20.00	0.715	474.2	0.51		
20.00-21.00	0.625	414.5	0.39		
21.00-22.00	0.6	397.9	0.36		
22.00-23.00	0.535	354.8	0.29		
23.00-24.00	0.5	331.6	0.25		

$I_R\ [A]$	663.2
μ	0.509
$I_{ave}\ [A]$	473.14
lf	0.685
M	1.33
$I_{R(IEC)}\ [A]$	883.56
$I_{R(GRØFT)}\ [A]$	844.5

The peak load current for the specified cycle load found analytically and with GRØFT for LAYOUT 1, as presented in Table 3, are in a good agreement. The analytical approach is not fully consistent, due to the transient calculations being performed for a rated current I_R found with the IEC 60287 and not with IEC 60853 (as discussed in Section 3).

For LAYOUT 2, as presented in Table 4, the resulting current peaks of the cycle load differs by 39 A. The GRØFT results are not only more realistic, but also more conservative.

EXAMPLE 3: The GRØFT approach that introduces the IEC method for the cycling rating calculation, if only the load factor lf is specified, is compared with the analyses carried out for a full cycle load based on data given in Table 3 and Table 4 for LAYOUT 1 and LAYOUT 2.

I) Cable circuits (LAYOUT 1 and LAYOUT 2) are simulated in GRØFT for the daily cycle loads as specified in Table 3 and Table 4 for a peak current load $I_{R\,(GRØFT)}$, accordingly, 1032.1 A for LAYOUT 1 and 844.5 A for LAYOUT 2. The results are presented in Figure 7. The maximum temperature of the cable for LAYOUT 1 is $\theta_{G1} = 90.0\,°C$ and $\theta_{G2} = 90.0\,°C$ for LAYOUT 2.

II) Then, the cyclic analysis which utilizes the IEC approach is carried out in the software, if only the rated current I_R and daily load factor lf for a cable circuit are specified. The user specifies the general characteristic of the load, i.e. distribution or the transmission grid (see equation (3) for reference). Then, the analysis proceeds with the application of the continues current I_{ave}, established based on $I_{R\,(GRØFT)}$ and lf (see Table 3 and Table 4). The steady-state conditions established for that current, are followed by the application of a 6h step-load, that increases linearly from I_{ave} to $I_{R\,(GRØFT)}$. The maximum temperature of the conductor obtained with this method for a distribution grid are $\theta_{G1} = 88.1\,°C$ for LAYOUT 1 and for LAYOUT 2 $\theta_{G2} = 92.0\,°C$. This temperature differs slightly in comparison to the temperature reached upon the application of the full cycle load. Considering the limited input for this case, i.e. only the rated current I_R and daily load factor lf, this result provides a satisfactory approximation.

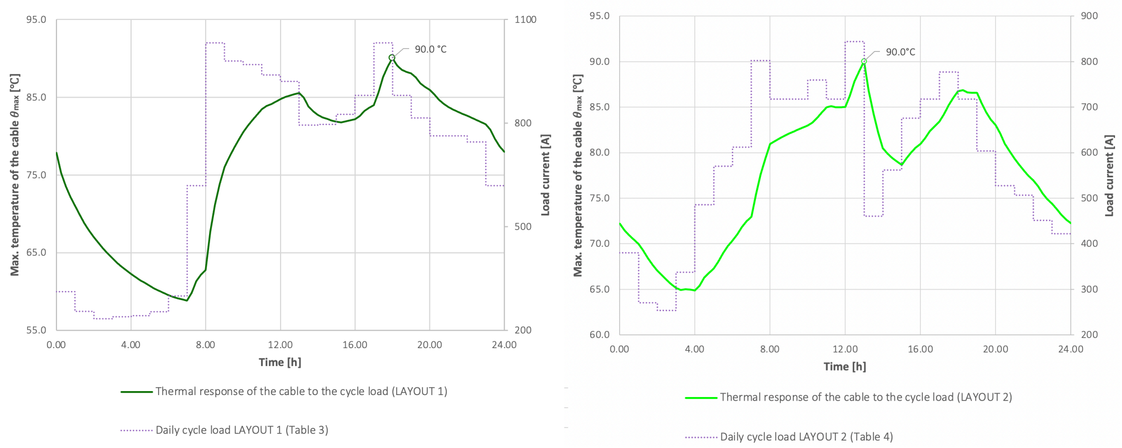


Figure 7 Temperature response of the cable to the daily cycle load for LAYOUT 1 and LAYOUT 2

7. VERY DEEP INSTALLATIONS

The problem of the current rating of cables installed at a great depths, up to 40 m [8], is well recognized in the literature, Examples of very deep installations can be directional drillings, under the metropolitan areas, river crossings or on the landfall site for a submarine cable installation. The application of the IEC 60287 in these cases usually lead to conservative results. The large amount of soil above the cable has a very large time constant which leads to considerable lag of the cable temperature increase in comparison to cables installed near the ground surface. The seasonable temperature variations on the ground surface makes this effect even more pronounced. For cable installations at laying depths of more than 10 m the IEC 60287-2-1 [6] standard recommends the approach which determines the current rating of cables upon the application of the load current for designated time period (usually 40 years) from the initial unloaded state. Dorison *et al.* [9] developed the analytical approach which introduces the so-called *equivalent laying depth*. This may be applied in the steady-state algorithms of the IEC 60287 standard corresponding the analyses performed with a transient algorithms presented in IEC 60853.

In GRØFT the analysis of cables at great depths is performed iteratively with the application of FEA. The user may specify either the isothermal temperature conditions on the ground surface or specify the seasonal/monthly temperature variations. The analysis is being carried out for the continuous load current for a time period of 40 years. The advantage of the application of GRØFT in comparison to the analytical methods in this case, is the possibility of specifying various soil layer of different thermal properties and model multiple circuits at different lengths. Furthermore, the soil drying out effect may be included.

EXAMPLE 4: Ampacities for LAYOUT 1 and LAYOUT 2 are defined with a steady-state approach at different installation depths, as presented in Figure 8 and Figure 9. The GRØFT, IEC [1] and Dorison *et al.* [9] models are compared. For each model the individual ampacity is found. These ampacities are used to define the temperature reached after application of load current for the period of 40 years.

For LAYOUT 1 ampacities at given depths for the IEC 60853 model were found based on the analytical formulas incorporating the exponential integral for the calculation of thermal resistance of the cable environment T_4 (see equation (1) in Section 3). Although the results obtained with this model and the Dorison model are expected to be consistent, the increasing discrepancy is observed with increasing installation depth. On the other hand, for LAYOUT 2 these model gives almost the same results. The lack of consistency between the IEC standards is, again, pointed out. Because GRØFT utilizes the Finite Element Method and solves the multiphysics problem in the time-domain, for this case, the accuracy of the results is more reliable in comparison to the analytical approach.

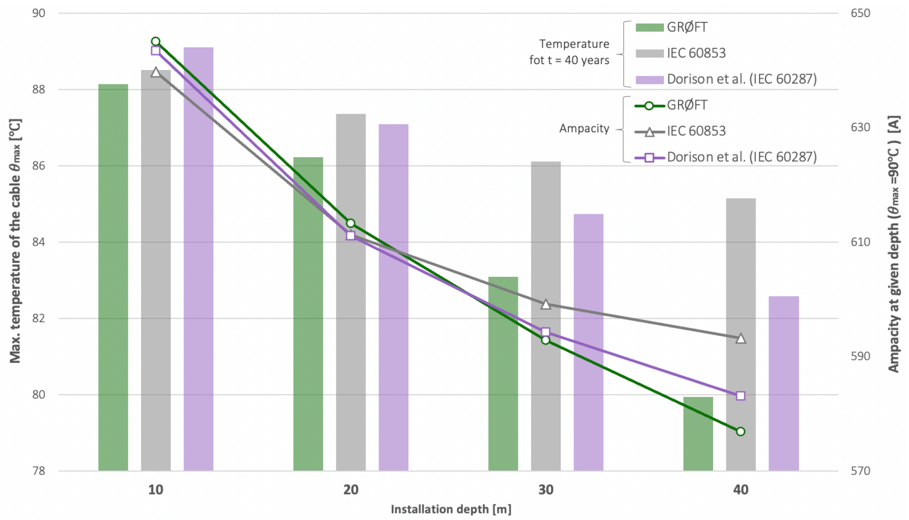


Figure 8 Comparison of the maximum temperature of the cable for LAYOUT 1 at different laying depths

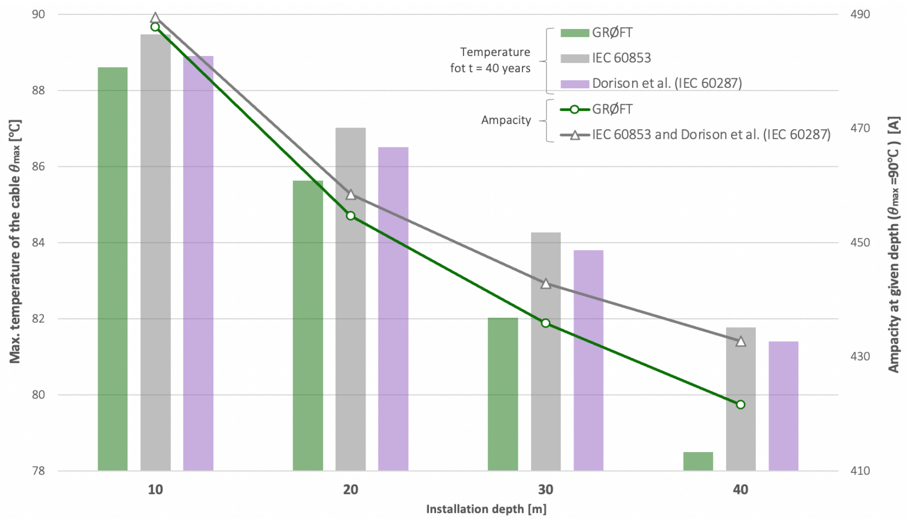


Figure 9 Comparison of the maximum temperature of the cable for LAYOUT 2 at different laying depths

8. COMPARISON OF GRØFT DESIGN® WITH REAL-LIFE INSTALLATION

The application of the dynamic loading module in GRØFT was investigated based on a real-life installation of a 233 kV SCFF cables for which Distribute Temperature Sensing (DTS) measurements were available. The cables are placed in a concrete duct-bank with DTS installed in a spare duct, as presented in Figure 10. The load current and the DTS temperature were measured on-site for a period of 19 days as presented in Figure 11. The input for the analyses is limited, therefore the following assumptions were made:

- The isothermal temperature of the ground surface
$$\theta_a = 9\,°C$$
- The initial state preceding the dynamic load analysis correspond steady-state analysis for the load current of 250 A for which the DTS measured temperature is 19.58 °C.
- Volumetric specific heat according to IEC 60853
- Thermal resistivity of the surrounding
$$\rho_{T_{4(1)}} = 1.0\ K.m/W$$
- Thermal resistivity of the backfill above the duct bank
$$\rho_{T_{4(2)}} = 0.8\,K.m/W$$
- Thermal resistivity of the duct bank
$$\rho_{T_{4(3)}} = 0.6\ K.m/W$$
- The model of 233 kV SCFF cable and the fiber optic cable with specifications are made available for users in the software

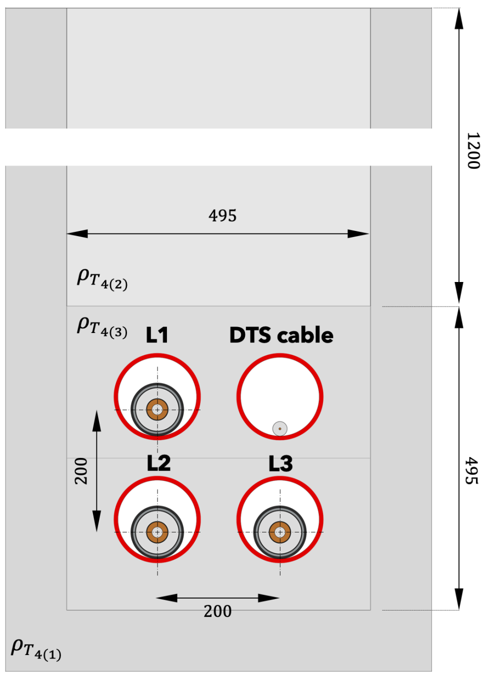


Figure 10 The reference installation of 233 kV with the DTS fiber optic sensor in the duct bank

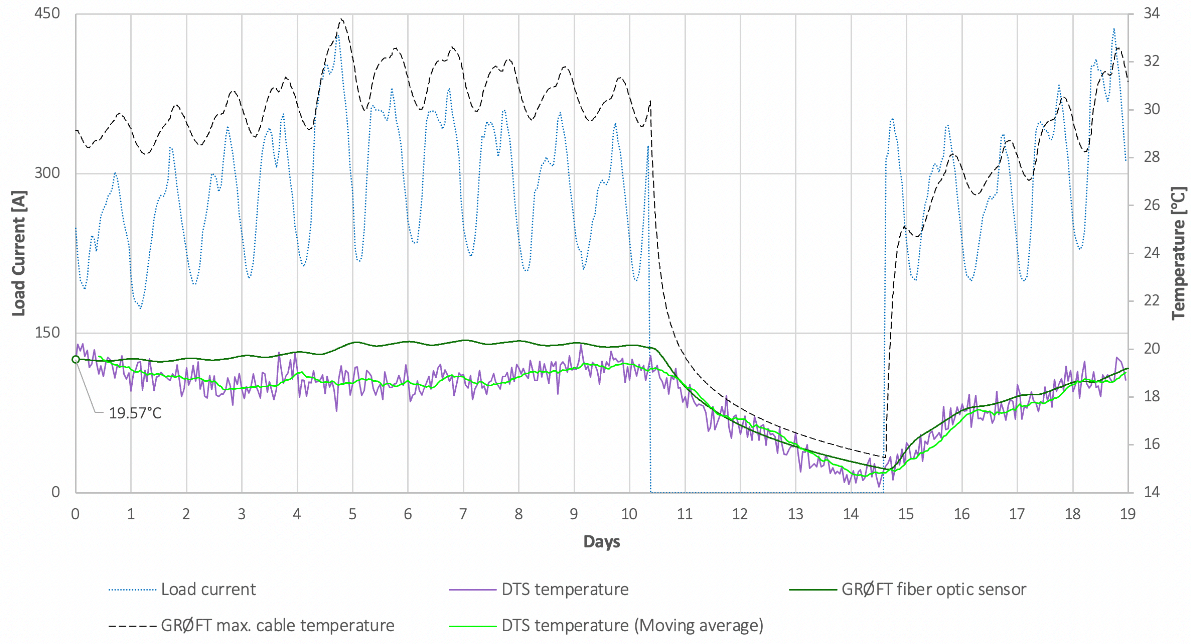


Figure 11 The comparison of the DTS on-site measurements with the GRØFT analysis temperature results from the fiber optic cable

The loading pattern in Figure 11 presents the case of the approximately. 4th-day load outage. A good correlation between the temperature calculated with GRØFT and on-site measurements is observed, especially from around day 11th (outage start) to 19th day. However, from the start of the measurements to approximately day 5, the load current and on-site measured temperature are not consistent. Considering the undisturbed reference conditions, one would expect that the measured temperature would increase slightly due to the gradually increasing load current, as the GRØFT analyses indicates. The opposite is observed. Furthermore, from around day 5 to the start of the outage, the load decreases, however temperature increases slightly. The correlation of the result would benefit from more detailed data gathered from the field measurements, such as loading characteristic before day 0 and the reference conditions. The overloading of the cable installation for short period would also help to obtain higher temperature gradients across the analysis domain and later, with the correlations.

9. DISCUSSION AND CONCLUSIONS

The analyses performed in Grøft Design® and presented in this report gives results that are in line with the IEC standards [1, 2]. The IEC standards are, however, limited to basic cable installations [8]. Grøft Design® supports analyses of much more complex cable arrangements with a lot of flexibility in defining the boundary condition, both stationary and time-varying. It is worth pointing out, that the user benefits from the increased accuracy of the FEA engine provided by Grøft Design® compared to analytical models.

A key advantage of Grøft Design® is the increased accuracy provided by its full FEA solution, which surpasses analytical models in precision. This is particularly beneficial in scenarios where standard analytical approaches may introduce simplifications that impact the reliability of the results. Furthermore, the dynamic load module opens the possibilities for correlating the models in the software with field measurements considering the varying load and the reference conditions. This will be the main focus of the ongoing INCA research project.

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