INTEGRATED CONDITION MONITORING FOR SUBSEA POWER CABLE SYSTEMS

Roman SVOMA
PowerSure Technology Ltd. – UK
Roman.Svoma@PowerSureTechnology.com

Colin SMITH
IPEC Ltd. – UK
Colin.Smith@IPEC.co.uk

Chris CONWAY
Bandweaver - UK
Chris.Conway@bandweaver.com

ABSTRACT

Due to the drive for renewable energy, offshore generation schemes are planned and constructed at an increasing rate. Due to the high cost of repairing subsea cables and the onerous installation and operating conditions, monitoring of the cable can be used as an effective asset management tool. By having reliable and continuous asset condition monitoring system, preventative maintenance and condition based maintenance can deliver large savings. Finite element modelling and pre-sanction engineering can be used to establish how effective the monitoring can be and also calibrate the models against actual conditions.

INTRODUCTION

There has been significant growth in the construction of offshore windfarms. The size of the windfarms has also been increasing from several MW in 2000 to permitted schemes of 1GW or more[1]. The full extent of offshore distributed generation assets location may not have been fully appreciated in the late 1990, however drive for higher reliability in order to demonstrate schemes are economically viable has meant greater focus on inter-array and export cable connections as these are usually the critical assets in terms of availability and redundancy. Using appropriate specifications for subsea applications has already been discussed in a previous contribution [2]. This discussion paper argues that due to the asset importance, the onerous nature of the installation and operating conditions and the reduced scope for inspection points and non destructive testing means the additional monitoring systems can provide an effective and efficient way of asset condition monitoring.

SUBSEA CABLE FACTORY TESTING

Subsea cables are manufactured in the longest lengths possible to avoid inserting either factory or field joints into the cable. Even inter-turbine cables can be 2km in length. Land cables would normally be despatched in lengths of 500m and therefore present 5 sampling points in 2 km in comparison to the subsea cables 2. Partial discharge measurements cannot also be effectively carried out to the specified calibration levels due to the pulse attenuation.

INSTALLATION

During installation subsea cables are subjected to high sidewall pressure loads and tensile forces as well as various combinations of forces which may induce fatigue in cable elements. The design of the cable armour package, careful consideration of the installation methodology, simulations and calculations and testing to CIGRE 171/189 suggested guidelines are used to mitigate most of the known risks.

RISKS

Under operating conditions, external factors can effect the cable performance.

Dynamic Cable Movement

Mitigation measures for cable movement can already be designed in, if cables are exposed to waves and currents in water. Bellmouths of I/J tubes are typical examples where cables can be subject to constant motion due to water waves and currents. Historical as well as projected sea states are assessed to calculate whether under certain conditions the loads on the cable are beyond the cable specifications .

Curvature which is the inversion of the bend radius is a suitable variable for specifying an operational window. As different stresses are present in the cable elements at different bending radii, it is logical to quote a Δ Curvature about a static curvature which can take into account the fatigue properties of the materials within the cable construction.

Movement can occur due to the following:

Extreme sea states
When already exposed as at the bellmouth of an I or J tube, the extreme condition can induce movement beyond the maximum parameters in the cable specification.

Sea-bed Mobility
Sea currents can be responsible for moving substantial amounts of seabed. Sand Ripples, waves and scarp can grow, be moved or disappear. Scour is also responsible for de-burying cables.

Third party damagee
Fishing equipment and anchors can also hook the cable, debury it or damage them to the extent an electrical failure occurs.

Thermal Effects

Thermal Runaway
As mentioned above, sea-bed mobility can remove material but material deposits can also increase the depth of cover. Depending on the material, it may be prone to drying out

even below seabed and can thus cause the cable to overheat.

Thermomechanical

Combination of loadcycling and movement either subsea or where on land can cause the onset of partial discharge and failure.

MODELLING

In order to mitigate the effect of external risk, modelling of particular scenarios is common. Models are generated to reflect either historical or projected conditions in the form of differing loadcases are carried out.

Mechanical

The following is an example of predicted movement by a cable emerging from an I tube into a scour pit generated by the movement of seawater around the wind turbine foundations. The 132kV 300sqmm cable is exposed over a much greater length. Figure 1 shows the initial position from side view.

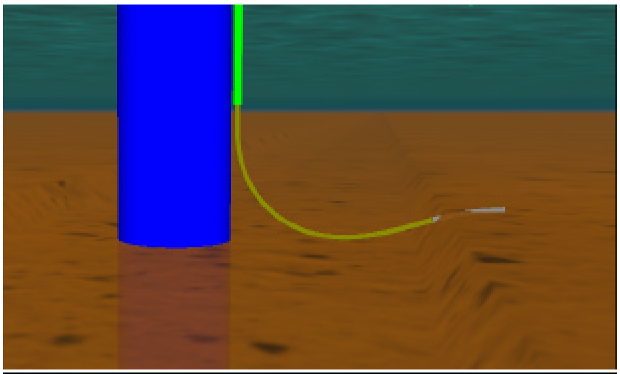

Figure 1 Initial cable position side view

The cable is allowed to settle in a catenary subject to the geometry, gravity and buoyancy experienced.. Figure 2 is the front view of the initial position.

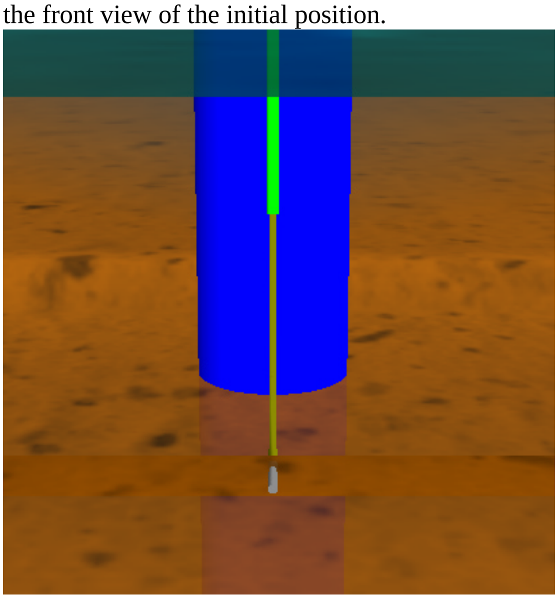

Figure 2 Initial cable position front view

The model is then subjected to 1 year maximum significant waves superimposed on the maximum current at 90degrees to the catenary. Figure 3 shows the resultant deflection and movement experienced by the cable.

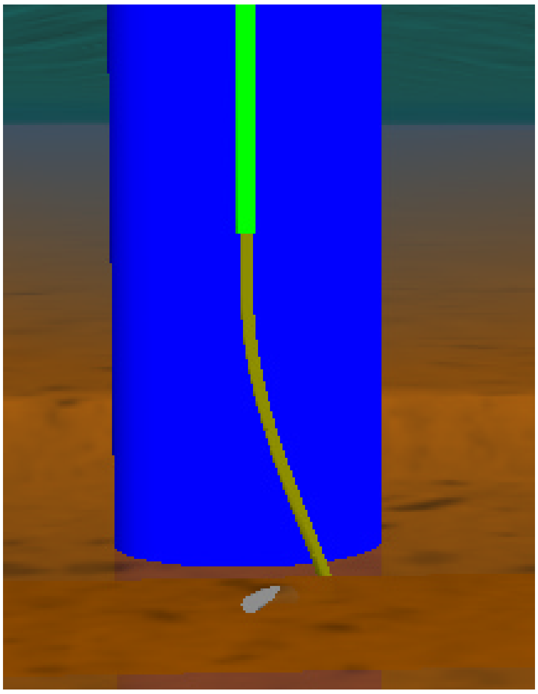

Figure 3 Resultant movement on application of loads

The values relating to the maximum deflection as shown in figure 3 are graphically represented in Figure 4. Majority of problems even during moderate metocean conditions are experienced at exit of the I/J tube. Just clamping the cable does not improve matters as it is the step difference in the stiffness that creates the tight curvature. Figure 4 shows how a bend stiffener /restrictor can be used to contain the deflection below the maximum allowable value.

Thermal

Similar models can be built to simulate cables going through sea defences and gradual increase in burial depth due to seabed mobility.

TEMPERATURE AND STRAIN MONITORING

Majority of export and inter-turbine subsea cables have fibre optic cables embedded in the interstices. These can be utilised for the measurement of temperature and strain [ref Jicable] (due to thrust and compression as well as bending). The DTS/DTSS systems available presently have the following capabilities.

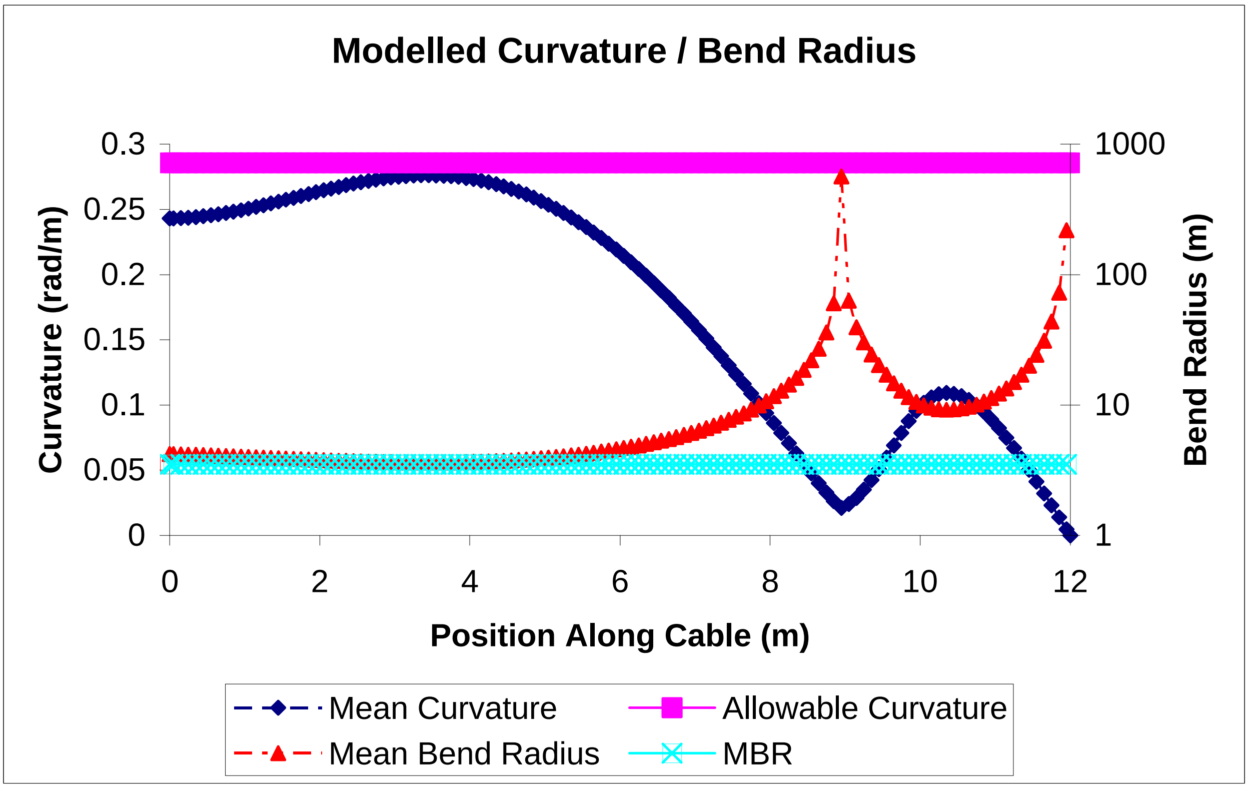

Figure 4 Curvature and Bending Radii corresponding to displacement in Fig 3

DTS technology for distributed temperature sensing tends to be based upon the principle of Raman scattering of light within the fibre optic cable. Such DTS technology is capable of monitoring the temperature, with a temperature resolution of 1 °C, along a fibre of up to 30km in length, within a measurement time of approximately 1 minute. The system determines the temperature for each individual meter of fibre embedded within the power cable and is therefore a very power monitoring device in terms of the quantity and quality of temperature data produced. DTS technology is network scalable and this temperature data can be redirected using appropriate network technology, so that the temperature data from multiple DTS units can be presented to the network operator using an appropriate interface. Presently, the temperature data produced by the DTS may be interfaced to a Dynamic Rating Sytem. A real-time thermal model for each cable zone runs continuously, providing calculated values for the cable conductor temperature. These real-time thermal models provide the input for ratings calculations. These calculations can be initiated by a user request or generated automatically according to a predefined schedule and used to populate system ratings databases.

DTSS instrumentation technology is capable of measuring strain at all points along a single length of optical fibre up to distances compatible with current DTS technology. This DTSS technology tends to be Brillouin based technology. It is important that the solution is able to accurately negate the effects of temperature on the quality of the strain measurement. DTSS is optimised for single-ended measurements, needing access to just one end of the optical fibre. It can be controlled and interrogated remotely. DTSS units can be used to identify any sections of cable that become exposed and alarms can be set to notify asset operators of excessive movement.
System calibration is recommended and this can be achieved at the cable factory during the manufacturing process. Once correlation between signals and DTSS is complete,the system is capable of monitoring stain along the entire elngth of power cable. 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. Strain and stress in the cable can thus be monitored from the point of manufacture to the end of the design life.

PARTIAL DISCHARGE MONITORING

Partial discharge activity is well established as a reliable indication of cable condition giving warning of defects in the cable insulation that may have resulted from its manufacture, installation or damage during its life cycle.

Continuous on-line PD monitoring of subsea power cables can be achieved by fitting high frequency current transformers to the earth return connections on the cable terminations. These active sensors embedded into each node transmit via the fibre optic cables high frequency signals back to a PD monitor located on the off-shore substation. The PD monitor detects, quantifies and stores all PD detected and sends out alarms when pre-set thresholds are exceeded. Export cables and factory joints can similarly be monitored.

Continuous monitoring for partial discharge ensures that the onset of PD activity will be detected regardless of the activity's dependence on environmental or loading conditions.

If activity is detected, PD location techniques can be used to accurately determine the location of the PD source enabling an informed approach to the planning of remedial action. Extensive field use has shown on-line PD location generally locates a PD source or sources with an accuracy within approximately 1% of the cable's length.

CONCLUSION

By significant presanction engineering, the designs and specifications can be used to mitigate the risks arising from connections of offshore assets.

Coupled with Integrated Condition Monitoring consisting of Distributed Temperature Strain Sensing and Partial Discharge monitoring a significant amount of data would be available to assess cable condition, available capacity, ageing, residual life, reliability. Maintenance would thus be better planned and based up the condition and trends. Subsea surveys would be unnecessary to a greater degree as depth of burial would be shown by the thermal trends and a pipe tracker survey would only be required to calibrate the system.

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