



## THERMAL TRANSIENT ANALYSIS OF UNDERGROUND CABLES



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### ABSTRACT

For companies active in distribution or transport of electrical energy, it is important to know the maximum short time ampacity of underground high voltage cables. With the knowledge of the transient thermal behaviour of underground cables, the energy companies should be able to operate temporarily in current overload conditions, without exceeding the maximum cable operating temperature. Existing cable standards describe correction factors for different conditions in steady state, but do not deal with transient behaviour.

The proposed research analyses the temperature of underground cables as a function of the initial load conditions, magnitude and duration of the overload, taking into account both cable and soil parameters and cable configuration. A software is developed for transmission system operators in order to simulate thermal transient behaviour of underground cables in a quick and easy way with respect to the boundary conditions.

### KEYWORDS

Underground cables, thermal transient behaviour, simulation software, measurements, cable ampacity.

### INTRODUCTION

The analysis starts with the description of the simplified model that is used in the simulation software for the calculation of transient temperatures of underground cables. Subsequently the test set-up built for the validation of the software, is presented, as well as the comparison of simulation and experimental results. Finally some conclusions are drawn.

### SOFTWARE MODEL

In the software model, only the thermal conduction is considered. Since convection and radiation are neglected, this simplification will lead to worst case results. Also other effects, such as underground water flows who reduce the cable temperature are neglected.

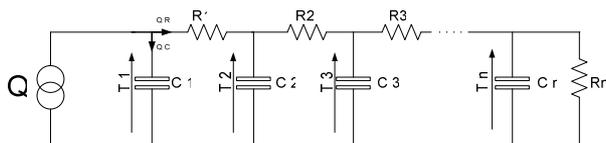


Figure 1: Model for simulating cable temperatures

The analysis of the thermal behaviour of the underground cables is made on the base of a distributed equivalent electrical network (Figure 1) consisting of a current source,

resistors and capacitors, representing respectively the heat generation in the cable, the thermal resistances and thermal capacitances of the different cable and earth layers.

The heat generation in the cable due to Joule power losses  $R \cdot I^2$ , where  $R$  represents the electrical cable resistance (temperature dependent) and  $I$  the load current. For the determination of the thermal resistances and capacitances, the knowledge of respectively the thermal conductivity and capacity of the different cable and earth layers is required, as well as the layer dimensions. The temperatures of the layers are calculated through the voltages in the equivalent electrical network.

### Equations for temperature calculations

#### Steady state conditions

The temperature  $T_i$  in node  $i$  (Figure 1) is given by:

$$T_i = Q \sum_{k=i}^n R_k \quad [1]$$

In particular, the conductor temperature  $T_1$  equals:

$$T_1 = Q(R_1 + R_2 + \dots + R_n) \quad [2]$$

where  $T_i$  [K] the temperature in node  $i$ ,  $Q$  [W/m] the heat generation per meter cable and  $R_i$  [m.K/W] the thermal resistance of layer  $i$  (between nodes  $i$  and  $i+1$ ).

#### Transient conditions

The relation between the heat flux and the temperature change per time in a volume with thermal capacity  $C_i$  is given by:

$$Q_{Ci}^j = C_i \frac{T_i^{j+1} - T_i^j}{\Delta t} \quad [3]$$

where  $i$  and  $j$  are indices for place and time respectively,  $Q_{Ci}^j$  [W/m] the heat flux in volume  $i$  at time  $j$ ,  $T_i^j$  [K] the temperature in node  $i$  at time  $j$ ,  $C_i$  [J/(m.K)] the thermal capacity of volume  $i$ , and  $\Delta t$  [s] the time step. The combination of [3] and the heat flux balance in each node results in [4]-[6].

$$T_1^{j+1} = \left(1 - \frac{\Delta t}{C_1 R_1}\right) T_1^j + \frac{\Delta t}{C_1} \left(Q^j + \frac{T_2^j}{R_1}\right) \quad [4]$$

$$T_n^{j+1} = \left(1 - \frac{\Delta t}{C_n} \left(\frac{1}{R_{n-1}} + \frac{1}{R_n}\right)\right) T_n^j + \frac{\Delta t}{C_n} \frac{T_{n-1}^j}{R_{n-1}} \quad [5]$$

$$T_i^{j+1} = \left(1 - \frac{\Delta t}{C_i} \left(\frac{1}{R_{i-1}} + \frac{1}{R_i}\right)\right) T_i^j + \frac{\Delta t}{C_i} \left(\frac{T_{i-1}^j}{R_{i-1}} + \frac{T_{i+1}^j}{R_i}\right) \quad [6]$$

with:  $i = 1, 2, 3, \dots, n$

and  $n$  the number of considered layers