INFLUENCE OF THE SURROUNDINGS AND MAINLY OF THE SOIL ON MV CABLE SYSTEMS

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ABSTRACT

The increase of the load of some Medium Voltage (MV) cables, due to, amongst other things, the development of decentralized production, brings up "new" issues. A practical case of failure in Belgian MV cable networks, highlighted the importance of the thermal characteristics of the soil around highly loaded cables. An analysis of the thermal physical parameters of three types of soil (backfill, sandy and "local soil" type) used around the Belgian cable networks was performed. In order to assure good heat evacuation during the life time of the cable, the characteristics of the soil around loaded MV cables, especially if a "local soil" is used, have to be defined by a set of parameters and not only by the thermal resistivity.

INTRODUCTION

The increase of the load of some Medium Voltage (MV) cables, due to, amongst other things, the development of decentralized production, brings up "new" issues. Even if the first failures often occur at the joints, the cables themselves undergo a premature/ ageing process, caused by an overheating around the cable. The consequences can sometimes be the replacement of kilometers of cable.

The first part of this article presents a practical case of failure in a Belgian MV cable network. The case highlighted the importance of the thermal characteristics of the soil around highly loaded cables.

Based on this case investigation, it was decided to analyze the thermal characteristics of two types of soil used around the Belgian MV cable network (sandy type and "local soil" type). The results were compared to the characteristics of backfill soils, "proper soils" especially laid for heat evacuation around cables.

The second part of this article represents the characterization in terms of the capacity of heat evacuation of those soils. This characterization is made through means of different parameters measured in the laboratory on several soil samples.

FAILURE CASE IN BELGIUM

The fault on 2 XLPE cables, 400 mm^2 Al, 10.5 kV with a constant load of around 490 A, showed the importance of a cable surroundings in Belgium MV network (Figure 1). It was noticed that, at some locations, the outer sheaths of the cables were melted and the soil was dried out, compared to other places where the cables seemed intact and the soil was still humid.

Figure 1: Melted cables and dry soil around

A temperature measurement of the cable outer sheath at two points, separated by a few meters, indicated a temperature difference larger than 55°C (Table 1).

An onsite and laboratory investigation of the cables and the soil around were performed (according the cable laying specifications, temperature measurements along the cables in several points and temperature calculations).

The soil samples were characterized by thermal resistivity, water saturation degree, dry density and porosity measurements.

Measurement showed poorer thermal properties of the soil at the dried-out location (sample 1 from Table 1,) compared to the properties of sample 2, from a few meters further along the cable. Poorer thermal properties mean higher thermal resistivity & porosity and a smaller saturation degree (see Table 1 and Table 2).
This difference was sufficient to induce a thermal run-away of the water around the location 1 of the cable.

Sample	Outer sheath Temperature [°C]	Saturation degree [%]	Thermal resistivity (dry state) [K.m/W]
1	110	34	2.28
2	55	80	1.01

Table 1: Thermal resistivity measurements and the corresponding saturation degree

Sample	Porosity [%]	Dry density [kg/dm^3]
1	53	1.248
2	46	1.429

Table 2: Other thermal properties of the two samples

Simulations highlighted that the fault was caused by an overheating around the cables due to effect of soil dry-out around the cables (Table 3).

Deep 0,3 m; current 490 A; Ambient temp. 10 °C; dist between cable 20 cm; XLPE 400 mm²		
Thermal resistivity [K.m/W]	**Outer sheath Temperature [°C]**	**Conductor temperature [°C]**
2.28	139	147
1	55	61

Table 3: Results of the thermal simulations

The high temperatures are caused by:

- the high load factor
- the use of a non adequate soil around the cables
- the laying conditions : Some parts of the cables were buried close to the surface (30 cm) and to close to each other.

Obviously, the guidelines for cables used in cyclic and redundant networks need to be reviewed for connections with high load factors.

Therefore, to prevent such situations around highly loaded MV cables in the future, a soil investigation from a thermal point of view is recommended and, if necessary, the use of a soil with good heat evacuation properties (the backfill type soils) instead of the local soil.

The case showed that other parameters related to the soil heat evacuation around the cables have to be taken into account in projects of cable installation, like the impact of soil compaction level of, the use of a cover cable, ….

DEFINITION OF STUDIED PARAMETERS

In this context, we decided to investigate extensively different types of soils in order to characterise their relevant physical parameters and to evaluate their influence in the heat transfer. The most important parameters in the heat transfer in the soil around a cable are:

- the dry density: measured in laboratory by the ratio between the weight of a the dry sample and the sample's known volume
- thermal resistivity of the constituent materials in K.m/W. A soil with an optimum heat transfer will have a low thermal resistivity. Its lower value will be measured for its maximum dry density obtained by compaction for its Optimum Proctor moisture level
- the soil constitution, soil compaction and grain size distribution: A good heat transfer depends on the soil constituent material. A soil with a good heat transfer is a mixture of quartz, sand and limestone grains (materials with low thermal resistivity) [1] and the occupied volume must be filled as much as possible with solid (a mixture of different grain size particles, Figure 3). Air, clay and organics have to be avoided.
- the porosity: is a fraction of the volume of voids (air) over the total volume of soil
- the moisture content : measured in laboratory by weighing the sample before and after drying. It is expressed in % (g of water / g of dry soil x 100)
- the saturation degree: calculated by the ratio between the volume of water present in the soil and the pore volume
- the hydraulic equilibrium inside the soil; defined by its critical degree of saturation. The critical degree of saturation represents the moment when the flow of liquid towards a cable is sufficient to maintain the particles moisture against the flow of vapours getting away from the cable (from the pores nearly empty). For a saturation degree lower than the critical one the soil will dry out. This parameter was determined by graphical method for one backfill and a soil from Belgium MV electrical network.

RESULTS

Six soils were investigated: three backfill types, two river sand types (used in the Belgium MV network), one soil of local origin (placed around an existing MV cable), “local soil”. For all samples of soil we analyzed the composition and diameter grain size distribution, the dry density, the porosity, the thermal resistivity for different water contents and the compaction level.

Soil constitution and grain size distribution

The three types of investigated soils are described in table 4 and the grain size distribution in Figures 3, 4 and 5.

Soil type	Description
Backfill	a mixture of different types of soils with a low thermal resistivity, a well defined and good grain size distribution, exceptional coarse, very silty, very gravelly brown
River Sand	sand, moderately fine, slightly silty, slightly gravelly brown and bad grain size distribution
Local soil	Clay-loam, slightly silty, slightly gravelly grey, good grain size distribution

Table 4: Soil description

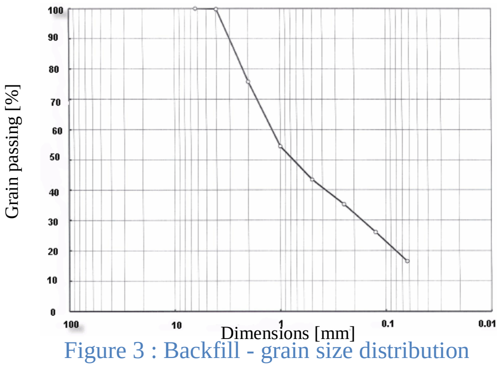

Figure 3 : Backfill - grain size distribution

The grain size distribution was evaluated by measuring the percentage of soil grains passing through a calibrated collector with trays of different dimensions. The grain size distribution of the sand samples is too uniform and the particles are too small to obtain a good heat evacuation (Figure 4). This grain distribution will not allow avoiding air pockets. The local soil has a good grain size distribution, even the grain size is small (Figure 5).

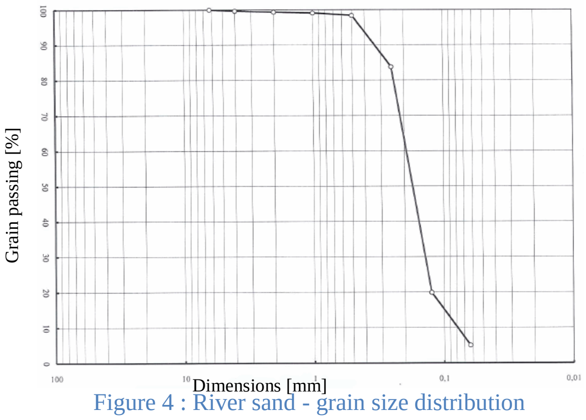

Figure 4 : River sand - grain size distribution

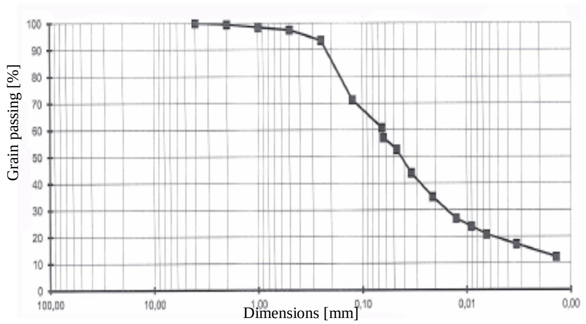

Figure 5 : Local soil - grain size distribution

Dry density, porosity, water content and compaction level

Laboratory measurements of the soil characteristics are performed according to the reference [1], [2], [3] and [7].

The measurements have shown that by compaction, the particles can be rearranged in order to obtain a high density. High densities are not attainable only by compaction. Uniform sized particles compact only to a given maximum density. To attain densities beyond that, without crushing particles, smaller particles must be added to fill the voids between the larger particles.

Highest densities are therefore attained by using well-graded materials (backfill soil type).

For a given dry density of the soil the thermal resistivity reduces as the moisture content increases. Water distribution on the surface of the grains will increase the contact between grains and by a capillarity phenomenon the heat transfer will be improved.

The grains will slide easier and a higher dry density will be obtained. Too much water will move the fine grains to the surface and will not allow a good compaction (water will not allow the particles to be close to each other).

There is a maximum amount of water that a soil may contain in order to obtain maximum density after compaction (the greatest density, g/cm^3, of a soil is obtained for a certain moisture content and is called the Proctor Optimum).

The inter-influence between those parameters is measurable by the thermal resistivity.

Thermal resistivity

Thermal resistivity measurement was performed in the laboratory based on the procedure proposed by [1].

The calculation model is described here under:

$$\rho=(4\pi(T_2-T_1))/2{,}303\ q\ln(t2\ /t1)$$

where:

ρ = resistivity, K.m/W

T_1, T_2 = temperature measured at two different times

q = heat dissipation per unit length, W/cm

t_1, t_2 = elapsed time at which temperature was measured

The thermal characteristics measured for the three types of soils under investigation are presented in Table 5. A first series of measurements were performed on several samples (see table 5).

	Backfill	River sand	Local soil
Dry density (kg/dm³)	1.664 – 1.905	1.487 – 1.516	1.259
Water content (%)	8.5 - 11.9	3.6 - 8	14
Saturation degree (%)	33	12 – 28	53 - 58
Porosity (%)	28 - 37	43 - 44	53
ρ wet state (K.m/W)	0.3 - 0.4	26 - 45	0.81
ρ dry state (K.m/W)	0.6 - 1.9	1.3 - 2.26	1.98

Table 5: The minimum and maximum measured values of soil characteristics

A second series of thermal resistivity measurements was performed to investigate the influence of the water content on the heat evacuation capacity of a soil from the MV Belgium network.

The “local soil” thermal resistivity evolution with the water content was compared to the one of a “backfill” (Figure 6).

The curves highlight that even a backfill in dried-out state could have a thermal resistivity higher than 1 K.m/W.

The thermal resistivity- saturation degree dependence allows an evaluation of the water equilibrium in the soil, the estimation of the critical saturation degree by graphical method. For the backfill, the critical saturation degree is 33% and for the “local soil” it is 55%.

This difference highlights a better water equilibrium in the backfill then in the “local soil”, that means a higher risk of drying out of the “local soil” compared to the backfill.

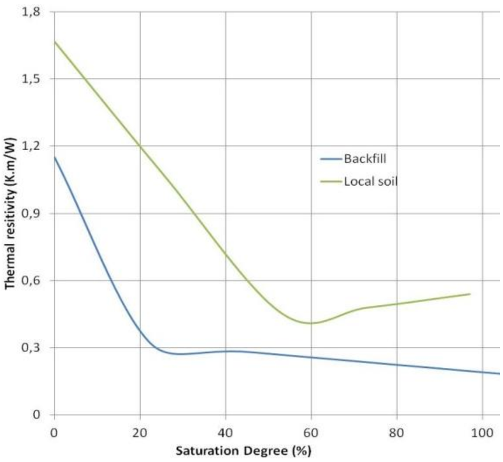

Figure 6 : Thermal resistivity evolution with the soil saturation degree

Some observations can be derived from the measurements:

- The critical saturation degree underlines the better behaviour, in time, of the backfill compared to the other soils.
- The soil used for river crossing has characteristics far from optimal.
- To achieve a proper cable laying grain distribution, density and soil type, but also humidity and compaction are important.

CONCLUSIONS

This study showed the high interest for the MV network managers of a more detailed investigation of the surroundings of highly loaded MV cables.

We can conclude that the characteristics of the soil, especially if a “local soil” is used, have to be defined by a set of parameters and not only by the thermal resistivity, in order to assure the good heat evacuation during the life time of the cable.

The need of understanding the influence of all parameters will become more important with the evolution of the load. The various parameters and their influence are analyzed and confirmed by measurements.

The performance of a soil material depends on the difference between its critical degree of saturation and the degree of saturation of the soil. It is important in the selection of a backfill to have a low critical degree of saturation, low porosity and high dry density after compaction. On site, to achieve such properties it is important to verify the compaction process and the dry density after the compaction, in order to assure a low thermal resistivity (a good evacuation of the heat around the cable).

Efficient backfills have well distributed particle sizes (even particles below 100µm), capable of being compacted to dry densities of 1700 to 2000 kg/m^3 (low porosity).

The results of this study were used as input to compute the temperature of some cable circuits and checked on site by temperature measurements (thermocouples).

The observations are helpful in understanding the benefits of a suitable backfill and the consequences of using an “improper soil”. Therefore similar projects correlated to the temperature simulations and measurements on site are still ongoing in Belgium.

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