Power and Communication Architectures for Cabled Subsea Observatories

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I. INTRODUCTION

A subsea observatory by definition is a hub that allows multiple instruments to be connected to a shore-based station while being monitored and controlled remotely. Many of the observatories today use a telecommunications-based electro-optical trunk cable supplying communication to the experiments through fiber-optics, while simultaneously supplying 10's of kilowatts of power. The node then routes the communications to the appropriate resource and conditions the power for use by the various instruments. In the past, these observatories were limited in resources and expensive to maintain. The systems were largely hardwired nodes that were deployed and left; if something failed or needed to be changed, the resources required to pull the node and perform maintenance were exhaustive. Today's subsea observatories do not suffer the same requirement for support. The underwater mateable connector has allowed the node to be maintained, serviced and updated at pressure using a much simpler remotely operated vehicle or ROV. The ROV can be used to reconfigure an instrument array or it can assist in the removal of the node. Generally, the use of an ROV reduces the need for a large scale support vessel.

Figure 1: ROV Installation of Wet-Mateable Connector

Architectures for the early nodes, such as JAMSTEC's VENUS, employed electrical communications through electrical telecommunications coaxial cable. Even the Oil and Gas community has also relied on electrical communications until quite recently. The systems used serial communications providing limited data rates, until the advent of MBARI's MARS program. The Ethernet architecture for this node was a gigantic step forward from the previous systems and provided, for the first time, the ability to monitor experiments in real time and obtain a continuous stream of data. The increased data rates have allowed scientists to explore the oceans using new instruments including acoustic doppler current profilers and high definition cameras. Electrical systems do have their limitations in the subsea environment and must capitulate to the same physics that apply to similar systems at surface pressures. A 10/100BaseT Ethernet cable has a maximum transmission distance of 100 meters at standard atmospheric pressure. After that, the signal begins to degrade to an unrecognizable state and a router must be put in place to read the signal and re-transmit it along the next section of the cable. The telecommunications industry recognized this issue in the mid-to-late 1980's when optical communications were developed and the first system deployed. A significant cost saving was immediately recognized due to the number of repeaters that were removed from the system and the significant increase in bandwidth. As an added benefit, because the number of repeaters were reduced, the reliability of the systems went up almost exponentially. Since this change, fiber-optic systems have been making their way into the subsea industry with many different applications. However, raw component initial cost has traditionally been a limiting factor to widespread use of the technology.

Ocean Design's history in the subsea industry is based on extensive experience with engineering interconnect systems for the Oil and Gas, Oceanographic, Telecommunications and Defense industries. Thus, this paper will explore the hardware options available to the Oceanographic community to construct a subsea network based on various projects including Japan's Venus, University of Victoria's Neptune, MBARI's MARS and University of Victoria's VENUS. Through the development of these projects over the past 20 years, the requirements for communication have changed. Each of the systems mentioned above have their place in a subsea observatory, and learning from previous experiences and understanding where to use their technologies is the key to having a cost-effective and efficient node.

II. EXAMPLES OF OBSERVATORIES

Subsea observatories became a reality for the scientific community in the early 1990's when Japan deployed some of the world's first cabled subsea observatories. They employed the latest technology for their period, using wet-mateable connectors for both electrical and optical communications. These observatories have become a testament to their survivability providing almost 15 years of service to date. They provide real-time data from a myriad of sensors including acoustic Doppler current profilers, seismometers, hydrophones, video cameras, pressure and temperature sensors, as well as radiation sensors. Japan demonstrated the feasibility of using telecommunications cables to provide information to its scientists, enabling them to learn more about their ocean environment than ever before. The global scientific community has recognized these accomplishments and is constructing similar observatories in other locations with great scientific potential.

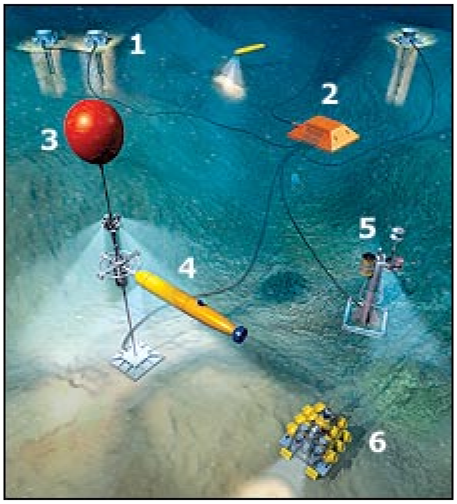

Figure 2: Example of a Subsea Observatory

Monterey Bay Research Aquarium Institute's (MBARI) MARS program pushes the envelope of the observatory again by increasing the amount of power a node could supply to its instruments into the 10's of kilowatts. University of Victoria's VENUS program was the first observatory to push the limits of Ethernet step-out distance. With each new observatory new lessons are learned and new horizons are realized. The most recently funded system is Neptune, which will be deployed off the West Coast of Canada. It will be the first time that researchers have the opportunity to study an entire tectonic plate and will provide the most advanced and expandable communications architecture yet deployed.

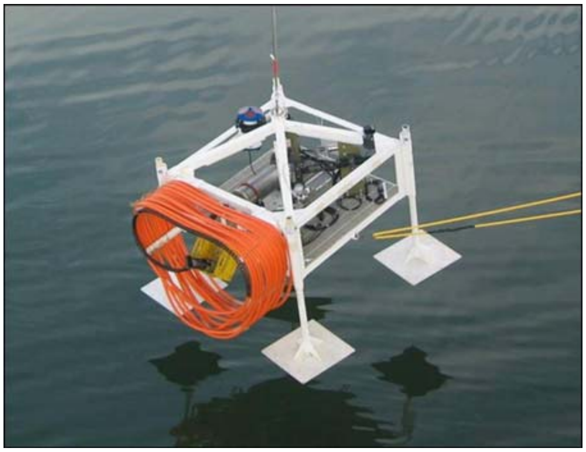

Figure 3: Secondary Node Installation

The future of the subsea cabled observatory shows no signs of slowing in growth or scientific potential. The days of scientists spelunking into the deepest caves around the world to study the elusive neutrino are over. NEMO has been under development for deployment off the Italian Coast and will use an optical communication system to route the information from the extremely delicate photomultiplier tubes back to anxious scientists on the shore to study massive celestial events from the deepest regions of space. The subsea observatory has truly grown beyond the bounds of simply understanding the ocean and is helping us understand the universe around us as well.

Even further on the horizon are programs like Celtnet, which continues to push the limits of observatories by claiming the deepest observatory proposed to date. While at the same time, having the largest number of nodes planned for deployment and retaining the high reliability and maintainability needed to keep all of the nodes functioning at full capacity.

III. A BRIEF HISTORY IN ELECTRICAL COMMUNICATION ARCHITECTURES

Electrical communications in the subsea environment have their roots embedded deeper into the community than any other architecture. They have been employed for over 50 years and the technology is advanced to the point of becoming routine. Electrical systems are used to do everything from controlling subsea oil wells, to driving ROVs, to gathering intelligence for the Defense industry. They are used on every oceangoing platform known to man in some fashion. However, when it comes to data transmission, they are not always the optimum choice. The requirements for the application must be weighed carefully to ensure a system that will function as required. For something as simple as operating a valve servo, electrical architectures work well. When it comes to transmitting high definition camera data over long distances, electrical architectures have their limitations.

Figure 4: Electrical Communications Pressure-Balance Oil-Filled Harness

The subsea market has developed many technologies for electrical interconnect systems that range from polyurethane molded cable assemblies, to pressure-balance oil-filled hoses (PBOF), to engineered cables with custom terminations. In deep water applications, each of these technologies requires a connection to be made with the entire assembly submerged, as it is frequently impractical to lift the assembly out of the water to make the connection. Currently, the Oil and Gas community leads the way in these technologies. With so many extreme applications, many lessons have been learned and technologies created to overcome these tasks.

One of the first technologies required is the subsea wet-mateable electrical connector. Many companies have made connectors that claim to be wet-mateable connectors, but the majority of them are actually only wet-plugable connectors. This means that the connector may be mated underwater, not unmated and then re-mated at pressures greater than a few atmospheres. It wasn’t until the late 1980’s that a competent connector was placed on the market that allowed assemblies to be deployed to the ocean floor and used as hubs for electrical systems, being plugged and unplugged as many times as needed. This enabled a change in the industry making oil rigs more practical for deep water applications. Equipment could now be placed on the ocean floor as modular components and connected in-situ while providing high reliability and maintainability.

The original subsea electrical cables were made with an inexpensive polyurethane over-molding process. This allowed a water-tight seal to be created between the cable and the terminated connector. Extensive use of these cables reveals their inherent weakness which, ironically, is the very bond that made them so popular. By far, the biggest issue with these joints is the bond strength with the various substrates. Often times, the polyurethane will delaminate from the various components, losing the water-tight barrier. Or, when the polyurethane bonds to the cable and conductors, it adheres to all of the surfaces. Exposure to pressure allows the polyurethane to contract to withstand the added pressure, placing stress on conductors and connections each time, often leading to a failure. The combination of these issues yields an extremely short expected life of 2-8 years for these types of terminations. As these requirements for electrical cables matured, stronger designs became required to allow the production facilities to produce without interruption and/or constant replacement of cabled systems spawning the introduction of the field installable and testable assembly or FITA. FITAs utilize a variety of mechanical seals to adapt between cable and connector. Some of the earlier FITA designs suffered from issues related to both the cable and to the termination due to the lack of sealing redundancy in the design. If the cable was punctured, the termination would flood, thereby shorting the conductors or connector. The next generation deepwater termination mitigates these issues by the development of a sealing penetrator which is installed between the cable and the connector. This increased reliability termination, called FACT (Field Assembled Cable Termination), completely isolates the cable from the connector or pressure vessel ensuring that any issues seen with either component will not affect the other. The increased reliability to the system far out strips the increased cost of the component.

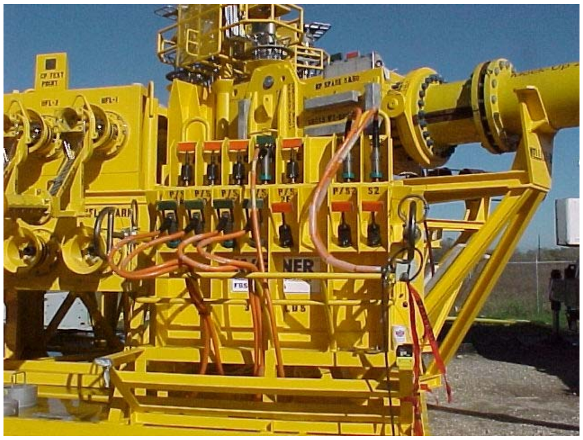

Figure 5: Interconnect Harness Installed on Oil and Gas Production Equipment

The final evolution that enabled electrical communications architectures to become what they are today is the integration of Ethernet into these assemblies. Combining the pinnacle of each technology, while simultaneously developing a termination process, Ethernet can now be transmitted subsea. The technology does have its natural limits as Ethernet is extremely susceptible to a change in the impedance of the transmission path. The impedance is a measure of how the signal reacts as it travels down the cable based on the naturally occurring electrical phenomena. For example, two wires placed beside each other will naturally share a capacitance between them; this will typically round out the digital signal and degrade it over distance. Capacitance is only an example; there are many other characteristics that can be affected at subsea operating pressures that must be accounted for when developing such an assembly. Using capacitance as an example again, a standard Ethernet conductor has a specific spacing between the conductors. As pressure is applied, the spacing between the conductors changes which also changes the characteristic impedance of the cable. These effects combined with the required size of the wet-mate connector rationalize the change from the surface distance limit of 100 meters to the empirically obtained distance of 70 meters subsea.

When designing subsea communications architecture, it is important to understand each of the previously discussed topics. Electrical systems are reliable, available and proven. They can be designed for almost every application and designed around the required life. They have a lower initial cost than an optical system and can perform their tasks as long as they are appropriately allocated. The ideal electrical system should cover a small area of interest where the information from various instruments can be collected and retransmitted. This local system is best supported by an optical system which allows an increased distance from the repeater/node.

IV. A BRIEF HISTORY IN OPTICAL COMMUNICATION ARCHITECTURES

Multi-channel, wet-mateable optical connectors were first introduced into the subsea industry in the mid-1990's and allowed eight (8) optical connections to be made in a completely submerged condition a minimum of 100 times without degradation to performance. The first applications for these connectors was oil rigs in the North Sea for use in flow metering systems, as well as some telecommunications industry applications. Once perceived as "new" and "untested" technology and therefore risky, there are now in excess of 2,500 of these wet-mate optical and hybrid interconnect systems deployed subsea worldwide with over 400 million hours of accumulated operation.

Figure 6: Optical Wet-Mateable Connector

The Oil and Gas industry has been using optical signals on the platforms for years to bring communications from subsea fields miles away back to the rig without the need for a processing control unit. They have found that this increases the reliability of the system while providing expanded bandwidth to their equipment subsea. Currently, optical systems are only limited by their processing components to ~40 Gigabytes/second, but have the capability to support communication rates in the Terabytes once new processors are developed. Optical product not only boasts high communication rates when compared with its electrical counterparts but is less susceptible to the surrounding environment. Optical signals are not subject to interference from EMI sources, nor are the signals affected by the surrounding seawater environment. They have exhibited increased reliability over electrical systems in the long-term condition based on the aforementioned points. The success of optical product subsea and hurricane Katrina's influence over BP's Thunderhorse rig, inspired a new project which is in the deployment process in the Gulf of Mexico. It will connect many of the major oil rigs to control stations on the shore and uses an electro-optical telecommunications cable to make a loop encompassing many of the major oil rigs. To facilitate using this system, a Mini-Gateway system of up to four (4) optical connectors was developed to splice in-line with the cable which enables the oil rigs to integrate into a backbone system and, in the event of an emergency, be controlled from the shore stations without the need of a manned crew on the rig.

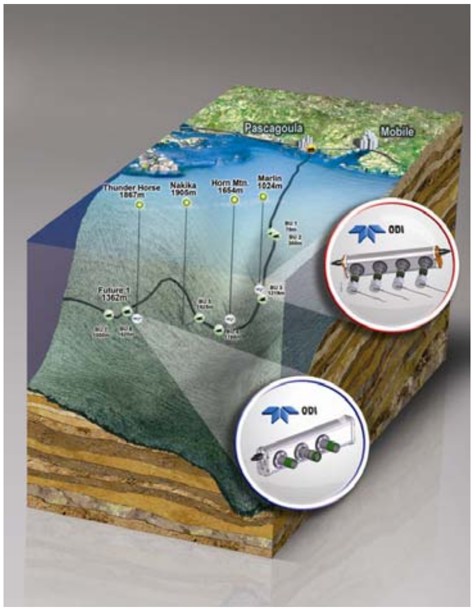

Figure 7: Gulf Fiber System Schematic

Optical inter-connect systems employ many of the already proven technologies used by the electrical connectors. These include submersible dry-mate connectors, pressure-balanced oil-filled hose and cable terminations. All of these options can be arranged as either all optical configurations or a combination of electrical and optical circuits. These solutions benefit from the proven field reliability based on experiences with the electrical products and only strengthen the growing change to optical-based systems in the subsea market.

V. TECHNOLOGIES AVAILABLE TO THE SUBSEA COMMUNITY

With the extensive development in hardware over the years and with so many lessons learned from the various subsea industries, a host of equipment options have become available to better aid in the survivability and maintainability of the subsea observatory. With a need for connectors, cable terminations, pressure-balanced oil-filled hose, polyurethane molded terminations to junction boxes and Mini-Gateways, navigating the options can be a daunting task. For example, wet-mateable connectors can be found in a variety of configurations from optical to electrical to various combinations of both. The drivers for choosing the correct connector are determined by a careful evaluation of how many optical circuits are required, what voltage is required and how much current is required. How does one know when to choose a polyurethane termination versus a mechanical cable termination such as a FITA? Choosing the optimal part always comes down to understanding the system requirements and working with the supplier.

Figure 8: Mini-Gateway, Compact Wet-Mate Distribution Assembly

The majority of these technologies are driven by the demands of the subsea market. Currently, the greatest need is for a simple electrical connector with a multipurpose role. Most companies offer a standard electrical connector with up to 12 circuits that can operate at around 1000VAC and ~30 amps. Some of the more advanced requirements for electrical connectors include Ethernet and high power/high voltage connectors. The Oil and Gas industry uses high power connectors to run subsea pumping and heating systems which run on AC. Therefore, the majority of the high power connectors available are AC rated connectors. These range in size from standard connector size to 50kg and .5 meters in diameter, currents up to 500 amps, voltage ratings up to 36 kVAC and pressure ratings depending on the projects that they have been designed for. The telecommunications industry has been using DC systems since the beginning to power their repeater systems, driving the development of a DC rated connector. The existence of a wet-mate 10kVDC connector adds to the available inventory of power interconnect options.

The optical connectors follow a similar development path; the majority of the optical connectors deployed are in an eight (8) circuit configuration with limited electrical capabilities. Typically, the power through these connectors was used only to process the signal, not power instruments, so little was required. Recently, optical connectors have been developed that broaden the capabilities, allowing a single connector to supply both 30 amps of power and up to four (4) optical circuits to a system. Next-generation wet-mate connectors are currently in development, with a goal of connecting high fiber counts (up to 24 single mode fibers) along with high capacity electrical circuits.

Using these two basic technologies and combining them with other available technologies, the electrical and optical communications architectures are born. Systems can be designed using cables, hoses, junction boxes and Mini-Gateways to create an interconnect system that is best suited for the requirements of the application. For example, Neptune uses an optical cable from the shore to an observatory where the cable is terminated to a high power connector and an optical connector. These connectors are, in-turn, plugged into the node itself where the signal is processed, the power conditioned and the combined signal sent out over a hybrid electro-optical connector to a secondary node. The secondary node houses the local instruments which collect data from an area conducive in size to sustain an Ethernet-based architecture. The data is collected, converted in the secondary node and returned to the observatory for transmission to the shore station. Many of these secondary nodes can be used to study regions not just directly adjacent to the observatory but many miles away at other regions of interest.

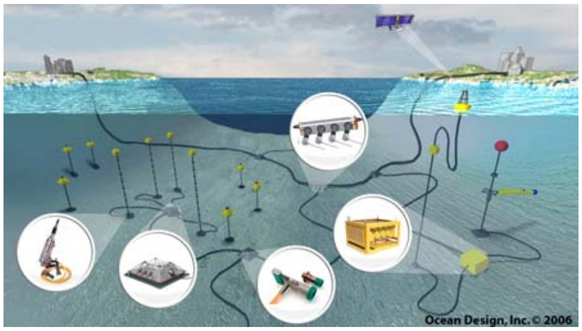

Figure 9: Future Gateway System

VI. CONCLUSION

Through industry development and requirements over the last 25 years, many technologies have become available for the subsea cabled observatory to allow many tasks that were previously impossible to perform. Electrical wet-mateable connectors, optical wet-mateable connectors and their inter-connect solutions have been developed and deployed in many systems providing reliability, interchangeability, modularity and maintainability in a host of different applications. However, knowing when to use optical versus electrical architectures is a daunting task. The optical system may have a higher initial cost, but will provide larger step-out distances, increased reliability, increased communication speeds while remaining upgradeable. Where as the electrical systems are less costly, have a longer history in the subsea industry but provide limited communications and step-out distances. The best solution is to learn from the experiences of previous projects in both the scientific community, the Oil and Gas community and the Defense community to come to the optimum solution for each application. Over the years, the subsea industry has learned many lessons that can be shared amongst the fellow submariners curious to explore and test the limits of technology.

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