MODERN APPROACHES TO CABLE RATINGS IN THE UK

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ABSTRACT

This paper considers some recent UK developments in cable ratings. They are considered by reference to the CRATER cable rating software package, commissioned by Distribution Network Operators, to cover the whole range of cables commonly used in the UK.

INTRODUCTION

The CRATER (Cable Rater) software is being developed for the mainland UK Distribution Network Operators, who commissioned the work through the aegis of the Strategic Technology Programme (STP), run on their behalf by EA Technology.

Ratings for 11 kV and 33 kV solid paper insulated cables and polymeric cables are covered by the Energy Networks Association Engineering Recommendation P17, Parts 1 to 3 (hereafter referred to as P17). These documents [1], two of which were created in the 1970s, introduced the concept of the "distribution rating". However, to determine the distribution rating for a circuit, and especially for a group of circuits, requires the cable engineer to look up a set of tables, which process is tedious and prone to error. Further, the tables can only be applied to certain prescribed conditions, e.g. when applied to groups of equally loaded circuits and particular soil conditions. The need to create a user friendly electronic mirror version of P17 was the initial driver for developing CRATER.

CRATER has since been extended to a much wider range of cables and conditions. It is the intention to cover all widely used cable types in the UK, from LV to EHV (400 kV). This task is nearly complete. Currently, if one considers all metric and imperial conductor sizes, as well as conductor material, over 3,500 different cables are catered for.

Further extensions, in progress or planned, include CRATER programmes for cable crossings and for dynamic ratings. These will be discussed in the paper.

DISTRIBUTION RATINGS AND CRATER

Before proceeding with discussion of recent UK developments in cable ratings, it is important to define the distribution rating. For a single circuit it can best be explained by reference to the specific example of Figs. 1 and 2. During "normal" operation the circuit is assumed to operate in continuous repetitive cyclic mode, represented in Fig. 1 by all times lower than minus 72 hours. At minus 72 hours the peak load is then increased and for the next 72 hours, the load cycle shape is maintained. At the end of the 72 hours the conductor temperature reaches the maximum design operating temperature, in this case 65 °C, which is appropriate for the 11 kV belted paper insulated cable rated by CRATER in Fig. 2.

In this particular example the distribution rating, i.e. the peak load that causes the temperature to rise to 65 °C, is 766 A for the given conditions, for a "normal" operating utilisation of 50% (half the distribution rating) and for a limited time (the time of increased loading) of 3 days.

Distribution ratings can be determined for different utilisations and for different limited times.

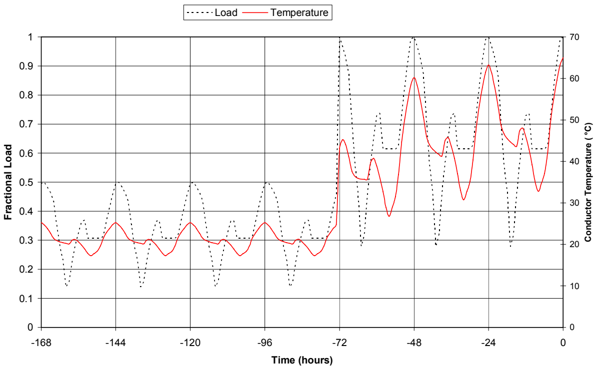
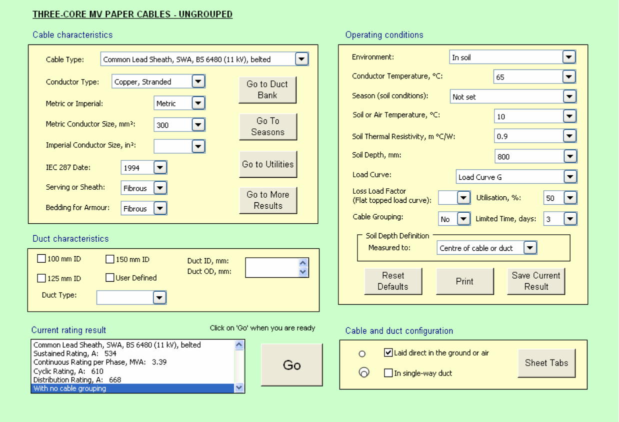


Fig. 1: Showing typical load and temperature profiles before and after the limited time excursion



Cable Type: Common Lead Sheath, SWA, BS 6480 (11 kV), belted
Conductor Type: Copper, Stranded
Metric or Imperial: Metric
Metric Conductor Size, mm²: 300
Imperial Conductor Size, in²:
IEC 287 Date: 1994
Serving or Sheath: Fibrous
Bedding for Armour: Fibrous

☐ 100 mm ID ☐ 150 mm ID
☐ 125 mm ID ☐ User Defined
Duct Type:
Duct ID, mm:
Duct OD, mm:

Common Lead Sheath, SWA, BS 6480 (11 kV), belted
Sustained Rating, A: 534
Continuous Rating per Phase, MVA: 3.39
Cyclic Rating, A: 610
Distribution Rating, A: 668
With no cable grouping

Environment: In soil
Conductor Temperature, °C: 65
Season (soil conditions): Not set
Soil or Air Temperature, °C: 10
Soil Thermal Resistivity, m °C/W: 0.9
Soil Depth, mm: 800
Load Curve: Load Curve G
Loss Load Factor (Flat topped load curve): Utilisation, %: 50
Cable Grouping: No Limited Time, days: 3
Soil Depth Definition
Measured to: Centre of cable or duct

○ ☑ Laid direct in the ground or air
○ ☐ In single-way duct

Fig. 2: A sheet from CRATER showing rating calculation for a 3-core 11 kV paper cable

From Fig.2 it can be seen that CRATER does more than simply generate distribution ratings. It calculates sustained and cyclic ratings, as well as catering for soil drying out, grouped identical circuits and for duct banks. Non-identical circuits will be discussed later.

The work of Duke and Homer [2], from which P17 was derived, indicated that distribution rating was independent of laying depth. This assumption, which is implicit in all the P17 tables of distribution ratings, obviously simplified matters. The assumption has been confirmed for **50% utilisation** and **single circuits** by recent rating calculations using CRATER software, not only for 3-core cables, but also for all cable types and circuit configurations; distribution ratings are within ± 2% of the rating at 1.6 m over the laying depth range of 0.6 m to 3 m.

Thus for the paper cable of Fig. 2 it is found that the distribution ratings are:

Table 1: Effect of laying depth on distribution rating for different % utilisations

Burial Depth (m)	Sustained Rating (A)	Cyclic Rating (A)	Dist. Rating (A)		
			50%	75%	100%
0.6	548	621	664	644	621
0.8	534	610	668	641	610
1.5	507	589	670	633	589
3.0	481	568	665	619	568

It can be seen that sustained ratings are strongly dependant upon depth, the cyclic rating somewhat less so and the distribution rating at 50% utilisation hardly at all. Homer and Duke predicted a distribution rating of 665 A for the 50% utilization condition.

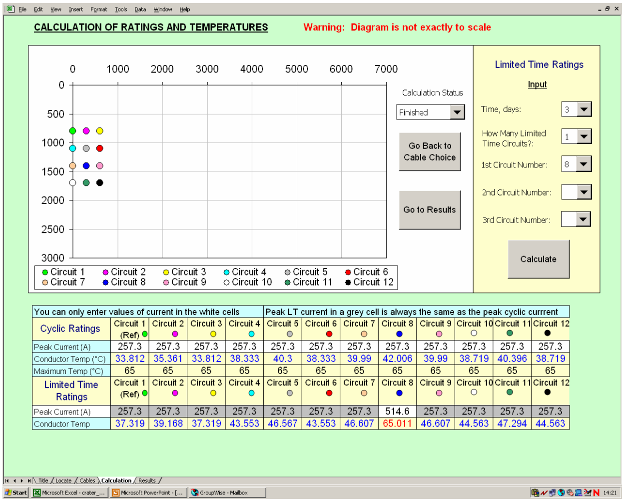
The 100% utilisation figures are, of course, cyclic ratings. It can be seen that at 75% utilisation, distribution ratings are slightly dependant upon depth, i.e. they fall with burial depth. This is expected, because clearly as we move from 50% to 100% utilisation, we go towards the cyclic rating, which invariably falls with depth. However, the fact that distribution rating changes slightly with depth at 66.66% and 75% utilisation does not seem to have been recognised by the authors of P17.

In the 1970s it was not realised that, at any utilisation, grouped distribution ratings (calculated for the hottest cable in a group) are also dependant upon laying depth. This is illustrated by Figs. 3 and 4 for a group of 12 identical circuits.

It can be seen from Figs. 3 and 4 that distribution ratings (for 3 days and 50% utilisation) of **grouped** circuits decrease with laying depth.

GROUPED CYCLIC AND EMERGENCY RATINGS

Another CRATER programme allows grouped cyclic ratings and emergency ratings (up to 4 hours) to be calculated. Each circuit may be different and each may have a different 24-hour load curve.



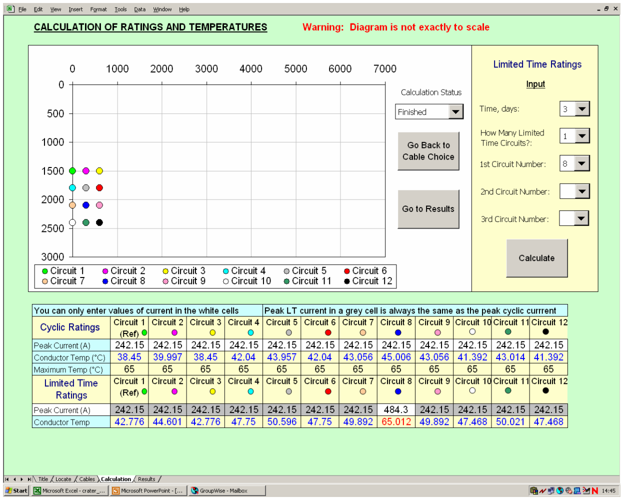
Time, days: 3
How Many Limited Time Circuits?: 1
1st Circuit Number: 8
2nd Circuit Number:
3rd Circuit Number:

You can only enter values of current in the white cells

Peak LT current in a grey cell is always the same as the peak cyclic currrent

Cyclic Ratings	Circuit 1 (Ref) ●	Circuit 2 ●	Circuit 3 ●	Circuit 4 ●	Circuit 5 ●	Circuit 6 ●	Circuit 7 ●	Circuit 8 ●	Circuit 9 ●	Circuit 10 ○	Circuit 11 ●	Circuit 12 ●
Peak Current (A)	257.3	257.3	257.3	257.3	257.3	257.3	257.3	257.3	257.3	257.3	257.3	257.3
Conductor Temp (°C)	33.812	35.361	33.812	38.333	40.3	38.333	39.99	42.006	39.99	38.719	40.396	38.719
Maximum Temp (°C)	65	65	65	65	65	65	65	65	65	65	65	65
Limited Time Ratings	Circuit 1 (Ref) ●	Circuit 2 ●	Circuit 3 ●	Circuit 4 ●	Circuit 5 ●	Circuit 6 ●	Circuit 7 ●	Circuit 8 ●	Circuit 9 ●	Circuit 10 ○	Circuit 11 ●	Circuit 12 ●
Peak Current (A)	257.3	257.3	257.3	257.3	257.3	257.3	257.3	514.6	257.3	257.3	257.3	257.3
Conductor Temp	37.319	39.168	37.319	43.553	46.567	43.553	46.607	65.011	46.607	44.563	47.294	44.563

Fig. 3: Distribution rating for group buried shallow



Time, days: 3
How Many Limited Time Circuits?: 1
1st Circuit Number: 8
2nd Circuit Number:
3rd Circuit Number:

You can only enter values of current in the white cells

Peak LT current in a grey cell is always the same as the peak cyclic currrent

Cyclic Ratings	Circuit 1 (Ref) ●	Circuit 2 ●	Circuit 3 ●	Circuit 4 ●	Circuit 5 ●	Circuit 6 ●	Circuit 7 ●	Circuit 8 ●	Circuit 9 ●	Circuit 10 ○	Circuit 11 ●	Circuit 12 ●
Peak Current (A)	242.15	242.15	242.15	242.15	242.15	242.15	242.15	242.15	242.15	242.15	242.15	242.15
Conductor Temp (°C)	38.45	39.997	38.45	42.04	43.957	42.04	43.056	45.006	43.056	41.392	43.014	41.392
Maximum Temp (°C)	65	65	65	65	65	65	65	65	65	65	65	65
Limited Time Ratings	Circuit 1 (Ref) ●	Circuit 2 ●	Circuit 3 ●	Circuit 4 ●	Circuit 5 ●	Circuit 6 ●	Circuit 7 ●	Circuit 8 ●	Circuit 9 ●	Circuit 10 ○	Circuit 11 ●	Circuit 12 ●
Peak Current (A)	242.15	242.15	242.15	242.15	242.15	242.15	242.15	484.3	242.15	242.15	242.15	242.15
Conductor Temp	42.776	44.601	42.776	47.75	50.596	47.75	49.892	65.012	49.892	47.468	50.021	47.468

Fig. 4: Distribution rating for group buried deep

Solutions to the problem of the interaction of mixed circuits under different intermittent loads were obtained by Goldenberg at BEAIRA (nowadays ERA Technology) in the 1950s [3], and this method is enacted by CRATER.

CRATER calculates a set of maximum conductor temperatures corresponding to user-supplied peak currents for all circuits in the group.

Consider the circuits disposed as shown in Fig. 5. It is required to add a 3 × 1-core 500 mm^2 Cu XLPE circuit in trefoil configuration to the centre duct. Can it carry 620 A peak cyclic load (partly consisting load shed from a nearby oil cable circuit) in the worst case scenario?

Fig. 6, which takes into account drying out of the soil, indicates that the maximum operating temperatures of two of the circuits are likely to be exceeded. Suppose, however, that a bentonite-water suspension is pumped into one or more of the ducts. In this case it is reasonable to suppose that a circuit in a duct with bentonite will behave like a laid direct circuit (actually a slightly pessimistic assumption).

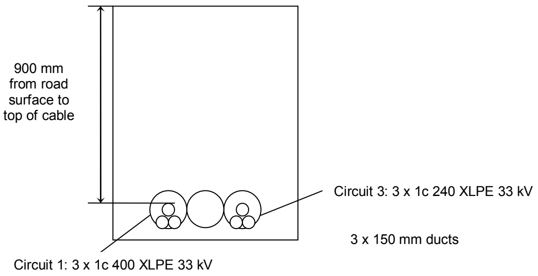


Fig. 5: Arrangement of ducted cable

Table 2 shows the result of this exercise. It can be seen that with bentonite filling at least two of the ducts should allow the desired cyclic rating of 620 A being achieved without overheating, but if only at least two ducts are filled. This real-life problem was posed by one of the Distribution Network Operators.

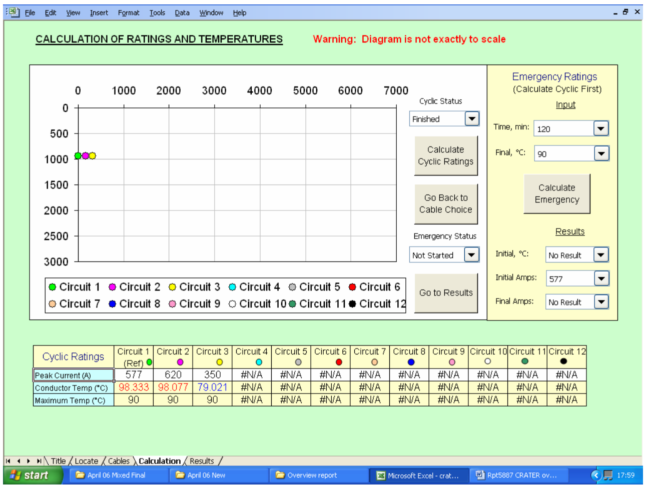
As Figure 6 indicates, it is possible to calculate emergency ratings (10 minutes to 4 hours). In addition to single circuits, ratings for each circuit in a group can also be calculated to a good approximation.

OTHER DEVELOPMENTS

Load Cycle

A routine has been added to CRATER to allow the user to generate 24-hour load curves directly from half-hourly SCADA data. These load curves (in one-hourly steps) can then be used to calculate cyclic and distribution ratings.

It is planned in the near future to study the effect of load cycle and season on cyclic ratings appropriate for cables supplying demand with a high penetration of micro-generation.



CALCULATION OF RATINGS AND TEMPERATURES

Warning: Diagram is not exactly to scale

Cyclic Status: Finished

Emergency Status: Not Started

Emergency Ratings
(Calculate Cyclic First)

Input

Time, min: 120

Final, °C: 90

Results

Initial, °C: No Result

Initial Amps: 577

Final Amps: No Result

Cyclic Ratings	Circuit 1 (Ref) ●	Circuit 2 ●	Circuit 3 ●	Circuit 4 ●	Circuit 5 ●	Circuit 6 ●	Circuit 7 ●	Circuit 8 ●	Circuit 9 ●	Circuit 10 ○	Circuit 11 ●	Circuit 12 ●
Peak Current (A)	577	620	350	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Conductor Temp (°C)	98.333	98.077	79.021	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Maximum Temp (°C)	90	90	90	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Fig. 6: Grouped cyclic rating of ducted circuits

Cable crossings

A CRATER for Cable Crossings is currently under construction. It is to be based on refs. [4] and [5]. All cable types featuring in other CRATER programmes, are being included in this new software.

Rating of cables in ventilated tunnels

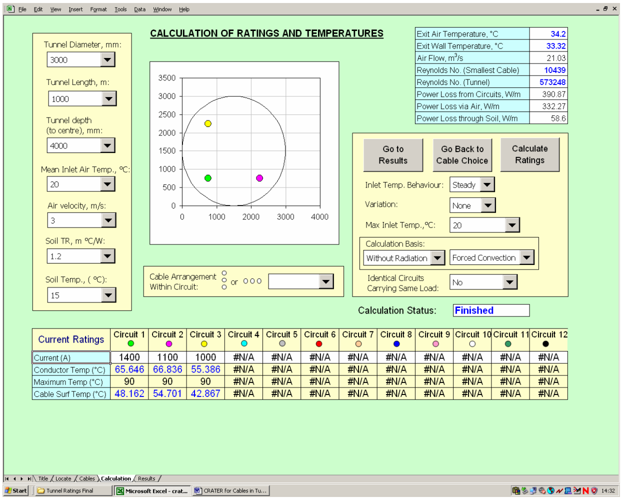
A CRATER for Tunnel Ratings has recently been created for EDF Energy. It is based on analytical solutions for ventilated tunnels given in Electra [6] for N identical circuits, with or without heat transfer by thermal radiation, and with or without cyclic variation of tunnel inlet air temperature. In addition, a solution has been obtained for *p* non-identical circuits, without thermal radiation.

The software uses the engine room of the CRATER for Grouped Cyclic Ratings, i.e. any of the 3,500 plus cables can be selected, and the required iterative calculations of the power loss per circuit can be carried out.

Table 2: Effect of adding bentonite to one or more ducts (maximum conductor temperature = 90 °C)

Ref No.	Circuit	Duct Filling	Maximum Cyclic Load of Circuit 2 (A)
A	Circuit 1 (3 × 400 mm^2) Circuit 2 (3 × 500 mm^2) Circuit 3 (3 × 240 mm^2)	Air Air Air	482
B	Circuit 1 (3 × 400 mm^2) Circuit 2 (3 × 500 mm^2) Circuit 3 (3 × 240 mm^2)	Bentonite Air Air	573
C	Circuit 1 (3 × 400 mm^2) Circuit 2 (3 × 500 mm^2) Circuit 3 (3 × 240 mm^2)	Air Bentonite Air	474
D	Circuit 1 (3 × 400 mm^2) Circuit 2 (3 × 500 mm^2) Circuit 3 (3 × 240 mm^2)	Air Air Bentonite	481
E	Circuit 1 (3 × 400 mm^2) Circuit 2 (3 × 500 mm^2) Circuit 3 (3 × 240 mm^2)	Bentonite Bentonite Air	675
F	Circuit 1 (3 × 400 mm^2) Circuit 2 (3 × 500 mm^2) Circuit 3 (3 × 240 mm^2)	Bentonite Bentonite Bentonite	673

Fig. 7 shows a calculation for three non-identical circuits, each carrying a different load:



CALCULATION OF RATINGS AND TEMPERATURES

Tunnel Diameter, mm: 3000
Tunnel Length, m: 1000
Tunnel depth (to centre), mm: 4000
Mean Inlet Air Temp., ºC: 20
Air velocity, m/s: 3
Soil TR, m ºC/W: 1.2
Soil Temp., (ºC): 15

Cable Arrangement Within Circuit: ○○○ or ○○○

Exit Air Temperature, °C	34.2
Exit Wall Temperature, °C	33.32
Air Flow, m³/s	21.03
Reynolds No. (Smallest Cable)	10439
Reynolds No. (Tunnel)	573248
Power Loss from Circuits, W/m	390.87
Power Loss via Air, W/m	332.27
Power Loss through Soil, W/m	58.6

Inlet Temp. Behaviour: Steady
Variation: None
Max Inlet Temp.,ºC: 20
Calculation Basis: Without Radiation Forced Convection
Identical Circuits Carrying Same Load: No

Calculation Status: Finished

Current Ratings	Circuit 1	Circuit 2	Circuit 3	Circuit 4	Circuit 5	Circuit 6	Circuit 7	Circuit 8	Circuit 9	Circuit 10	Circuit 11	Circuit 12
Current (A)	1400	1100	1000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Conductor Temp (°C)	65.646	66.836	55.386	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Maximum Temp (°C)	90	90	90	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Cable Surf Temp (°C)	48.162	54.701	42.867	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Fig 7: Tunnel rating calculation for 3 circuits

It is also possible with this version of CRATER to compare ratings of identical circuits in ventilated tunnels with those in non-ventilated tunnels (both with thermal radiation accounted for).

Duct type

As Fig. 2 shows, CRATER allows the user to specify a duct type. A theoretical study of heat transfer in various duct types indicates that ratings in twin wall corrugated plastic ducts should be reduced compared to those in earthenware or uPVC ducts. This is illustrated for an 11 kV polymeric cable by Table 3, which also includes thermal resistances.

Cable configuration and laying conditions are important factors in determining the degree of de-rating. It turns out that the trefoil of cables in one duct is worse in this respect than a trefoil of ducts with one core per duct.

A comparative experimental study of current rating of trefoil circuits in ducts (uPVC vs. twin wall) is planned.

Cable economics

The UK Regulator (OFGEM) has instituted a loss-reduction incentive, nowadays on the basis of a 5 years rolling retention mechanism. There is therefore potentially an incentive to increase cable size, although whether there are actually advantages depends on a number of factors.

The economics of selection can be considered for two cables of different sizes by:

a) calculating variable losses in the cables on the basis of annual or seasonal load profiles;
b) estimating the incentive (currently 4.8 p/kWh) obtained by increasing the size;
c) annuitising the additional investment required to make a reduction in losses to present year prices.

The effect of cyclic loads and utilisation are both important factors, which can be studied. The reduction of losses is recognised by the STP Programme to be of importance across all asset classes. In the next year or so an all-embracing project on loss reduction is to be carried out, with CRATER playing its part, because it routinely calculates all losses in a cable and at any temperature.

Dynamic ratings

The final part of CRATER planned for completion in 2008 will embrace dynamic rating functionality. There are, however, many such rating packages in the market. Therefore, its construction will enable network operators to gauge the effect of recent load history and to predict the effect of future load on circuit temperatures, but not necessarily requiring monitoring by DTS.

REFERENCES

[1] ENA Engineering Recommendation P17, “Current Rating Guide for Distribution Cables”: 1976, Parts 1 and 2; 2004, Part 3.

[2] K. J. Duke and I. R. Homer, 1976, “Calculation of 11 kV distribution ratings and correction factors”, Electricity Council Memorandum ECR/M931.

[3] H. Goldenberg, 1957, “The calculation of external thermal resistance and cyclic rating factors for groups of cables laid direct in the ground or in ducts”, BEAIRA Report F/T192.

[4] E. Dorison, 2003, "Cable crossings", *JICABLE ‘03*, Paper A.9.4, 285-290.

[5] Draft IEC 60287-3.3, 2006, "Calculation of the current rating - Cables crossing external heat sources".

[6] Cigré WG 21.08, 1992, “Calculation of temperatures in ventilated tunnels”, *Electra* No. 143, 39-59; *Electra* No. 144, 97-105.

Table 3: Sustained current de-rating of 1-core circuit; g = 0.9 m.K/W; T_a = 10 °C; trefoil 11 kV XLPE circuit laid direct and in a single duct (⊛); 150 mm nominal duct ID

	Thermal resistance (m.K/W)					Rating (A)	De-rating Factor
	T_1 Insulation	T_3 Oversheath	T_4' Air gap	T_4'' Duct	T_4''' Soil		
Laid direct	0.3848	0.0817	-	-	1.5228	698	1.000
Earthenware Duct	0.3848	0.0817	0.3416	0.0314	0.4134	596	0.854
uPVC Duct	0.3848	0.0817	0.3261	0.0593	0.4293	588	0.842
Twin Wall	0.3848	0.0817	0.3200	0.2108	0.4142	552	0.791