Efforts on developing the technologies of abyssal cabled observatory in China*

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***Abstract*—Cabled ocean observatory system that enables abundant power and broad bandwidth communication has attracted many scientists during the last decade. In order to build cabled ocean observatory system in China, Zhejiang University along with some other Chinese institutes are developing the technologies of cabled observatory suitable for coastal and abyssal ocean under the support of National High-Tech Research Program of China from 2004. In this paper, the efforts of the last five years on the development of the relative technologies are introduced, including the power, communication and timing. Serial tests and experiments were carried out in lab, coastal and deep sea to validate that the studied technologies and methods were suitable for a long term seafloor observation.**

Keywords—Cabled ocean observatory system; Power system; Communication system; Timing

I. INTRODUCTION

China has a long coastline and vast ocean, that makes it an excellent field to study the ocean science especially the East Pacific. As an example, many phenomena occur at the area of East China Sea Shelf. The freshwater from the Yangzi River, the kuroshio current from the Pacific and the Taiwan warm current interact here and induce a series of influence on chemical, biological environment. It is the boundary of suspend sediment transport from the Yangzi River. The deposit rate and concentration change sharply, which might be the cause of demarcation of western fine-grained sediment areas and eastern sea-self sand ridge developing areas. Besides, it is rich in nutrient elements, and 70% of the red tie occurs here, however, the primary productivity varies by season. It is hard to study the mechanism of these kinds of science phenomena using traditional approaches such as R/V, satellite, AUV, battery powered instruments, et al. To observe these time-dependent complex processes that occur in the coastal oceans, long-term, real-time, and in-situ observations are required. Cabled ocean observatory system is an innovative approach to light the dark ocean and has been or being developing all over the world[1-17]. Early from 2004, under the fund of the Ministry of Science and Technology of the People's Republic of China, Zhejiang Univ. started to study and develop the technologies of cabled ocean observatory. Some efforts were made to realize cabled system from coastal to abyssal area for science research. In this paper, the authors will review the recent studies and developments of cabled ocean observatory system in China.

II. TECHNIQUE REVIEW

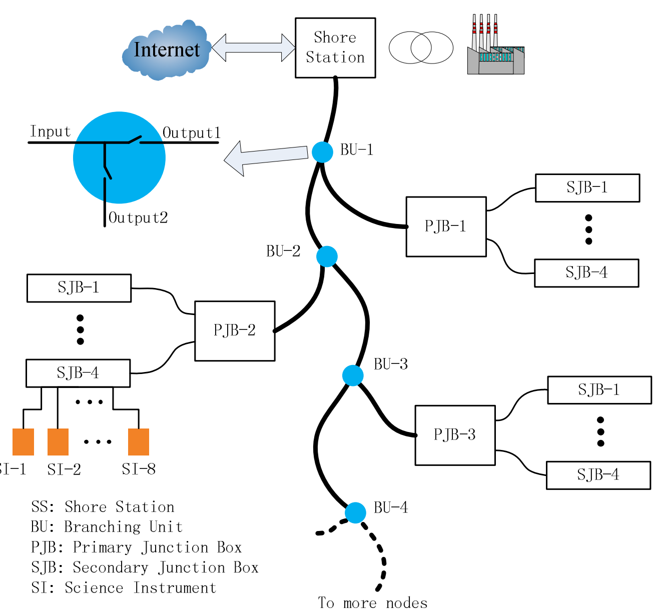

Fig. 1 Tree-topology cabled observatory system

A cabled ocean observatory system is shown in Fig.1, in which the optical-electrical trunk submarine cable is connecting the shore station and the seafloor. The shore station is the joint of terrestrial and seafloor power and communication, as well as data archive and management center. Along the cable, several nodes named Primary Junction

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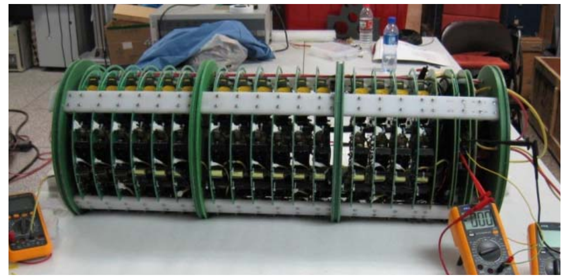
Boxes (PJBs) attach onto it via short branch cables and distributing to science interesting area on the seafloor. Each PJB provides four extension ports for high power instruments or Secondary Junction Boxes (SJBs) which in turn provide up to eight science ports. Power and communication are transmitted and managed by each distribution junction box. By netting instruments through junction boxes, submarine cables, cabled ocean observatory system employs hundreds to thousands kilometers cables and covers tens to hundreds square kilometers.

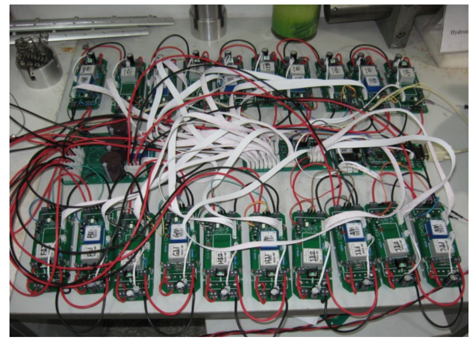
A. Power

Power is the most important function of such cabled system. Negative, high voltage, parallel, monopole and Direct Current (DC) power is employed for its power system due to several reasons[18-19]: 1) using high voltage to deliver electrical power can reduce loss on cable; 2) a parallel power system can deliver more power compared to a serial one; 3) DC voltage reducing devices are much smaller than Alternating Current (AC) voltage reducing devices, and a smaller device is preferable in the deep sea. In addition, when AC voltage is used to transmit power, the parasitic inductance and capacitance of long cables may induce additional problems, such as decreased system stability; 4) in contract to the AC system or bipolar DC power system which have three or four conductors, two or even one conductor with seawater is enough as the current return path in the unipolar DC system; 5) when using a seawater return power system, negative delivery voltage solution can keep the electrode in a lowest corrosion condition, which in turn reduce the cost of electrode maintaining. Based on these considerations, the public 380 VAC power is converted into -10kVDC power and delivered down to the seafloor. At each PJB, the high negative DC input is stepped down to 375V, which in turn is brought down to even reasonable levels such as 48V and 24V in SJB so that SI can draw power without additional conversion. A customized -10kV to 375V PWM controlled DC/DC power converter is set at each PJB for voltage reduction (Fig. 2 a), while off-the-shelf converters are parallel stacked to bring the 375V to 48/24V at each SJB (Fig. 2 b). A cathode is mounted at the PJB to form a seawater return.

It has no generation source in cabled system, and all power is delivered from shore station, that restricts its power capacity, as well as its power storage capacity, so any short fault will cause system collapse in ultrashort time. Meanwhile, short fault is the most popular fault underwater. Power short fault detection and isolation become a priority of cabled system. In order to keep the cabled system at high reliable level, fast protection against short fault or ground fault should be set at each output of each junction box, e.g. the extension port of PJB will be shut down when short current reaches 15A@1ms or ground fault occurs to avoid further damage or influence to other ports. Generally, mechanical or semiconductor relay are commonly used to interrupt DC power. However, the off-time of mechanical relay is over 1 ms and sometimes up to tens of microseconds. Semiconductor has an off-time of less than 1 us which is fast enough for switching the power off. However, it has up to hundreds of uA leakage current. This can induce serious damage on port conductor for long term operation. To solve this issue, we introduced two relays method by applying both mechanical relay and semiconductor to interrupt the fault DC current in less than 1us and isolate the leakage current synchronously.



(a) -10kV-375V converter



(b) 375V-48/24V conversion system

Fig. 2 Power conversion system

B. Communication

The cabled system is designed to provide up to Gigabit bandwidth communication for underwater instruments. Optical fiber has high bandwidth capacity and can transmit long distance. In the original design and proposal, two methods were discussed for the trunk communication. The first one is by employing multi-channel Dense Wavelength Division Multiplexing (DWDM) solution to achieve high bandwidth using only one pair of fibers. This solution was adopted by NEPTUNE (Canada and MARS) and could reduce the cost on cable. With this solution, we concerned more or less about its communication reliability when considering it might fail when a single point failure occurred on the only pair of fibers. In this case, we get another solution more costly but higher reliability and simpler applying. Each PJB will occupy one individual pair of fibers. Both of its advantage and disadvantage are distinct: 1) any failure on one pair will not affect other pairs, so its reliability is higher in a certain extent; 2) its supporting facilities are much smaller and cheaper; 3) it will require lots of pairs when extending many nodes. Considering a large scale network like NEPTUNE (Canada), it had only six PJB, we finally adopted the latter solution as a compromise choice. It is worth noting that even optical fiber has a limited transmitting distance, longer than hundred kilometers will require repeater to amplify the optical signal. A lab simulative test showed that Alcatel-Lucent PTN worked well on a 150 km single mode fibers, beyond which its capability will decrease (Fig. 3). So we can construct a network less than 150 km without repeater, or longer than 150 km with certain repeaters.

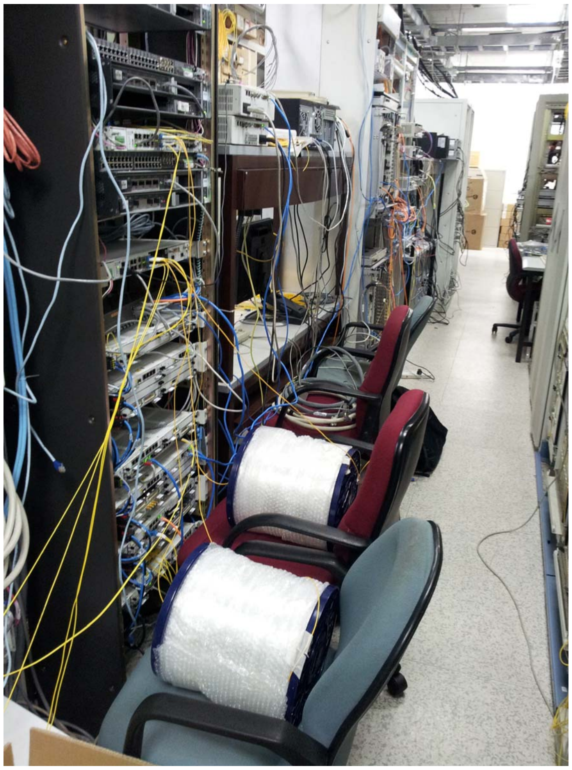


Fig. 3 Communication test on 150 km optical fibers

C. Timing

Precise time information is especially important for distributed systems in automation technology, as well as cabled ocean observatory system. Instruments collect data at different locations must be time-stamped for analysis and correlating with other data collecting from a few meters to thousands of kilometers away. For some observations, low time-stamp accuracy is adequate, whereas for other observations like acoustic signal or seismic signal, sub-millisecond precision level is required to accurately estimate earthquake, storm, submarine volcanic eruption, tsunami and other disasters. Two methods are commonly used to achieve accurate time information. Network Time Protocol (NTP) is one of the most popular protocols used for Internet time clock synchronization between a trusted time server and its clients and can achieve a precision of tens of milliseconds. The Precision Time Protocol (PTP), as defined in the IEEE-1588 standard, provides an approach to precisely synchronize controller or computer over a Local Area Network (LAN) to an accuracy up to 1 microsecond or even better that was previously unobtainable. Both two methods have their own advantages and different SIs have different requirements on timing. Considering the diversification of SIs, both NTP and IEEE1588 protocol are employed and provided for attaching SIs. Fig. 4 is the lab test of PTP timing via 150 km optical fibers.

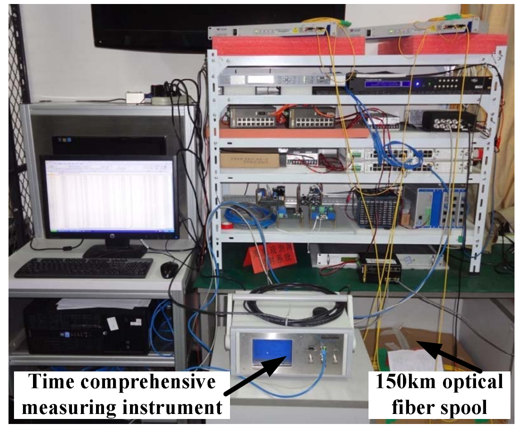


Fig 4. The PTP timing test over 150 km optical fibers

III. Experiments

Reliability is the first priority in building a long term cabled ocean observatory system. Efforts were carried out to validate all employed technologies and different prototypes were made and tested in lab, shallow sea and deep sea since 2010.

A. Laboratory Test

Series of tests were carried out in the laboratory to validate the performances of each part, such as the pressure tests of pressure casings, heat dissipation performance of the power system, electrical characteristic of power converter, et. al. Some components used in this prototype were off-the-shelf ones and had excellent qualified performances; thus, only the customized components, such as the high voltage power converter, the low-voltage conversion system, and the control and communication systems, were tested. Finally, a cabled system with one junction box providing multi-port was assembled in laboratory (Fig. 5). The Power Feeding Equipment (PFE) and Data management System (DMS) formed the shore station. Through an armored 1 km submarine cable, the power and communication were transmitted down to the node, which was attached at the other end of the cable. This node consisted of high- and low-voltage power vessels as well as a control system vessel. The high-voltage power vessel housed the high voltage power converter, whereas the low-voltage power vessel housed the low-voltage conversion system. Three vessels were suspended below a high-intensity stainless steel frame. Subsea instruments could be easily plugged to or removed from the node using 12-pin wet-mateable connectors, thus making maintenance highly flexible. Lab tests were carried out in water tank for several days focusing on its working performances.

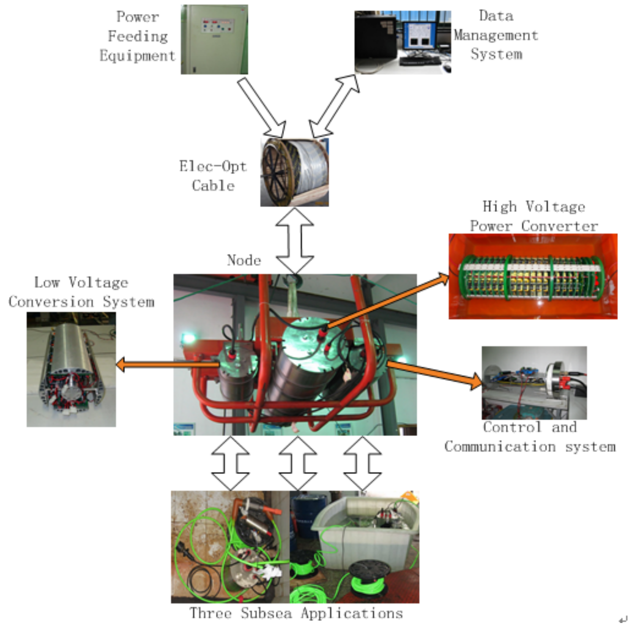


Fig. 5 Laboratory test of the prototype system [20]

B. Shallow Sea Trial

For application on the sea bed, a sea trial was performed in the East China Sea in September 14, 2010, at the coastal area of Shenshan Island at the mouth of Hangzhou Bay (122°50′10″ E, 30°42′10″ N). It was a single node cabled system plugged with three subsea instruments. All equipments were fixed at a 3.5 m×2.2 m×1.5 m test frame weighing 2.5 T (Fig. 6). The junction box was placed in the middle of the frame and around by the three instruments. The experimental cable was only 1 km, and the frame was deployed only 500 m offshore, at a depth of 31 m. The shore station was installed at an earth radar station near the beach, where 10 kVDC power and Internet were available. The system went online on September 14. On September 26, the system failed because of a ground fault on the high-voltage power cable, which might be accidentally damaged by a fish boat anchor. In this experiment, time series data for the water column physical parameters, the high-quality active video of the seabed, and the in situ analysis of seawater chemical parameters were obtained, as well as the inner physical status such voltage, current of power, temperature and so on.

Fig. 6 Shallow sea test of the 10 kV powered system [20]

C. Deep Sea Test

A SJB prototype was constructed and deployed in Monterey Bay for long term test on April 21, 2011. With the cooperation of MBARI research vessel R/V *Western Flyer* and ROV *Ventana*, the SJB and three scientific packages were deployed around the MARS node. The SJB had a 50 m cable with a ROV wet-mateable plug connector and was connected to the MARS node and acted as its temporary secondary node. Two of the three instruments were connected onto the SJB via individual ROV wet-mateable connector. The third instrument was a camera system and was loaded on the SJB frame to simplify the deployment. The SJB frame was 1.5 m × 1.5 m × 1.2 m and weighed 270 kg in water, which was beyond the holding capability of the ROV. Thus, it was deployed by winch and released on seafloor via acoustic control. The test lasted for about half year and it was recovered on October 26, 2011. During this period, the SJB worked fine with no fault occurred.

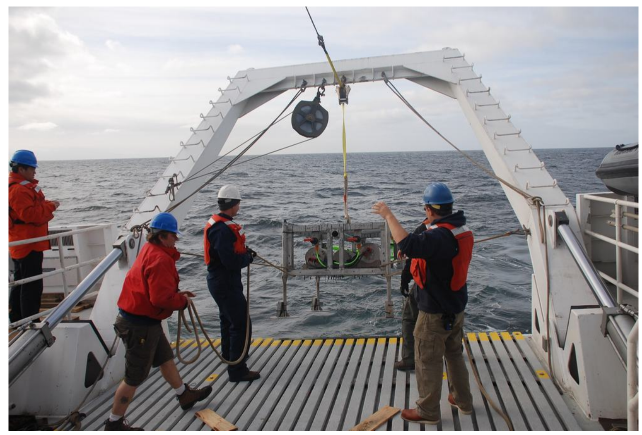


Figure 7. Deep sea test at MARS site[21]

IV. OUTLOOK

Cabled ocean observatory system will play an important part in ocean science research. Using the studied technologies, some small scale cabled system is now under developed and planed to deploy in the near future.

Under the funding of Zhejiang University, a cabled system named Zhejiang University (ZJU)-ZRS Experimental Research Observatory (Z_2ERO) serves as both an observatory and a test bed is planned to be deployed at 1.5 km offshore of Zhairuo Island in East China Sea late in this year. It is composed by one PJB, several SJBs or SIIMs and tens of instruments. Its depth is less than 100 m (Fig. 8).

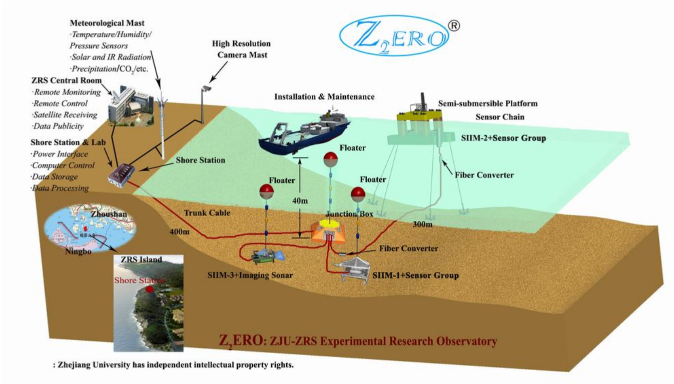


Fig. 8 Structure of the Z_2ERO

Under the support of National High Tech and Research Program of China, a cabled system with two PJBs and several SJBs will be constructed offshore of Hainan Island in South China Sea (Fig. 9). The two PJBs directly attach onto the armored cable. The PJB-A will locate at about 75 km offshore and 200 m in depth while the PJB-B locates at about 150 km offshore and 1500 m in depth. Around each PJB are three to four extensional SJBs that can reach to the locations of scientific interest. It will cover an observation area of 600 km^2. Both PJBs and SJBs are the terminals of the cabled infrastructure from which the scientific instruments draw electrical power and access a communication route via ROV operated connector. The first PJB is planned to deploy this year and then the second one in the middle of 2014.

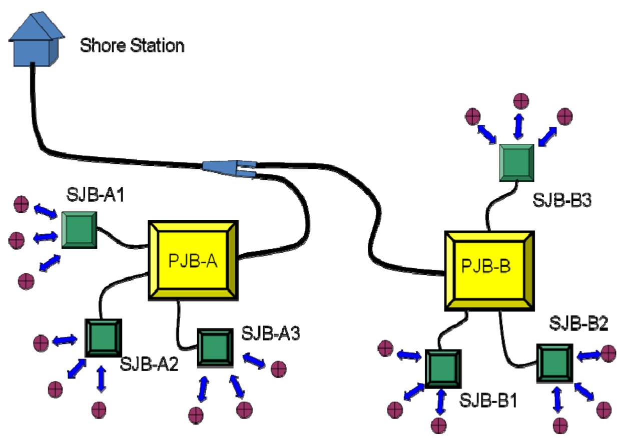


Fig. 9 Structure of the Sanya cabled observatory system

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