Continuous burial depth monitoring of offshore power cables using distributed temperature sensing (DTS)

Offshore power cables are the Achilles heel of the offshore wind industry. Without them, no energy is delivered to the main land. Unfortunately, these cables are often damaged by external reasons, most by collision with anchors or fishing nets. The Belgian start-up company, Marlinks, has a solution and PES wanted to know more.

Motivation for burying the cable

The most effective way of protecting these cables is by burying them in the sea bottom. However, the sea bottom is not static, but a moving landscape. Therefore, it is crucial for a cable owner to know what the depth of burial (DoB) of the power cable is. Especially the range between 0 (uncovered cable) and 1m DoB (minimum DoB for power cables in many areas) is critical. As the current monitoring techniques are expensive and require the mobilization of survey vessels, Marlinks has developed a technique to continuously calculate the burial depth based on the temperature of the cable, measured with a DTS (Distributed temperature sensing)

DTS measuring

The DTS technology offers the possibility of measuring the ambient temperature at which fibre glass is exposed, with some notable advantages compared to traditional temperature measurements. The temperature measurements take place along the entire length of the fibre glass, which can easily be several tens of kilometres, with a spatial resolution between 1m to 5m. By using fibreglass an enormous number of measuring points can thus be read where, traditional measurement techniques, cannot cope with number of measuring points, frequency of measurement or accuracy. As fibre optic cables are always present in a power cable and since the backscattered light is insensitive to extreme conditions, such as water, electric or magnetic fields, DTS is the ideal technique to measure the temperature in a power cable.

The measuring method itself is based on the dependency of the fibre optical properties, on its ambient temperature. Advanced algorithms enable accurate and reliable mapping, along the entire glass fibre. Figure 1 shows that a light source, in the form of a laser, sends a specific light pulse in the optical fibre. Due to the microscopic impurities in the glass, this light pulse is routinely scattered along its entire path and thus partially reflected as well.

The typical wavelength of the reflected light is shown in figure 2 which shows that the amplitude of the Anti-Raman frequency is dependent on temperature in contrast to

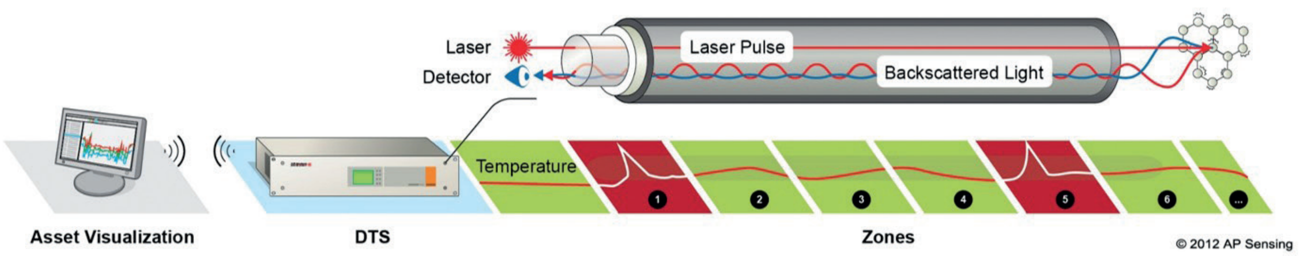

Figure 1: Schematic overview of the working principle of DTS (Source: AP Sensing)

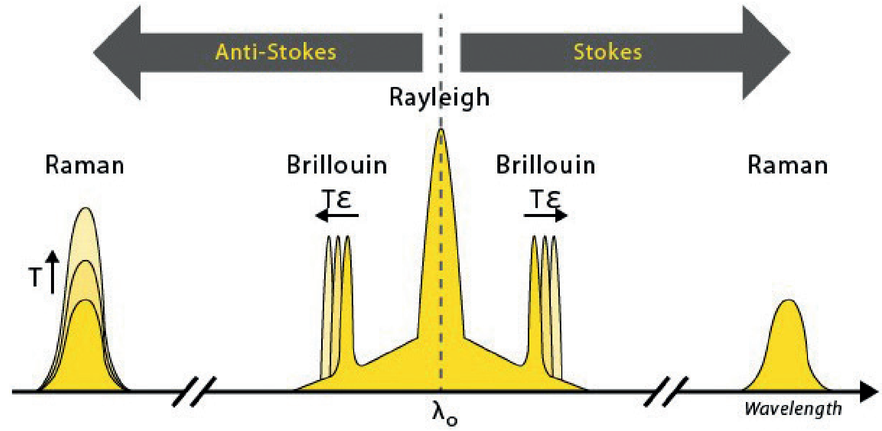

Figure 2: Wavelength of backscattered light (Source: Febus optics)

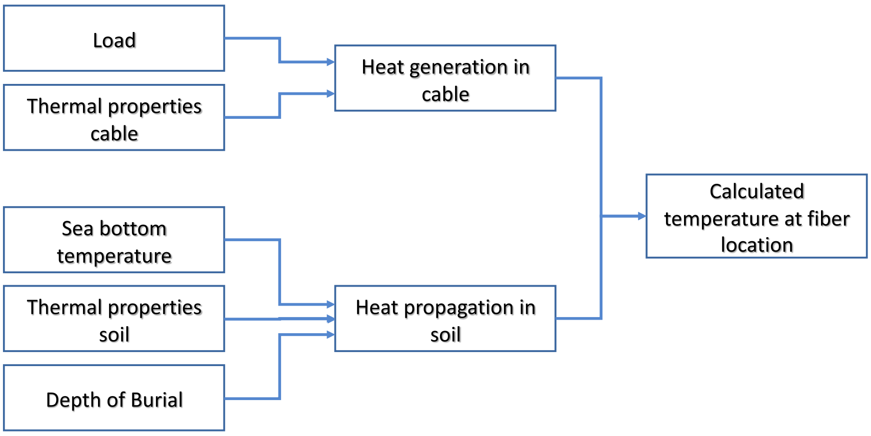

Figure 3: Block diagram of the Burial of Depth calculation model

the constant amplitude of the Raman frequency. Another temperature dependency can be observed with the Brillouin and Anti-Brillouin frequency, as these frequencies shift as a function of temperature but also of strain.

These phenomena are used to calculate the temperature on a single point of the cable. The location of the temperature measurements along the glass fibre is determined by multiplying the speed of the laser light in the glass fibre by the time between the laser pulse is sent and the reflection thereof called Optical Time Domain Reflectometry (OTDR). The accurate time measurements are translated into a spatial resolution of at least 1 measuring point per 5m. The low optical losses of the laser light in the glass fibre enable measuring over very long distances (tens of kilometres). This makes this technology very suitable for offshore applications.

The model

By using heat thermal resistance of the surroundings of the cable, combined with the measured DTS temperature, we can derive the Depth of Burial of the cable as it is a main drive of the total thermal resistance. In concrete terms, the model looks like figure 3.

The model consists of algorithms that simulate the fibre temperature along the power cable. The calculation starts with simulating the temperature response of the cable by calculating the heat generation in the cable, based on the measured cable load (time series of amps), the cable thermal properties and cable inductive and capacitive effects.

In a following step, the heat propagation in the soil is simulated taking into account the cable surface temperature calculated in the previous step, the sea bottom temperature, the soil thermal and geotechnical properties and an estimate for the depth of burial of the cable. Next, the heat propagation in the soil and cable are combined to calculate the temperature at different points in the thermal chain, including the temperature at the fibre location.

This calculated signal is compared with the actual measured temperature in the fibre (Figure 4). Finally, stochastic methods, such as Kalman filters are used to derive the burial depth corresponding to the modelled temperatures. Also associated model uncertainties are simulated, giving insight in the model accuracy.

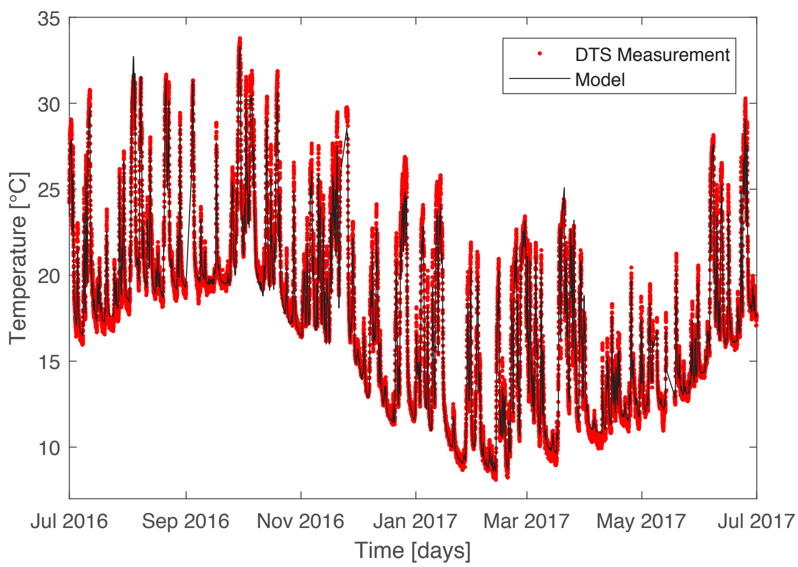

Figure 4: Comparison between measured Fibre temperature (red) and calculated fibre temperature (black)

Figure 5: Experimental setup

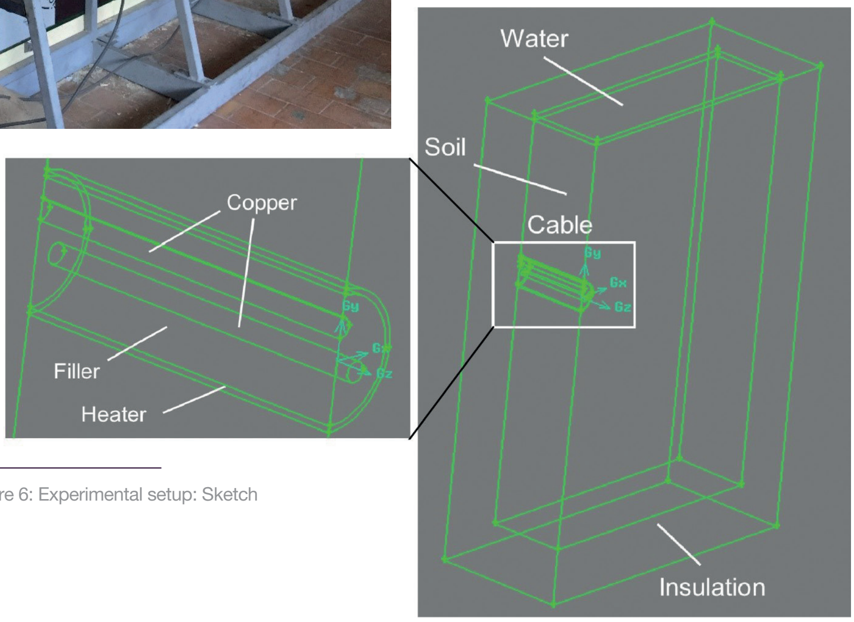

Figure 6: Experimental setup: Sketch

The experimental setup

The model results described in the previous paragraph were validated with an experimental setup (see Figure 5 and schematic sketch in Figure 6). A large box (3000 x 2500 x 600mm) was completely insulated and filled with sea sand and water. In the middle of this box, one type of offshore power cable was positioned, which could be heated in a uniform way to simulate the offshore power cable heating. Around the cable, at various distances from the centre, thermocouples were installed to measure the temperature of the soil.

Furthermore, thermocouples were installed inside the power cable. During the experiment, the heat generation in the cable was controlled and varied while the water was kept at a constant temperature of 4°C. By doing so, the heat propagation through the soil could closely be monitored. The experiment was repeated for different burial depths, by changing the height of the soil package on top of the cable and for different soil types by changing the soil type in the box from fine sand to very coarse sand.

The measured temperatures inside the cable and at different distances, were then compared to the outcome of CFD-models and our model algorithms. We could prove that our model can fast and accurately predict the heat propagation through the cable and the soil for different soil types as is visible in figure 7.

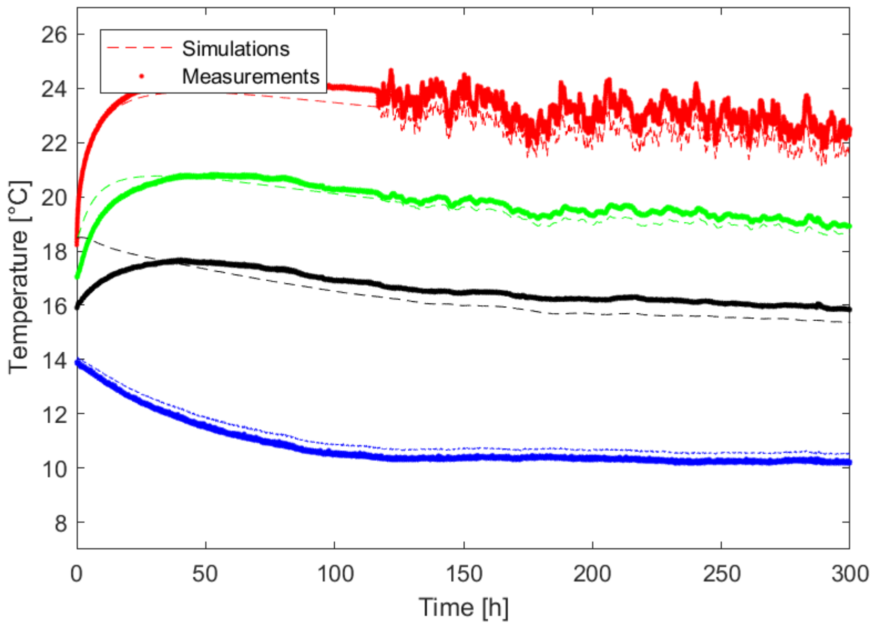

Figure 7: Comparison between experimental results and CFD calculations, first 120h with steady state heat signal, afterwards a periodic heat signal. (red: temperature at boundary cable-soil 60cm below the water surface, green: soil temperature 45 cm below the water surface, black: soil temperature 30 cm below the water surface, blue: temperature at the water surface)

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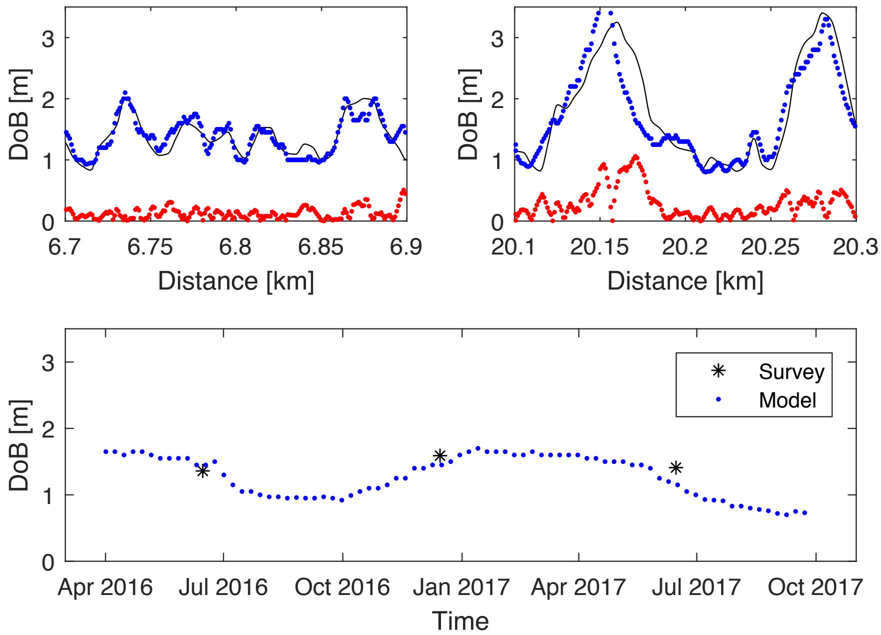

Figure 8:
- Part 1: Comparison between measured and calculated Depth of Burial for a distance of 200 m
- Part 2: Comparison between measured and calculated Depth of Burial for a distance of 200 m, area with moving sand dunes
- Part 3: Comparison between measured and calculated Depth of Burial for one point as a function of time (all graphs: Black: measured burial depth, Blue: calculated burial depth, red: error)

The results

Results were validated by comparing them with actual survey results in order to assess the performance of our algorithms.

In Figure 8 part 1 and 2, the calculated Depth of burial is given at 2 different locations (every time for an interval of 200m) and compared with survey results. It is clear that the result of the calculation is more accurate in case of a cable burial below 1 meter (accuracy of less than 20 cm). The graphs show also that with cable burial up to 3 m, the model error is still lower than 50 cm.

The continuous monitoring of the DoB enables to detect rapidly cable burial issues. An example is shown in Figure 8, part 2. The calculated peak at location 20.15 is not a deviation/mistake in the calculations but represents what happens as the sand dune moves towards the coast, compared to the previous survey 6 months earlier.

In Figure 8 part 3, the burial depth is given for one location based on survey results and on our calculations. It shows that even if survey results show a stable seabed, changes in a magnitude of 0.5m are perfectly possible which goes unnoticed in the case of classic surveys. The monitoring system based on DTS measurements and model algorithms, thus provides immediate insights, which would not be detected until the next survey, without the continuous burial depth calculation.

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