BOPTIC – Modelling offshore power cables for monitoring using optical fiber sensors

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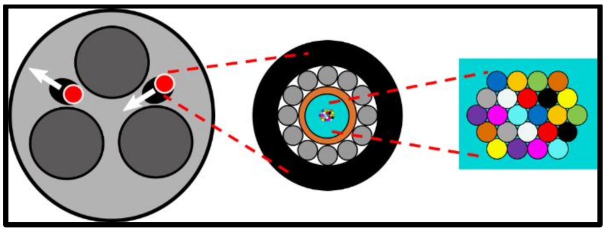
Motivation

Belgium is strongly investing in renewable energy as to reduce its carbon dioxide emissions by 40% starting from 2030. Expanding offshore wind farms as a source of renewable energy will be an important factor in reducing energy-related greenhouse gas emissions. A key vulnerability of offshore energy production facilities are submarine power cables, that can be damaged in all stages of their life. Major causes of subsea power cable failure include poor installation, cable ageing and fishing activities. Damages to offshore power cables make up almost 85% of total project insurance costs. A way to address this challenge is to monitor power cable deformations throughout their entire lifetimes.

1) Damaged submarine power cable (source: NKT)

Distributed Acoustic Sensing or DAS is a technique that is based on laser pulse reflections in optical fibers. It has been used for a variety of applications including intrusion and leakage detection of pipelines, and well integrity and seismic monitoring of boreholes. Optical fibers that are embedded in a submarine power cable allow monitoring the power cable deformations using Distributed Acoustic Sensing, giving an operator thousands of data points along the entire cable length.

These optical fibers are embedded inside a so-called fiber optic cable: a steel reinforced cable that is helically coiled inside the power cable. The fiber optic cable serves to protect the optical fibers, but it also reduces their detection sensitivity. Another challenge involves the spatial resolution of Distributed Acoustic Sensing; an event can only be localized within 10 m when monitoring a 40 km long power cable in its entirety.



2) Cable structure, left to right: power cable, fiber optic cable, and optical fibers

The main challenge of this thesis is **translating the Distributed Acoustic Sensing signal to mechanical deformation of the power cable** in a meaningful way.

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Objectives

In the above context, the objective of this PhD project encompasses the three topics below:

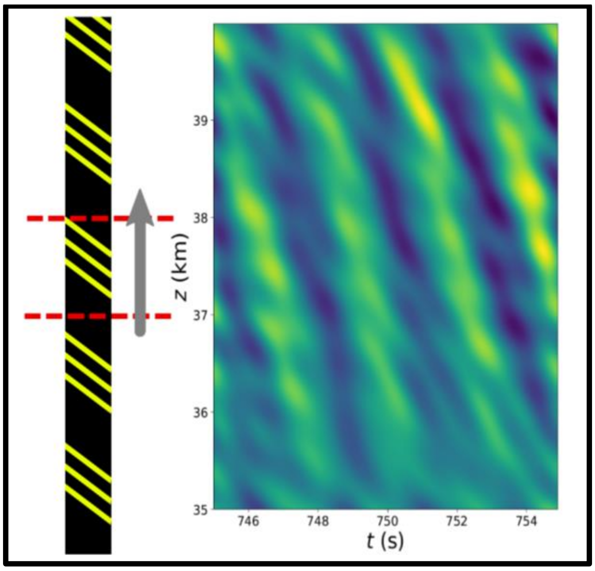
1) Creating a forward model as to go from deformations of the power cable to the measured DAS signal
2) Calibrating and validating this forward model using specifically developed tests at different scales
3) Reversing the framework to allow deriving power cable deformations from DAS measurement

Approach

We approach the **first objective** by tackling three different levels:

a. Power cable: How is global power cable deformation converted to strains at the fiber optic cable sheath?
b. Fiber optic cable: How is strain at the fiber optic cable sheath transferred to an embedded optical fiber?
c. Optical fiber sensor: How is optical fiber strain translated into a Distributed Acoustic Sensing signal?

At the level of the power cable and fiber optic cable, a 3D finite element model will be developed to simulate the deformations of the power cable and its constituents under different load scenarios. The main challenge will be capturing the correct material behavior and interaction of the multitude of parts of a power cable in an economic way. –At the level of the optical fibers and DAS sensor, analytical and empirical models will be implemented, supported by dedicated sets of experiments. These tests will look into the different dependencies of strain transfer from a tube to its embedded optical fibers. Specifically, the effect of the fiber optic gel and overstuffing (the embedded fiber is longer than the tube) on the strain transfer will be mapped for a range of relevant frequencies.



3) Typical DAS signal with z the length along the power cable. A segment between 35 and 40 km is here monitored for 10 seconds.

For the **second objective**, a power cable bending rig will be constructed as to validate the power cable finite element model in two ways: i) its global deformation, ii) the strains present at the fiber optic cable sheath. As mentioned higher, design and calibration of the analytical and empirical models to determine optical fiber strains and corresponding DAS signal is envisaged by small scale tests. Finally, the power cable bending tests will also allow to assess the the forward cable model as a whole, since the measured DAS strain signal can be checked against model predicted DAS strains.

We believe that the main challenge for inverting the forward model - **third objective** - will be the power cable finite element model. One way to tackle this problem is by using machine learning: one can generate many power cable deformations in software, derive the strains at the fiber optic cable sheath, and finally train a neural network that tries to reconstruct the total deformation of the power cable.

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