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APPLICATION OF TEMPERATURE SENSING AND DYNAMIC STRAIN MONITORING TO SUBSEA CABLE TECHNOLOGY

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ABSTRACT

Installation and operation of HV subsea cables is always challenging. When the cable enters water, first hand measurement and examination are not possible and secondary sources such as underwater video are used to monitor the status of the cable. With Distributed Temperature and Strain Sensing use is made of the Fibre Optic usually embedded in the cable construction for telecom purposes. The fibre is used as a continuous sensor and can supply thermal as well as stress/strain dynamic information to a monitoring station.

KEYWORDS

Subsea cable, Temperature Monitoring, Dynamic Stress Strain monitoring

INTRODUCTION

Power cable links can be critical assets in project commercial viabilities. In the Oil and Gas market power links are used to energise offshore installations. Outages have tangible commercial implications. Large scale offshore wind parks rely upon HV power cables for the export of the power to the land based power network. Inter-turbine power cables are configured in such a way as not to have major impact on power export in case of cable failure. However, export cables can limit power output unless sufficient redundancy is included in the wind farm scheme.
If due to capital constraints overcapacity/redundancy cannot be built into the systems, the cables become critical assets to project commercial performance.

In the last 15 years, temperature monitoring based on fibre-optic cable technologies have become common on land at voltages above 132kV. Application of this technology to subsea cables with the addition of dynamic strain mapping means project risks are managed more effectively through better asset life management (extensive condition monitoring means more effective maintenance).

SUBSEA CABLE ISSUES

Most longer length high voltage subsea cable installations are challenging and as a result there are risks that have to be mitigated [1].
Usual issues encountered:

- Routine testing equivalent to land cables cannot be carried out due to cable length
- HV XLPE subsea cables are normally dry core designs with lead sheaths – susceptible to fatigue
- Commissioning tests are even more limited than routine tests therefore any defects introduced as a result of transport or installation are likely to be undetected
- Quantitative installation data is limited especially if a two pass operation is required (laying and then trenching), mainly visual records are available (ROV surveys)
- Post commissioning cables are still at risk due to external damage as well as environmental effects such as scour and sediment migration. Exposed cables can vibrate in strong currents and thus susceptible to fatigue failure. Cables buried to much greater depth than expected can overheat and fail due to thermal runaway.
- Dynamic cable sections may be exposed to conditions outside of their design criteria (large oscillations, greater bending movement)

If not managed, most of these issues can lead to cable commissioning failures and early mortality problems. Some, like scour and sediment can be unpredictable with a few years of no change followed by a changing pattern of seabed movement.
Most HV three core XLPE cables have an embedded Fibre Optic (FOC) cable in one of the interstices, usually provided for trip protection and communication purposes. With the advances in using this technology as temperature and strain sensors a new way of monitoring key assets can be implemented.

SENSING TECHNOLOGY

Figure 1 shows a cross section of a typical HV power cable with a 6/12/16/24 FO cable laid up in one of the interstices. Lead sheath is used to provide an impermeable water barrier around each core.

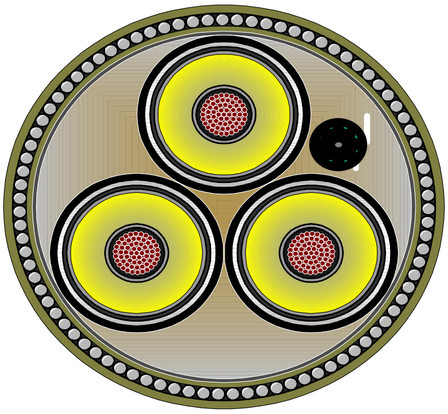

Figure 1 HV XLPE 3C Power Cable

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DISTRIBUTED TEMPERATURE SENSING

As already mentioned, temperature sensing is well established at EHV voltages, for subsea AC 3 core applications there is a benefit. Due to the embedded sensor, temperature accuracy is improved as the zone measured is in the T3 section rather than the more unpredictable T4 section of IEC 60287. Much better correlation between calculations, models and measurements is thus possible. Figure 2 shows a Finite Element model demonstrating a 150A derating due to a directional drill below layers of shingle and sand.

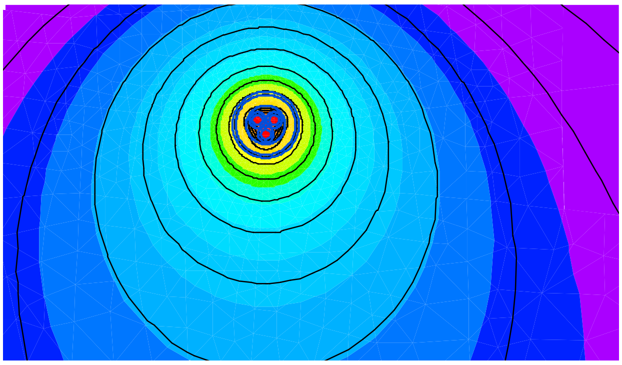

Figure 2 Power Cable Thermal Rating, beech landing through duct, in sand and shingle

Conductor temperature is the main driver in the cable ageing mechanism. If accurate thermal cable history is available asset life can be extended if loads are lower than specified for cable type or the asset can be used closer to it's full utilisation by increasing the load.

RELATING STRAIN SENSING DATA TO CABLE GEOMETRY

As shown in Figure 1, in multicore designs, the Fibre Optic Cable (FOC) is laid up in a certain position in the cable cross-section. The lay length is equivalent to the other elements however, the Pitch Circle Diameter (PCD) of the FOC will be different. The FOC design itself will consist of a Fibre Optic element laid usually around a central former with a specific lay-length and PCD. All these elements have to be considered when relating the cable bending or pulling tension forces to the strain shown by the fibres in the FOC.

The fibre monitored is essentially a smaller helix incorporated into a much bigger helix.

It can be shown [2] that the radius r of curvature for a helix with a mean helix diameter D is

$$r = \frac{D}{2}\left\{1 + \left(\frac{P}{\pi D}\right)\right\} \quad [1]$$

where P is the Fibre lay-length,

resultant strain s on the filament is the difference between the outer surface extension to the axis,

$$s = \frac{\left(r + \frac{d}{2}\right)}{r} \quad [2]$$

where d= diameter of fibre

If E is Young's modulus and N is the rigidity modulus and in most cases E>2N, the spring tends to coil up when stretched with the resulting increase in length of dL.

$$\delta L \frac{\delta L}{L_0} = \left(\frac{\pi}{D}\right)^2 \cdot \delta D \cdot \left\{D - \left(\frac{\delta D}{2}\right)\right\} \quad [3]$$

Assuming most FOC designs utilise loose tube fibre, slack in the fibre shall be used up before tension related to the cable axial stiffness is engaged.

The initial tension or compression of the cable is assumed to be elastic.

$$\frac{e}{l} = \frac{F/A}{E} \quad [4]$$

From the above expressions extensions and movement of fibres can be evaluated. For a representative cable build, with a 0.125 micron fibre in a 0.6mm loose tube, 900mm FOC lay-length, 75mm FOC PCD 3.64% of fibre extension can be accommodated by fibre movement within the loose tubes.

As fibres are normally proof-strain tested to 1%, and knowing the Young's modulus for Silica fibre is E=72000MPa , the equivalent stress on the fibre can be calculated. In majority of cable designs, extreme bending on it's own would not apply enough tension of the fibre to start to stretch it.

Figure 3 shows a graph of the expected extension of the fibre versus the bending diameter of the power cable. The dotted line in the y-axis direction indicates the extension where the cable is subject to a bend around a former 25 x outer cable diameter. The dotted line in the x-direction indicates the point at which all slack is removed from the fibreoptic and tension is exerted on the silica cores.

SUBSEA CABLE MOVEMENT

The question of damage from excessive subsea cable movement is often raised. It is now well accepted that burial is the key to subsea cable reliability. In some instances this can be difficult to achieve over the project lifetime. High tidal currents through channels cut in estuaries can generate significant scour. Cables buried in underwater banks can become exposed.

The vibration induced by these currents can be a threat to the reliability of subsea cables. Based on a 132kV 3C cable with an overall diameter of 185mm , a 20m span was found to have a natural frequency in the range of the highest

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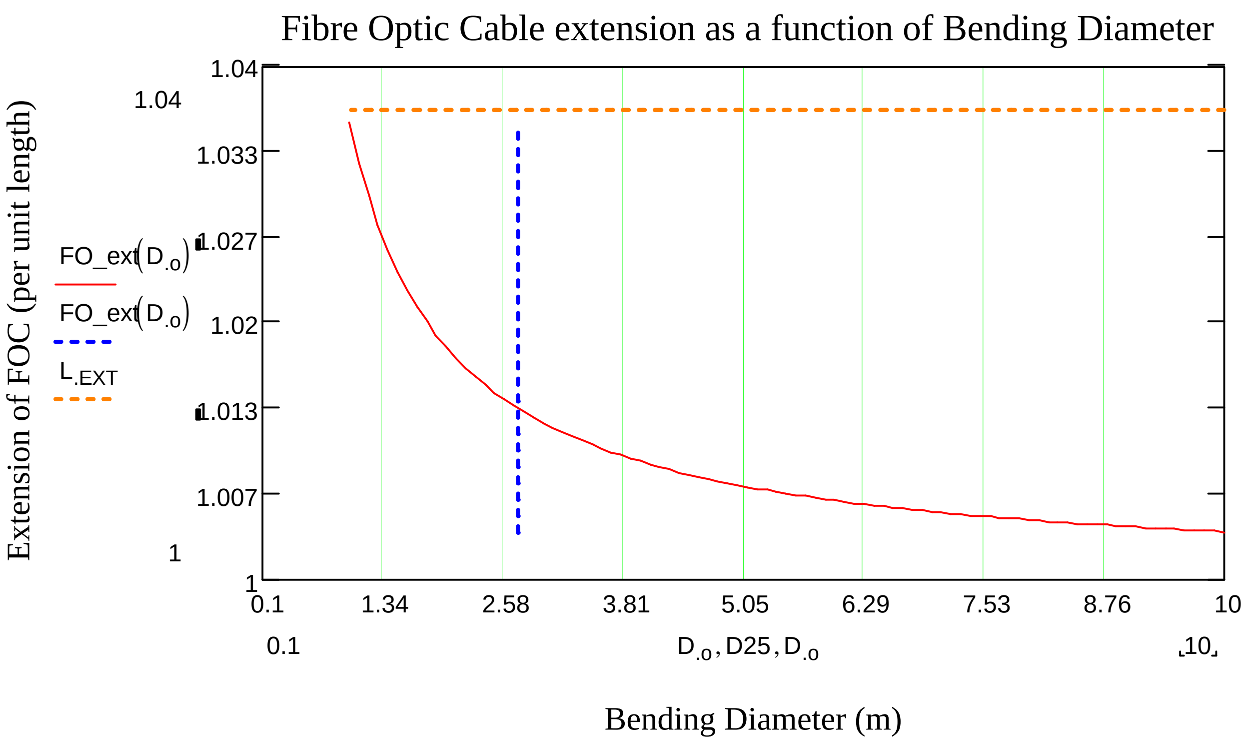

Figure 3 Fibre extension vs Cable Bending Diameter

vortex shedding frequency predicted by [3][4]. At low current velocities, the vortex force generated [3] is not powerfull enough to fully lift the cable during the majority of the predicted currents in a year although it is of the same order as it's weight. The horizontal line in Figure 4 indicates the natural frequency calculated for the cable, treating it as a cylinder of 20m in length.

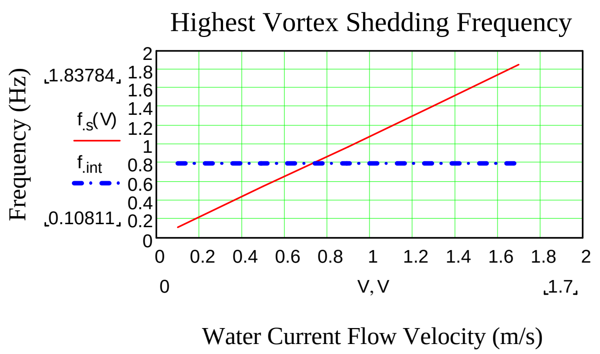

Figure 4 Highest Vortex Shedding Frequency

Any movement has fatigue implications on subsea cables, especially if lead sheaths are present.

DISTRIBUTED TEMPERATURE AND STRAIN FOR DYNAMIC MONITORING

With recent development in distributed sensing [5], both the temperature and strain can be monitored dynamically along the entire length of the fibre. Figure 5 shows the Distributed Temperature and Strain Sensor (DTSS) instrument developed by Sensornet.
DTSS units can be used to identify any sections of cable that become exposed and alarms can be set to notify asset installers and operators of excessive movement.

In order to accurately monitor status of the cable asset and because of the reasons outlined above, calibration of the cable movement is recommended. This can be carried out at the cable factory during final approval testing or on a sample cable.

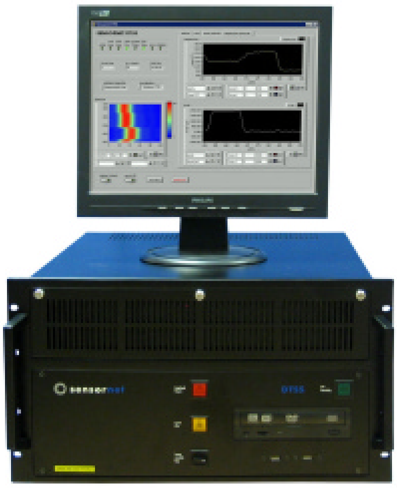

Figure 5 Distributed Temperature Strain System

Once correlation between signals and DTSS is complete, the system is capable of monitoring temperature and pressure. Stress resolution of 2psi and strain resolution of 20µε is possible. Dynamic monitoring of strain changes at acquisition rates of up to 10Hz is also possible along entire length of fibre. A histogram of cycle counts against strain/stress amplitudes can thus be collated in realtime to assess environmental effects on cable lifetime as shown in Figure 6.

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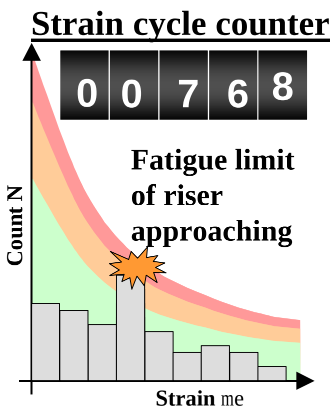

Figure 6 Monitoring

APPLICATIONS

The FOC sensing technology has a wide range of applications in subsea cables. Strain and stress in the cable can be monitored from the point of manufacture to the end of the design life.

Suggested regime would be:

- Testing/Qualifications
  - Monitoring during during mechanical preconditioning
  - During Type Approval Testing (to understand effects of thermal expansion)
  - During laying/trenching trials
- Installation
  - Monitoring during cable laying operation (to make sure specified tensions/sidewall pressures and bending diameters are not exceeded)
  - Before/during ploughing or trenching
  - Before energisation (monitor any signs of external damage, deburial scouring
- Operation
  - Temperature monitoring (to avoid excessive conductor temperatures and premature ageing/thermal failures through cover by high thermal resistivity material)
  - Stress/Strain monitoring to guard against
    - Deburial/scour
    - Vibration excessive movement if exposed (I tubes and channels)
    - Fatigue failure in dynamic sections
    - Signs of external damage by fishing or other activities (subsea subsidence)

CONCLUSION

The concept of dynamic temperature and strain sensing was introduced and equations relating to cable bending and cable extension given. These can be effectively used to interpret stresses and strains experienced by the cable.

The effect of water current on the cable was considered and a representative cable chosen was shown to be susceptible to vortex shedding at lengths of 15m or more. With the recent developments in distributed temperature and strain sensing (DTSS), the standard embedded fibre can be used to monitor and thermal and mechanical problems before an unplanned outage is required.

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