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SUBSEA TO SHORE – CHALLENGES AND SOLUTIONS FOR SUBSEA CONNECTIONS

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Abstract - Portuguese

Este ensaio revisa projetos que extendem os limites da tecnologia de tie-back, e os sistemas de potência e fibra ótica que os apoiam. Ao revisar configurações de tie-back com inovações em transmissão de potência e comunicação imunes à interferências, este ensaio demonstrará que conectores de potência e sistemas de conexão de fibra ótica existem para apoiar step-outs longos ou até mesmo tie-backs do fundo do mar até à margem. Este ensaio inclui a revisão de um método inovador que foi desenvolvido para observatórios oceanográficos, utilizando cabeamento de potência direto que tem potencial para distâncias acima de 500 km.

Sistemas de conexão de potência confiáveis são essenciais às instalações e futuras expansões em águas profundas e desenvolvimentos de step-out longos. Sistemas de alta voltagem minimizam perdas na transmissão, enquanto que a disponibilidade de potência é necessária para assegurar fluxo em aquecimento de dutos, bombas submersas e sistemas de processamento subsea. Adicionalmente, conforme as distâncias e requerimentos de banda aumentam, comunicação baseada em fibra óptica imune à interferências torna-se o meio preferido.

Metodologia de qualificação é essencial para se estabelecer confiabilidade do design de vida útil dos conectores. Este ensaio revisa os métodos de qualificação existentes para conectores de potência AC e potência DC. Este ensaio também inclui discussão sobre a confiabilidade de sistemas ópticos, baseado em 9 anos de instalações subsea.

Abstract - English

This paper reviews recent projects that push the limits of tie-back technology, and the high power and fiber-optic communication systems that support them. By reviewing tie-back configurations with innovations in power transmission and noise immune communications, this paper will show that reliable wet-mate high power and fiber-optic connection systems are available to support very long step-outs or even tie-backs from subsea to shore. The paper includes the review of an innovative approach that has been developed for oceanographic observatories, utilizing high voltage direct current cabling, which has the potential for offset of over 500 km.

Reliable wet-mate power connection systems are critical to the installation and future expansion of deepwater and long step-out developments. High voltage systems minimize transmission power loss, while power availability is needed for flow assurance for pipeline heating, ESP's and subsea process systems. Also, as distances increase and bandwidth requirements grow, noise immune fiber-optic based communication is becoming the preferred medium.

Qualification methodology is critical to establish reliability over the design life of wet-mate connectors. This paper reviews the qualification methods and existing industry specifications for high voltage AC and high voltage DC connectors. This paper also includes optical connection system reliability based on nine years of subsea installations.

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1. Introduction

The economics of oil & gas production is driving the industry to look at ever longer tie-back to either existing facility (where available with capacity) or directly to shore. Two recent programs are good examples of the latter case. Statoil are in the latter stages of developing the 1st phase of the Snøhvit development. Further detail of this project can be found at http://www.statoil.com/statoilcom/snohvit/svg02699.nsf?OpenDatabase&lang=en. This is a gas field 145 km north of the north coast of Norway in 350m water depth in the Barents Sea, and is a direct tie back to shore. Here the power requirement is not great, but the performance and installation of Integrated Service Umbilical (ISU) required a balance between system voltage, power loss and copper cross section. This eventually led to a decision to build the ISU for 3,000 VAC performance and to develop and qualify a new, connection system based on ROV operable wet-mate connectors and Pressure Balanced Oil Filled (PBOF) jumper assemblies.

Also in Norwegian waters, Norsk Hydro are moving forward with the Ormen Lange development. Again this is a giant gas field, and again this is a direct tie back to shore, but here the technology challenges are greater with water depths between 800 & 1100m, with a 125 km controls umbilical and gas production tie back to shore at Nyhamna. Conditions at the wellhead are also extreme, with subsea temperatures down to -1ºC. Further detail of this project can be found at http://www.hydro.com/ormenlange/en/.

An innovative approach to long step outs has been developed for oceanographic permanent subsea observatories such as MARS and NEPTUNE located off the western coast of North America. These systems utilize standard telecommunication fiber optic cable with a single high voltage (10 KVDC) conductor element. Figure 1 is the typical cross section of a telecommunication cable used in deep water applications.

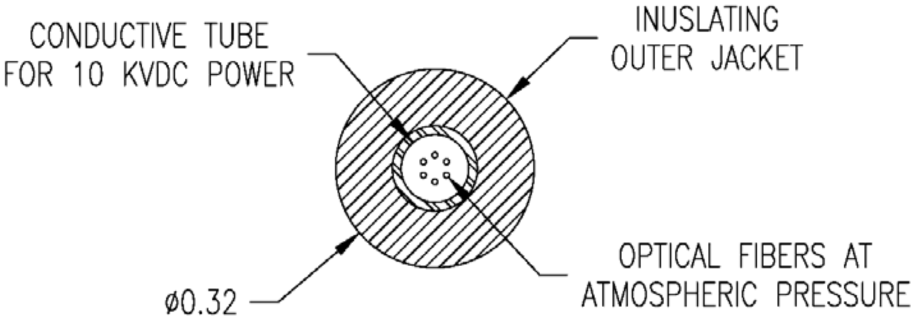

Figure 1. Typical Cross Section of Long Haul Telecommunication Cable

Using NEPTUNE as an example, 800 kilometers of trunk cable is laid in a ring with two shore locations; branching units to science nodes that connect to retrievable experiments are place along the trunk cable. Figure 2 shows the telecommunication branch cable entering the node base and the individual science ports on the science node. Communication is handled by the optical modems located top side and on the sea floor. Power for the subsea node is provided by DC/DC step down converter. The cable power can also be used to power repeaters that have been developed for telecommunication applications to span oceans. The optical signal and high voltage DC power are connected to the node by wet-mate connections. The node provides 100 BASE T Ethernet communication and low voltage DC power to the individual science experiments through standard Nautilus wet-mate connectors. For further details on these systems and technical solutions see www.neptunecanada.ca, www.mbari.org/mars/, Barlow et al. and Shaheen et al.

Reliable wet-mate connectors are essential components for the systems described above.

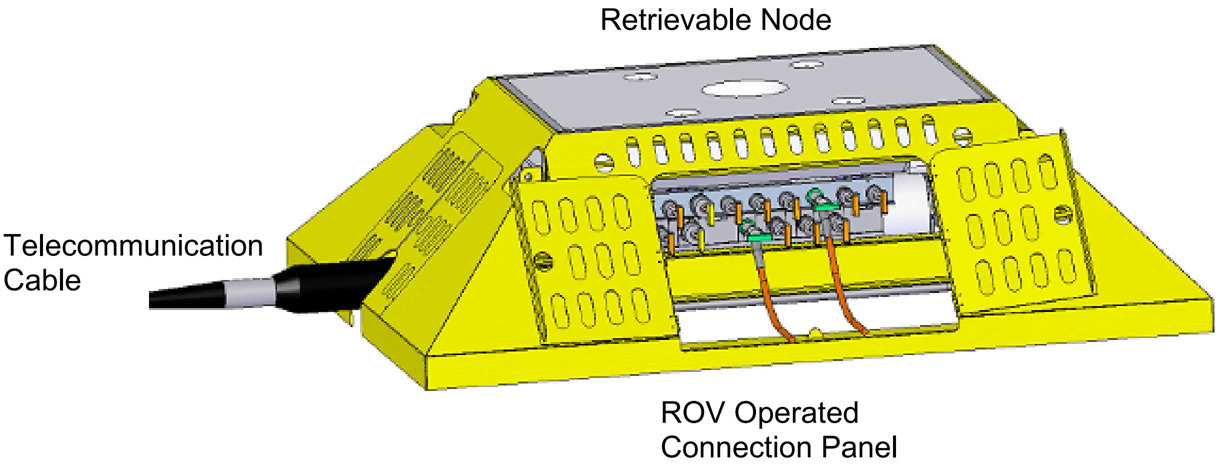

Figure 2. Permanent Subsea Observatory Node Base and Retrievable Node

2. Development of High Bandwidth Noise Immune Wet-Mate Fiber-Optic Connectors

Optical communication has been in use subsea since 1985, with the first fiber-optic transatlantic telecommunication cable being laid in 1988. Since then, enough fiber has been laid subsea to reach to the moon and back twice.

In 1994, the offshore oil industry kickedoff a program to develop all of the technology necessary to the installation and operation of a 100km unrepeated optical communications link. This link had to support communication for at least one subsea control system and provide topside access for optical communication. This development was driven initially by the need to support the future installation of subsea high-power multiphase pump systems. It had been identified that the 2 to 5 MW motors used to drive these pumps were generating an unacceptable level of interference to electrical communication. This 100km fiber-optic link development program identified that one critical technology gap was a high-performance, multi-circuit, wet-mate optical connector needed to permit the modular installation of equipment subsea.

The industry development program, in conjunction with R&D (already being undertaken by ODI), resulted in the development of the Wet-Mate Hybrid Connector, which uses telecommunications grade connections providing face-to-face contact between each pair of mated fibers in a pressure- balanced, benign, silt-free environment, Figure 3. The connector first saw commercial installation in the Southern North Sea in January of 1997. Since then, more than 2000 hybrid and optical wet-mate connectors have been delivered. They have proven to be an enabling and critical component on many of the most advanced production systems that have been tested or installed subsea since 1997. They are currently in operation at depths down to 20,000 ft.

Figure 2. 8-Circuit ROV Operated Rolling Seal Optical Connector

2.1. Reliability

Currently there are over 2,600 serialized optical assemblies in service with over 16,300,000 cumulative hours of service time. There have been few failures which can be directly attributed to the connectors themselves. In compiling the failure data, we have not seen a trend that would indicate either connector gender is more susceptible to failure if operated within the specified operating conditions. In order to assign a meaningful value to the connector's reliability, we conservatively set the number of failures to 5. Assuming the connectors fail at a constant rate and given the field data, the "mean time between failure" (MTBF) has been calculated as follows:

$$\text{MTBF} = \frac{\text{Cumulative Service Time}}{\text{Total Number of Failures}}$$

$$\geq \frac{16{,}300{,}000 \text{ Hours}}{5}$$

$$\geq 3{,}260{,}000 \text{ Hours } (\geq 386 \text{ Years})$$

3. Development of High Voltage AC Wet-Mate Connectors

For the last four years, Ocean Design, Inc (ODI) has been developing a new, increased reliability electrical power connector, the Nautilus HP. The product includes all of the design features of proven subsea wet-mate electrical connectors, while designing, testing and implementing the electrical terminations and performance to the challenging requirements of the IEC 60502-2 specification, “Power Cables and Their Accessories for Rated Voltages up to 30KV” and Statoil specification RA-SNO-00183. The first connector available from this development was a four-circuit connector, qualified for 6.2 KVAC (phase to phase) operation at up to 20A. This has since been re-qualified for an application to 8.6 KVAC (phase to phase) and 5KVAC (phase to ground) at 200A per circuit, and is available in diver, ROV and stab-plate configurations. Table 1 and 2 are summaries of the qualification testing that conducted in accordance with the specification listed above.

Table 1. Nautilus HP Mechanical Qualification Summary

	Test Description	Test Requirement
Mechanical	Thermal Cycling in air	-40° to 60°C
	Shock Vibration	3 X 11 ms 30g Horizontal and Vertical 25 Hz to 150 Hz 5g Acceleration
	Mate / Demate Force Cold Turbid	≤ 100 lbs Mate/Demate Turbid
	Misalignment	Radial: 0.65 Rotational: 10° Tilt: 2.5°
	Drop Test	2 meter

Table 2. Nautilus HP AC Electrical and Hydrostatic Qualification Summary

	Test Description	Test Requirement
Electrical	Rated Current in Air	200 amps
	Contact Resistance	$\leq$ 2.5 mOhms
	Insulation Resistance	$\geq$ 10 Gohms @ 5000 VDC
	Power Frequency Withstand	20.0 KV for 4 Hours
	Partial Discharge	8.6 KV $\leq$10 pC
	Rapid Ramp Breakdown	Average = 49KV
	High Voltage Impulse	75 KV
	Thermal Short Circuit	5000 amp for 0.16 sec
Hydrostatic	Thermal Cycling with applied Voltage and Current	30 Cycles 20.0 KV AC 200 amps
	Long Term Flooded backend[1]	1000 hrs
	Turbid Mate/Demate at pressure	100 Mate/Demate Cycles

The Nautilus HP connectors successfully complete all of the testing above and the product has been installed on the Snohvit project.

4. Development of High Voltage DC Wet-Mate

The ODI qualification test program was designed to qualify the same Nautilus HP wet mate connector described above for operation with high voltage DC systems. The methodology used was to test to failure samples at different voltage levels to determine life exponent “n” in equation 1.

$$t_{test} (V_{test})^n = t_{service} (V_{service})^n = k \qquad \textbf{(1)}$$

Where t = time
V = DC Voltage
k = Constant

The qualification uses the statistical models utilized by the subsea telecommunication industry to characterize the Nautilus HP connector’s ability to withstand the aging affects of high voltage DC operation.

A total of ten connector samples were utilized for the three tests conducted during this qualification. The experimental data was evaluated and applied to the statistical aging model. The qualification evaluated the Nautilus HP connector at the following three different aging rates:

Rapid ramp to failure at 97 KVDC
Medium term testing for 30 hours at 50 KVDC
Long term testing for 2 weeks at 37 KVDC

The aging characteristics demonstrated during this qualification closely agreed with the expected outcome generated by the statistical aging model with a R^2 of 0.9862 correlation. Extending the model's time vs. voltage line to a 25-year service life predicts a survival probability for a single channel of 0.922 at 10 KVDC. This low value for probability is attributable to the low sample size, 10 sets of connectors, for the initial qualification. Additional testing to increase the sample sizes is currently planned.

5. Conclusion

As ever longer tieback and higher voltage systems are deployed subsea, reliable high voltage electrical connector and optical connector are critical to operation. Fiber optic connectors have a proven track record of operation over the past 9 years. High voltage AC and DC qualification methodologies have also been established and connectors have been successfully qualified to these standards.

6. References

N.Shaheen, and G. Waterworth, “ROV Serviceable Science Node for Cabled Ocean Observatories,” Oceans Exhibition, 2005.

S Barlow, J Flynn, W Mudge, G Waterworth and N Shaheen, “The Evolution of ROV Wet-Mate Connecter Technology in Supplying High Bandwidth / High Power / Deep Water Solutions for the Scientific Ocean Observatory Market” SSC’06, Scientific Use of Submarine Cables.

Dr. J. Cairns, “Hybrid Wet-Mate Connectors: Writing the Next Chapter,” Sea Technology Magazine, July 1997.

IEC 60502-2 specification, “Power Cables and Their Accessories for Rated Voltages up to 30KV