Power and optical communications for long tie-backs

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Abstract

Large volume neutrino telescopes require real time communications back to shore and a sizeable amount of power at the bottom to feed the detectors and the associated electronics. The telecommunications industry has developed a family of cabled products that have been cost optimized over the years. These submarine cables using optical fibres and a single copper conductor are ideal to achieve the transport of signal and energy. Sea return is required but the overall solution is far less expensive than using a bespoke multi-conductor umbilical design.

The quality of neutrino detection may require photo-multipliers to be located in a relatively deep area to limit ambient light noise. This may dictate the choice of the location, which may be tens of kilometres away from the land-based station. If this distance is relatively short then high voltage AC powering can be envisaged. Yet the cable capacitance might become an issue for distances beyond 50 km where the amount of power lost in the cable may become too important. Alcatel-Lucent is developing a 10 kV DC solution based on the advent of a new device converting the 10 kV DC into a more usable 350 or 400 V DC user voltage.

Alcatel-Lucent believes that a 10 kV DC solution using Medium Voltage Converters can efficiently bring power to areas located up to 600 km from the shore. In this case, repeaters are used to amplify the light signal along the way. Alcatel-Lucent has qualified repeaters able to sustain a permanent line current of up to 8 A.

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1. Introduction

The field proven submarine cable solutions for the international telecommunication networks are characterized by: high capacity optical fibre transmission (hundreds of Gbit/s), DC power transmission (tens of kW), and high quality, highly redundant configurations for fault free operation over 25 years. Figures 1 and 2 illustrate the components and configurations of some typical systems.

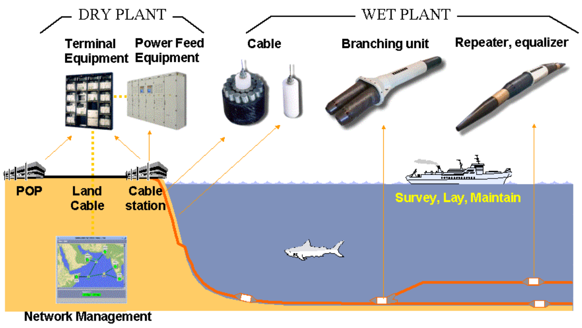

Fig. 1: Repeated system schematic showing Wet and Dry plant

This technology can be enhanced for the Scientific and Oil and Gas environment to achieve offshore and subsea connectivity.

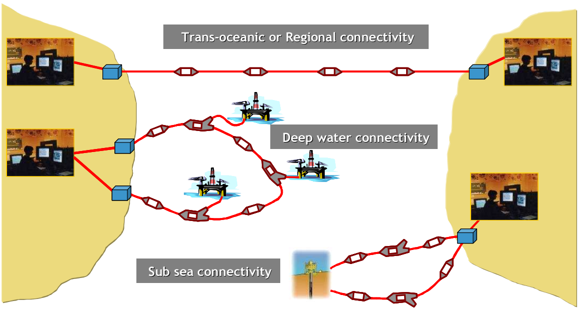

Fig. 2: Major applications

2. The offshore requirements

Scientific and undersea neutrino telescope applications need to deal with hard to reach offshore sites, located in deep waters. From a communication standpoint, the deep-water environment can be best characterized by extended reach, well over 100km between any two points, sometimes in excess of 500km away from shore.

The solutions proposed are all based on the use of a single conductor standard communication submarine cable. When used in conjunction with a subsea DC/DC converter and a sea return mechanism, a sizeable amount of power can be distributed locally on the remote subsea field. Supply at 10kV is used to minimize the current in the cable and reduce the transport losses to a minimum. Delay-free broadband communications are also provided locally using the optical fibres of the submarine cable.

In this new subsea cable network principle (Fig. 3) offering Ethernet and DC power distribution, the aggregated data flow is typically in a range of 100 Mbit/s to shore. The DC/FO cable solution is independent from any umbilical solution and a "1+1" redundant configuration is recommended. This solution provides open data communication interfaces for easier integration with subsea control system equipment.

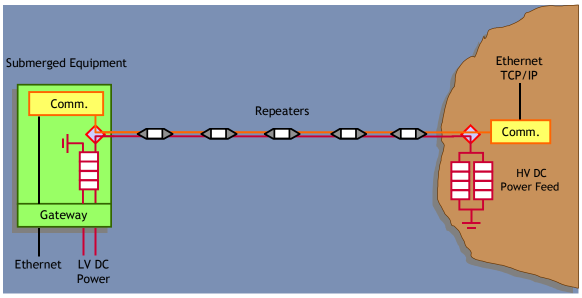

Fig. 3: Subsea network principle

The new real time processes that may be managed over these new networks will put a premium on availability. The proven technology and fault tolerant duplicated systems can enable a quality of service towards 99.99% availability.

3. The dry-wet solutions

3.1. Solution overview

This single conductor submarine cable technology is offered to connect subsea scientific applications with a step-out from land direct to a subsea site of interest. In the Oil and Gas industry AC and fiber optic communications is being used on the Snovit 145km step-out in Norway. However at these distances AC transmission is becoming inefficient, as the capacitance of the cables induces significant loss in the power transport (Fig. 4).

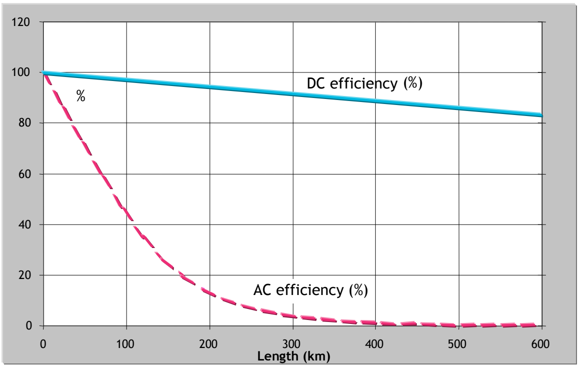

Fig. 4: DC vs. AC transport efficiency

Standard repeatered submarine cable systems have proven DC powering for much longer systems up to 12,000km, and of course can offer communications for equally long distances. As the capability of subsea telecomm cables is studied for this application, a number of their networking features become attractive:

- Branching units that can distribute power and communications from a single cable to several interfaces within a field. This introduces the possibility of conserving risers by using a single cable for the control of a number of fields;
- Duplicate cables that can provide hot standby capability, ensuring high availability, ~ 99.99%, whilst still each supporting multiple nodes;
- Connectivity that could be provided for additional subsea nodes on a permanent or temporary basis by provisioning extra fibres and underwater terminations.

3.2. Interfaces

The key to rapid progress and successful simple system integration is to develop open interface standards, where possible based on existing terrestrial standards and practices.

For communications it is proposed to adopt the widely used Ethernet standards. The most suitable initial choice appears to be 100Mbit/s. This offers high capacity that will provide substantial margin for future needs and good availability of high reliability components for practical modem and router implementations. This communications interface will be offered both subsea and topside. Other options are available if more bandwidth is required, for example at the GbE (Gigabit Ethernet) and 10GbE levels.

Similarly, for subsea power, the provision of a 400V DC supply allows a good balance between efficient power distribution and selection from the wide availability of components to be used within the control system. Furthermore, provision of power levels up to 10kW will enable a range of valve control systems to operate, including direct valve drive.

Additionally a subsea mechanical ‘interface’ is required. Wet-mate connectors may be used for the communications and power; the termination assembly will be a ‘lighter’ version of existing umbilical termination assemblies.

3.3. Qualified products

The submarine cable industry has developed a portfolio of field-proven, qualified products in more than 20 years of experience in optical fibre cable systems.

3.3.1. Cable

The cable is the standard cable used in repeatered telecommunications applications. The industry benchmark is a 17 mm diameter deep-sea cable. The deep-sea cable is built around a stainless steel tube, a pressure-resistant wire ‘vault’, a copper tube swaged onto it and a polyethylene wall. Figures 5-8 show the build-up of the cable structure.

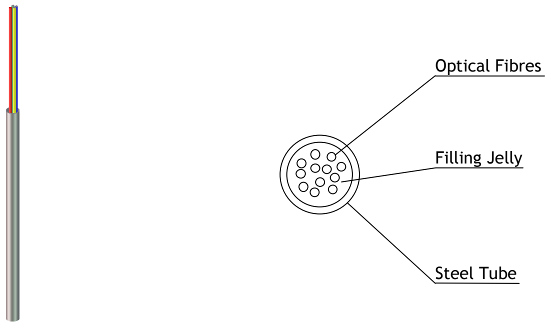

Fig. 5: Steel tube and fibres.

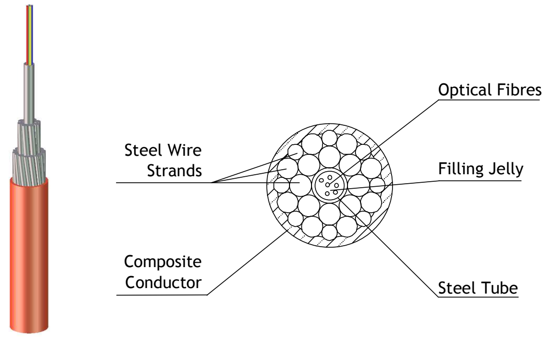

Fig. 6: Steel tube, vault and copper tube

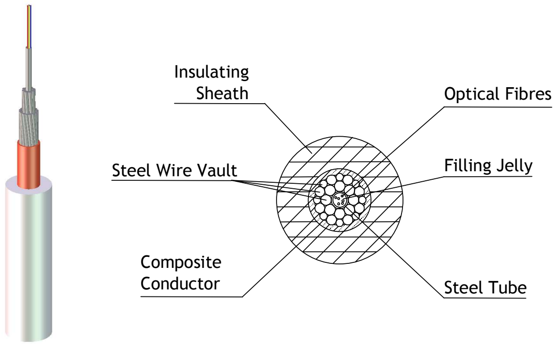

Fig. 7: Deep sea cable ("Light Weight", or LW)

This "Light-Weight" (LW) cable can be further protected with different types of armoured packages; Light Weight Protected (LWP), Single Armour (SA) and Double Armour (DA).

The fibres comply to the G.655 ITU recommendation. Their attenuation is specified to a precision of thousandths of dB/km with upper and lower boundaries (e.g. 0.208dB/km +/- 0.002dB/km).

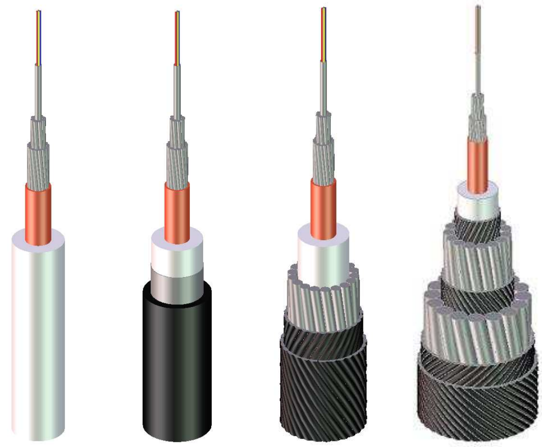

Fig. 8: LW, LWP, SA, DA cable types

The fibres are submarine-specific and are procured with a 1.8% screen test in order to guarantee excellent cable mechanical and optical characteristics. Fibre ageing is also a guaranteed parameter at 0.005dB/km over the 25 year life time of the system.

The cable electrical insulation is qualified to sustain a 12kV operational voltage for 25 years, and is compatible with the use of electroding fault detection methods.

Composite conductor resistance at 10°C	<1.0 or 1.6 Ω/km
DC. resistance temperature coefficient	4.10-3/°C
Insulation between composite conductor and water	105 MΩ.km
Dielectric strength between composite conductor and water	> 45kV DC for 5 min
Nominal capacitance in sea water	0.18 µF/km

Table 1: Cable electrical characteristics

3.3.2. Repeaters

The repeater (Fig. 9) provides amplification of two way optical digital transmission signals in the erbium amplification window around 1550 nm. It is also designed for a 25-year lifetime. The repeater is modular in construction and can be equipped for use with cables having from one to eight fibre pairs. The repeater performances such as output power level, amplifier gain, number of WDM (wavelength division multiplexed) channels and optical bandwidth are project dependent. The repeater employs invisible laser radiation and is designed in accordance with IEC-60825-1 & IEC-60825-2 specifications.

Repeaters are powered in series from the terminal station at a constant current of either polarity, and are provided with surge protection measures to prevent the internal circuits being damaged by the large transients that may occur along a cable. Standard current values are normally around 1A but repeaters have been qualified to work with both lower and higher current values up to 8A.

The internal atmosphere is controlled, the housing is sealed and the thermal behaviour of the repeater is managed through design.

There is a supervisory system embedded in the repeaters. The purpose of the supervisory system is to permit monitoring of the performance of the repeater. Transmission faults on a single fibre are readily located by using the facilities of a supervisory system. There is signaling to the repeater (in or out of traffic) and signaling from the repeater. Supervisory responses are sent to both ends of the system on all wavelengths.

A repeater is an extremely reliable piece of equipment with an MTBF of 10,000 years.

Fig. 9: Repeater picture

3.3.3. Branching Units

Branching units (BUs; Fig. 10) provide for capacity (add and drop capability) allowing the creation of derivations (spurs) from the main backbone line (trunk). Capacity drop can be partial, where only a few wavelengths can be dropped for each branch, or total - with a whole fibre pair diverted to the branch. Different optical filtering methods are available in the case of the partial drop (also called Optical Add/Drop Multiplexing or OADM) allowing adjustment of the amount of capacity that is required for each branch. The branching unit may house some optical amplifiers to extend the spur length and avoid the need for a repeater in the spur.

The branching units benefit from an optically commanded power switching capability. The BU electrical state is therefore stable, in any of only four possible configurations (below) and only an optical command can modify its electrical state. The standard configuration in such a Dry-Wet application would be to have all three BU legs: A, B and C connected together. The other three states, used for operation and maintenance purposes, consist of having one leg (A, B or C) locally grounded at the BU while the two others are connected together. In particular, any trunk section in between two BUs can be isolated. The most attractive characteristics of the optically power-switched BU are practicality (remote control) and safety.

Fig. 10: Branching Unit (BU) picture

3.4. New enabling elements

Alcatel-Lucent was awarded the NEPTUNE Canada contract, where six undersea nodes are being designed and qualified to be installed in the North East Pacific off Vancouver Island (Fig. 11).

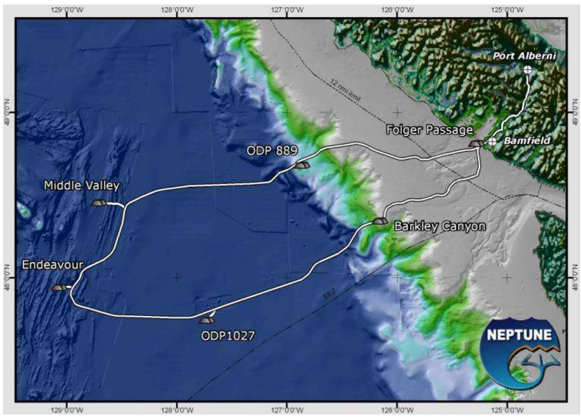

Fig. 11: NEPTUNE Canada layout

This 850km system demonstrates many of these new system capabilities and shows that long distance, networked communications and power step outs are feasible. The science nodes are gateways where the oceanographers will plug their science instruments using ROV (**R**emote-**O**perated submarine **V**ehicle) plugged wet-mate connectors (Fig. 12). Each science node is able to provide 400V DC with up to 25A of power and an optical GbE connection. Each node is composed of a Trawl Resistant Frame (TRF) where the ROV-serviceable node module (Fig.13) can be secured.

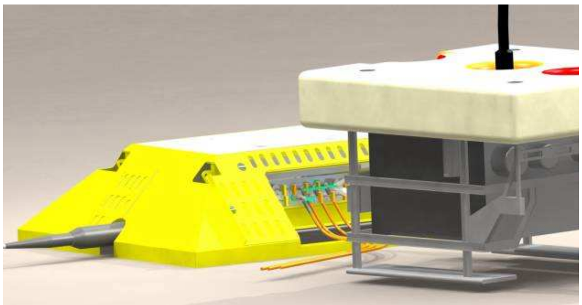

Fig. 12: NEPTUNE Node arrangement

The node module itself is a mechanical arrangement of two main pressure vessels, made almost neutrally buoyant with syntactic foam. The work class ROVs currently found on oceanographic vessels used by the scientists can handle the node module.

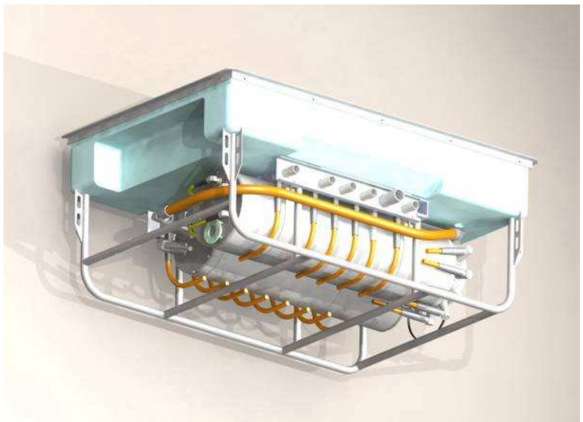

Fig. 13: NEPTUNE Node Module

The two pressure vessels are the Low Voltage/Comms (LV/Comms; Fig. 14)) and the Medium Voltage Converter (MVC; Fig. 15) units.

The LV/Comms pressure vessel houses the communication gear, handling both the repeatered WDM uplinks back to shore (with redundant East and West paths) and the GbE downlinks to the science instruments. Duplicated Ethernet switches are used in the module. The other main element of the LV/Comms unit is the low voltage control unit that performs the distribution of the low voltage signals (400V and under) to the science ports and to the internal loads.

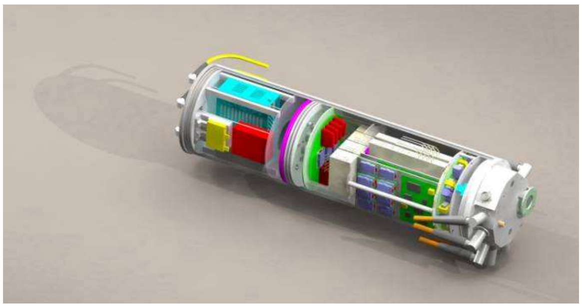

Fig. 14: LV/Comms pressure vessel

The other pressure vessel houses the MVC that steps down the 10kV DC required for low loss transport to a more useable 400V DC. Each converter is able to deliver up to 25A of current at full load on the secondary voltage side. The power converter is based on a design developed for spacecraft and is made up from a number of lower power sub-converters. These are arranged in a series-parallel configuration to share the load and provide redundancy. The entire power converter is housed in a pressure vessel containing a dielectric fluid.

Fig. 15: MVC pressure vessel

While it is very likely that an Oil and Gas application of this Dry-Wet concept may result in different mechanical arrangements and more stringent reliability requirements, the principle of using an MVC and a single conductor cable appears key to offer an economical solution for long tie-backs requiring optical communications and power.

3.5. Solution architecture and reliability

3.5.1. Architecture

A duplicated architecture is recommended for this crucial part of the overall system. A ring architecture similar to the NEPTUNE system above could be implemented, but a fully separate 1+1 configuration (Fig. 16) is best. The intrinsic (equipment) reliability of a duplicated system is similar to the availability estimated above, at around 99.99%. The duplication also protects against faults arising from external aggression (e.g. fishing) causing cable failure.

A typical architecture is shown in Figure 16:

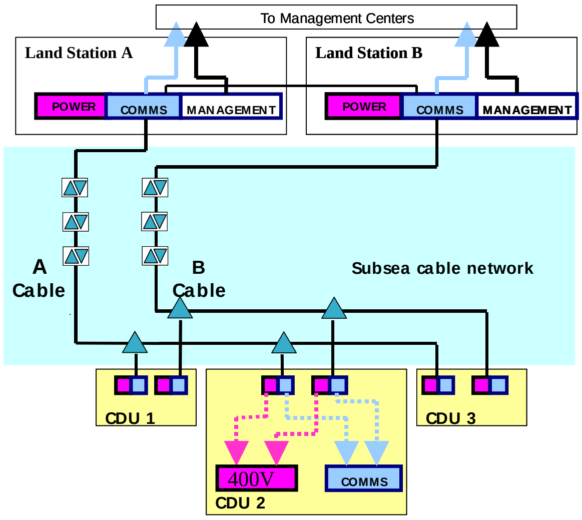

Fig. 16: Preferred 1+1 architecture

3.5.2. Installation, Operations and Maintenance

It is paramount to evaluate the hazards that submarine cables can face in order to ensure that the proper choices are implemented for cable protection. External aggressions can be considered as two categories: the human factors and natural factors. Human factors are mainly commercial fishing, vessel anchors and other seabed activities. Commercial fishing is responsible for over 75% of cable aggression faults and most trawler related faults occur in less than 500m water depth. Natural factors will be sea bed current, marine life, hostile sea bed terrain, earthquakes, underwater landslides, and abrasion. These natural factors usually account for less than 10% of cable faults. Cable burial is the natural remedy against bottom fishing and is an all round, field proven and effective mean of protecting the cable against bottom trawling. In stable seabed, cable burial to 0.75 meter is deemed sufficient against fishing aggression.

Alcatel-Lucent owns and operates a fleet of cable laying vessels (Fig. 17) equipped with deep sea ploughs capable of installing the cable 3m below the seafloor in soft soils. ROVs are also used for trenching or to perform other remedial work when the conditions are such that ploughing cannot be efficient. These DP2 (doubly-redundant Dynamic Positioning) vessels can perform best in class installation and repair operations even in adverse weather conditions.

Fig. 17: A Modern DP2 Cable ship

The cable repair operations are based on the use of cable joint techniques performed onboard the cable ship. Alcatel-Lucent has developed a series of jointing boxes (Fig. 18) using polyethylene over-moulding to repair the cables in any combinations.

Fig. 18: Deep sea cable jointing box

Rapid and secure fault location is key to be able to perform fast repairs. It can be achieved in several ways depending on the nature of the fault. Most faults are shunt faults; where the cable is damaged in such a way that the copper tube is exposed to the seawater thereby creating an electrical path to earth. In this case, the fibres are not damaged and by re-balancing the system voltage at both ends to put the system zero voltage point at the shunt fault location, the system can remain in service until a repair can be scheduled. "Electroding" is also possible, allowing a probe to locate a powered cable on the seabed.

The system requirement is to locate faults to within one section. For this purpose, a section is defined as the distance between identical monitoring points in adjacent repeaters. This can be used if the supervisory system is available in the Submarine Line Terminal Equipment. All hard faults involving the loss of transmission can be located using the input and output power of the repeaters.

3.6. Costs and benefits

The benefits of moving to a combined DC/Fibre Optic step-out include the following:

- Reduced umbilical costs: The umbilical is simplified compared to composite AC dual or quad copper cores;
- Extended length capability: up to 600km or more from shore limited by the powering;
- Huge data capability: 100Mbit/s, GbE, 10GbE are available options, enabling real-time applications;
- Multi-site capability from one step-out: offering backbone synergies between the subsea sites.

4. CONCLUSION

The present mature repeatered technology can provide high reliability communication and power distribution in all offshore environments. This technology has a high potential to simultaneously meet all the following prerequisites:

- Real-time broadband communications;
- Undersea networking and connection;
- Extended reach;
- Environment independency;
- Future proof;
- Proven and economic.

The competence to implement such solutions is available from the subsea communications industry, which has transformed international telecommunications with revolutionary progress since the rollout of subsea fibre optics 20 years ago. These achievements have been based on seamless design and qualification, comprehensive system integration testing and consistent application of standards.