Application of distributed sensing technology to the energy industry

F. Ravet, Etienne Rochat, M. Niklès

Omnisens S.A., Riond Bosson 3, Ch-1110 Morges, Switzerland

Asset integrity monitoring based on distributed fiber optic monitoring using BOTDA is playing an increasingly important role in today's oil and gas and energy industries. Existing applications, part of operator's asset integrity management plans are as diverse as fatigue monitoring of subsea umbilicals, thermal optimization of direct electrical heated subsea flowlines, pipeline leak and ground movement detection and 3D pipeline deformation monitoring or thermal management of offshore wind farm electrical export cable. The monitoring solutions developed and qualified by OMNISENS over the last decade are now installed world wild, providing 24/7 event detection and localization for its valuable customers.

Introduction

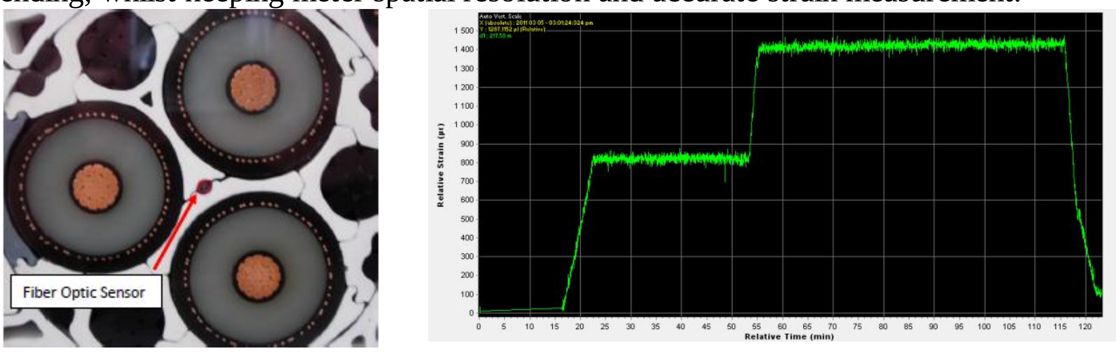
The energy demand is constantly and steadily growing, forcing actors in the field to access resources which are more and more remote or deeper in the sea, or which needs to be transported over longer distances. In particular, the quest for oil goes into deeper water fields, pipelines are crossing continents, including artic areas with frost, swamps and seismic zones, and wind farms are located to greater offshore distance so that their size can be increased easily. In these contexts, the energy transport structures must become more efficient and more reliable, despite challenging environmental conditions. To achieve these goals, the oil and gas and power industries are looking for efficient real-time monitoring solutions, which help guaranteeing the integrity of their structures and, at the same time, provide operational information to optimize them.

Today, fiber optic distributed monitoring is seen as an effective, viable and reliable solution for integrity monitoring (including functionalities such as flow assurance, thermal management, leak detection, ground movement, pipeline deformation, etc.) due to its capacity to localized and pin point different events. This paper presents a few examples of recent monitoring solutions, based on fiber optic distributed sensing and Brillouin optical time domain analysis that OMNISENS has successfully installed worldwide.

Umbilical condition monitoring

The Jack and St. Malo Chevron operated oil fields are located in the Gulf of Mexico about 450km south of New Orleans, Louisiana, by a water depth of around 2100m, and about 40km away from the closest platform. Due to this increased distance and depth, more power is required for subsea equipment, resulting in a power umbilical containing 2 circuits, each featuring three 35 kV power conductors.

In order to reduce the risk of failure, accidents, or downtime as well as to maximize operational efficiency, Chevron made the decision to incorporate a monitoring system that improves construction validation, provides installation certification and feedback, and allows permanent on-line temperature and strain monitoring of this high power, long tieback, power umbilical in deep water. Omnisens eventually developed a dedicated fiber optic strain and temperature sensor cable to be used with its Brillouin Optical Time Domain Analyzer (BOTDA), known as DITEST interrogator, for integration by Aker Solution into the umbilical [1]. The sensing cable was designed to provide fully distributed strain and temperature data and was located in the center of the umbilical, for optimum temperature sensing as well as for accurate dynamic and static tensile monitoring. The resulting cable is a balance of sensitivity and mechanical resistance. The sensor mechanical design was validated by stringent qualification testing prior to integration; in particular, tensile load, crush resistance and pressure resistance were successfully verified. Then, it was integrated into a 500m long umbilical prototype (Figure 1 a). Measurements confirmed the condition of the sensor and thus demonstrated the feasibility of such a manufacturing process together with the quality of its integration. A few sections of the prototype were used for flex fatigue, tensile and dynamic tensile tests. As an example, Figure 1 b) shows the result of a 0.14% elongation test. As can be seen, strain is stable, measured to the expected level and goes back to zero reading upon unloading the umbilical section. During dynamic flex fatigue tests, acquisition speed shorter than 2s were used to measure any possible strain variations due to the cyclic bending, whilst keeping meter spatial resolution and accurate strain measurement.



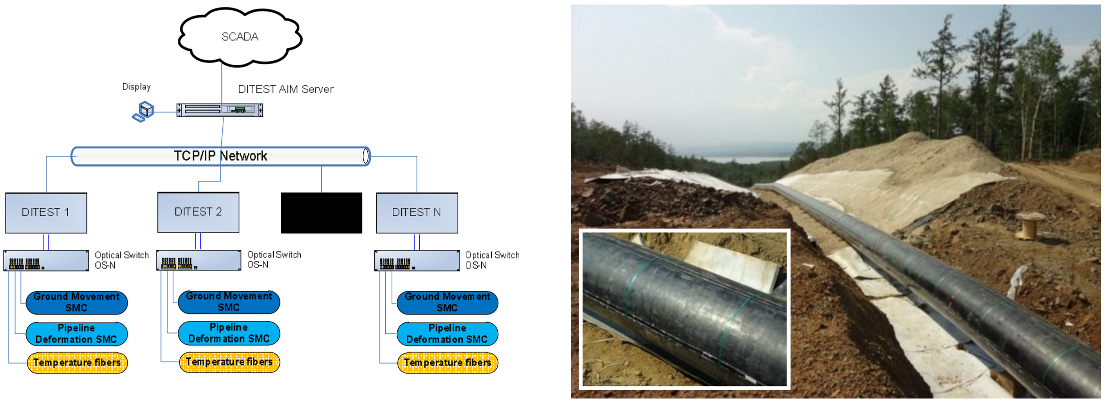
a) b)

Figure 1. a) Sensor integrated in the umbilical center and b) strain measurement during tensile test.

Thus, by taking a systematic approach to the design, integration, and validation of a fiber optic sensing system we succeeded in demonstrating strain and temperature sensing in a large power umbilical.

Pipeline integrity monitoring

The Sakhalin-Khabarovsk-Vladivostok pipeline will enable gas supply to extensive industrial customers in several Far East regions. Its route across Siberia is subject to considerable geohazard, including swamp areas, soil freezing and thawing as seasons change, unstable ground areas due to high seismic activity in Active Tectonic Faults (ATF) zones. Due to the pipeline length (1800km), distributed sensing became an obvious solution. Thus Omnisens proposed its Distributed Temperature and Strain Asset Integrity Monitoring (DITEST AIM) consisting of central server that collects measurements generated by the DITEST interrogators located along the pipeline route and processes them against pre-set alarms algorithms so that alarms are triggered when anomalous behaviours are detected [2] (Figure 2 a).



a) b)

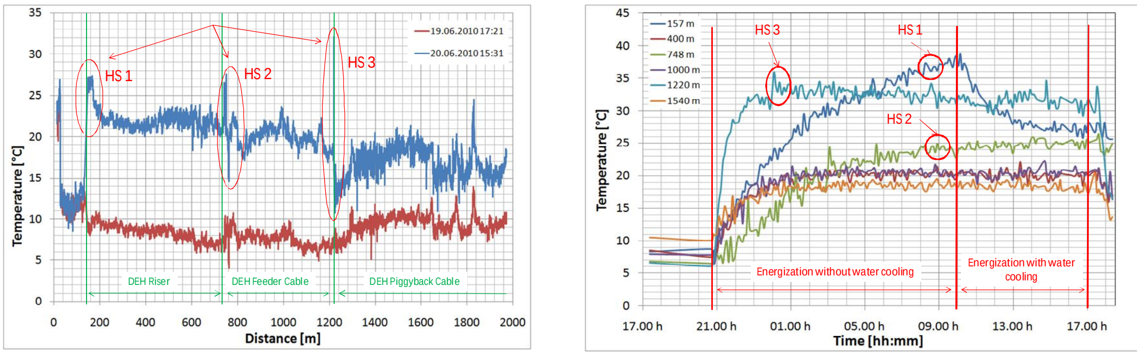
Figure 2. a) Monitoring architecture featuring multiple DITEST interrogator and TCPIP communication to a central AIM server for event monitoring and alarming and b) trench featuring a section of pipeline instrumented with 3 strain sensors for 3D deformation with close view (inset).

Ground movements are submitting the trunk pipeline to large strain, which may result in buckling [3]. In fact, as the pipeline is stiffer than the soil, it resists the impact of ground movement up to a certain threshold value. Thus, by measuring ground displacement, once obtains an early warning signal for potential threats to the pipeline integrity. In addition, for highly critical zones, pipeline deformation (3D pipe positioning) is measured by using three strain sensors attached to the tube whilst possible leaks are detected by a temperature sensor located on top of the pipeline [4][5] (Figure 2 b).

Altogether, strain sensors were deployed over a total of 26km of the pipe itself, using a specifically designed installation machine, in order to measure its 3D deformation, whilst more than 90km of ground movement sensors were buried to monitor no less than 32 ATF zones. Note that the strain sensor as well as the ground movement sensors where specifically designed to fulfilled the stringent monitoring conditions of this Siberian pipeline routes. As for umbilical monitoring, mastering the sensor design and its integration is the key to a successful project.

Subsea Pipeline flow assurance

To prevent hydrates and waxes formation within subsea flowline during shutdowns or to maintain fluid temperature above a certain critical levels during operation in case on long tie-backs, the oil industry has been using electrically heated flowlines as an alternative to chemical hydrates inhibitors. Direct Electrical Heating (DEH) is one of the approach currently used by Statoil. DEH cables are attached to the pipeline and flew large AC currents through the tube, resulting in the desired heating process [6]. Since the first installation in 2000, DEH has been selected as flow assurance tool for 17 pipelines operated by Statoil in the North Sea. For the system to be effective, any cable failure (hotspot or break) must be quickly detected so that power source can be disconnected, thus preventing damages. In addition, temperature data also participate to the optimization of the flowline operation.



a) b)

Figure 3. a) Temperature measured before (red) and during DEH Cable System Energization. Three hot spots (HS) are identified, and b) Temperature evolutions of the three HS and neighboring points before and during DEH energization.

Two such DEH pipelines in the North Sea, of 23km and 43km long respectively, have been instrumented over their complete length using OMNISENS DITEST AIM monitoring solution. Optical fibers were added to the electrical power cable and used for temperature measurement. The power cable itself was installed as a piggy-bag on top of the flowline.

Several energization tests, lasting from a few hours up to 20 hours, have been conducted in 2009 and 2010 whilst monitoring temperature. During the test, the DEH System carried an electrical current of 1,438A, dissipating a power of 9.43 MW. Figure 3 a) shows the temperature evolution along a short section of the pipe; clear temperature increase can be seen when power is on. In addition, three hotspots (HS) are identified, corresponding to specific point on the power cable. Figure 3 b) displays the temporal variation of the hot spots and neighboring points along these two kilometers. The thermal behaviors are extremely different, with HS1 never reaching stable condition. To prevent damages in this unexpected location, water cooling was used, reducing the temperature as can be seen in the second half of the curve.

Distributed monitoring, apart from helping in optimizing the pipeline operation, also clearly identified potentially dangerous thermal response in some unexpected location, resulting in some preventive actions.

Power cable condition monitoring

Walney 1 and 2 offshore wind farms in the Irish Sea are connected to mainland by two HVDC cables supplied by Prysmian Cables and Systems. The cables are 48 km and 49 km long respectively and made of three cores for a voltage of 132kV and power capacity of 370MW. They are mostly buried below the seabed but also cross some extremely hard soil. As the area is subject to seabed migration, the cables may be surrounded by cooling water one day and covered with several meters of mud the next, resulting in a dramatic temperature increase under the same load. In addition, the load varies as a function of wind, thus participating to the temperature variations and the risk of the cable being damaged by fishing and shipping activities is also significant. It is only by monitoring the entire cable length than such changes in the cable's environment and condition can be managed. The Omnisens DITEST-LTM (long term temperature monitoring) solution was installed to monitor cost effectively and with accurate temperature information, both cables along their entire length. No instrumentation is located offshore.

Future challenges and developments

The quest for more energy has never been more important, resulting in even longer distances than what has been presented here and achieved so far in the field. As such, today's standard measurement range of up to 65 km will soon be too short. Distances much greater than 100km are now the target using optical amplifiers and signal repeaters, whilst keeping a spatial resolution of the order of 3m to 5m.

Conclusion

Distributed sensing of large oil and gas and power energy industry structures using BOTDA together with dedicated monitoring software for event detection, identification of abnormal trends and alarming is now proven to be an efficient and reliable method through various industrial projects. It allows the operator not only to maintain their structure integrity through an efficient condition monitoring, but also to optimize their asset performance in view of minimizing operational costs whilst keeping capacity to its highest level over an extended period of time.

OMNISENS has successfully deployed its technology in various Energy related projects, ranging from condition monitoring and fatigue monitoring of subsea umbilicals to electrical monitoring of offshore wind farms export cables, and including pipeline deformation and ground movement monitoring and subsea flowline temperature monitoring. In most cases, new solutions were developed in terms of fiber optic cable designs and integration methods and monitoring algorithms to perform real-time condition and performance monitoring.

Acknowledgment

They authors are thankful to Carlos Borda, Dana Dutoit and Fabien Briffod, all with Omnisens SA, for their respective contribution to the projects described in this paper. In addition, the authors would like to thank Aker Solution, Laser solution, North European Gas Pipeline Project Company, Peru LNG, TGP, Statoil and Nexans, with which we collaborated for these projects

References

[1] Dutoit, D., Niklès, N., Rochat, E., Willemoes, P. and Little, H., “Distributed strain and temperature sensor for subsea umbilical,“ ISOPE, Paper 2012-TPC-0985 (2012).

[2] Borda, C., Niklès, N., Rochat, E., Grechanov, A., Naumov, A., Velikodnev, V., “Continuous realt-time pipeline deformation, 3D positioning and ground movement monitoring along the Sakhalin-Khabarovsk-Vladivostok pipeline,” International Pipeline Conference, IPC-90476 (2012).

[3] Palmer, A. C., and Williams, P. J. “Frost heave and pipeline upheaval buckling”, Can. Geotech. J., Vol. 40, pp. 1033–1038, (2003).

[4] Ravet, F., Ortiz, E.G., Peterson, B., Hoglund, G. and Niklès, M. (2011). “Geohazard prevention with online continuous fiber optic monitoring.” Proc. of the Rio Pipeline Conference and Exposition, Rio de Janeiro, Brazil, Paper IBP1277_11 (2011).

[5] Ravet, F., Briffod, F., Niklès, M. “Extended distance fiber optic monitoring for pipeline Leak and ground movement detection.” International Pipeline Conference 2008, Calgary, paper IPC2008-64521, (2008).

[6] A.Nysveen, H.Kulbotten, J.Lervik, A.Børnes, M.Høyer-Hansen, J.Bremnes, “Direct electrical heating of subsea pipelines - technology development and operating experience”, IEEE Transactions on Industry Applications 43, 1, 118-129, 2007.

[7] Ravet, F., Børnes, A., Borda, C., Tjåland, E., Hilde, H. and Niklès, M., “DEH cable system preventive protection with distributed temperature and strain sensors,” International Pipeline Conference, IPC-90274 (2012).