FEASIBILITY STUDY ON REAL-TIME SEAFLOOR GLOVE MONITORING CABLE-NETWORK

- Power Feeding System -

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Abstract-A concept of new scientific cable network of next generation surrounding Japanese Islands is proposed. The cable network has the following outstanding features, (1) real-time monitoring and power feeding, (2) covering interdisciplinary field, (3) mesh-like cable system configuration surrounding Japanese Islands, (4) 20-50km observatory's interval, (5) plural replaceable sensors connected in each observatory, (6) robust against faults, (7) high cost performance. This paper will mainly discuss the concept of the cable network and the power feeding system.

INTRODUCTION

In order to understand the nature of the globe and its behavior, it is very important to consecutively obtain scientific data from underwater in vast research field such as seismology, geo dynamics, marine environmentology, ecology and biology.

A seafloor observation system based on the underwater telecommunication cable technology enables a real-time high-bit-rate data transmission and power feeding between the land stations and seafloor observatories. Several underwater cables for scientific observation have already been constructed in Japan(1). The main object of these cables are earthquake monitoring. The first earthquake monitoring system in Japan was developed in 1978 by Japan Meteorological Agency. In 1998, a permanent deep ocean scientific research facility 'the Hawaii-2 Observatory(2)' was installed using a retired telecommunication cable that connected Hawaii and California. The facility consists of a junction box and multiple scientific sensors. In 1999, VENUS (Versatile Eco-monitoring Network by Undersea Cable System)(3) project installed a sea-floor observatory having seven replaceable scientific sensors using the retired telecommunication cable (former Trans-Pacific Cable-2).

Recently, information technology including underwater telecommunication cable technology, the Internet technology, and computer technology evolved very rapidly. Although the transmission capacity for the first underwater optical telecommunication cable installed in 1987 was 256 Mbits/s a fiber, its capacity increased to more than 1 Tbits/s a fiber. Today, flexible cable network of huge capacity can be made using Dense Wavelength Division Multiplex (DWDM) and optical amplification technology. Using computer and the Internet technology, small intelligent underwater sensors and communication equipment can be made. These technology evolution

Figure 1 Concept of the scientific cable network of the next generation

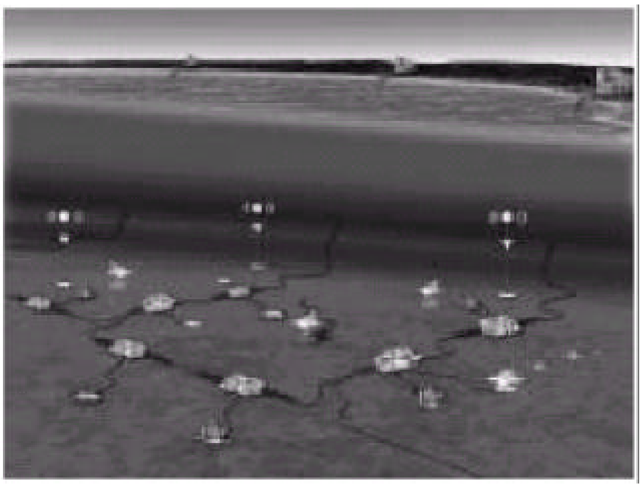

Figure 2 An artistic image of the seafloor obserbatory

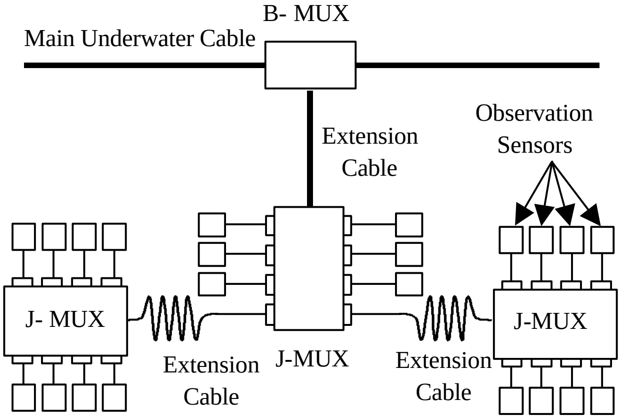

Figure 3 Architecture of a observation node

makes it possible to develop a new flexible and robust scientific cable network. In 2001, science community in the USA started a new scientific underwater cable project called NEPTUNE(4) taking advantage of these technology breakthrough. The NEPTUNE system will connect 30 seafloor node distributed over a 500 by 1,000 km area.

In 2000, a group of expert engineers was organized in Japan to discuss the feasibility of the scientific underwater cable network of next generation, named "Advanced Real-time Earth monitoring Network Architecture (ARENA)". The group was initiated by JAMSTEC and consists of engineers from private companies, Hakusan Corp., KDDI group, Mitsubishi Electric Corp., Mitsui Engineering & Shipping Co., Ltd., NEC Corpotation, Nichiyu Giken Kougyo Co., Ltd., OCC Corporation and Oki Electric Industry Co., Ltd.

This paper will mainly discuss some possible system architecture and power feeding system. The proposed cable network has the following outstanding features, (1) real-time monitoring and power feeding, (2) covering interdisciplinary field, (3) mesh-like cable system configuration surrounding Japanese Islands, (4) 20-50km observatory's interval, (5) plural replaceable sensors connected in each observatory, (6) robust against faults, (7) high cost performance.

The proposed cable network structure will be quite different from the conventional telecommunication cable systems. Plural measurement equipment will be placed in each observatory, and these sensors will be able to be replaced for maintenance and upgrade. The power feeding system and the data transmission system will be more sophisticated than those for the telecommunication cable system.

Overview of proposed scientific cable network

Figure 1 shows a concept of the future scientific cable network around the Japanese Islands. As many big earthquaqes occur on the plate boundary, the route of the cable network is located near the plate boundary to deploy seismometers there. It is desirable to locate many seismometers with interval of 20-50km to precisely monitor earthquakes. The deepest water depth of the cable network is 6,000m.

The cable network has several landing points. This means that the cable network can be divided in several segments, and can be expanded from a single segment to a large network. The network can be built step by step. Considering the size of the project, this expansiveness is very important.

Reliability of the system is another important viewpoint, as repair of the underwater devices is costly and not so easy. If a serious trouble occurred and the system broken down, it would interrupt the monitoring for a long period. Using a network architecture like Figure 1, each sensors can be accessed and fed from plural landing stations. This network structure is robust against cable faults. Even if power-feeding and data transmission is interrupted at a fault point, sensors can be accessed from another landing stations, and the network would continue to work.

Figure 2 shows an artistic view of the seafloor observatory, and Figure 3 shows the basic architecture of the observation node. The observation node consists of a branch multiplexer (B-MUX), joint multiplexers (J-MUS) and a number of sensors. A B-MUX is incorporated into the main cable and branches power and communication line. J-MUXes work as hubs for sensors. The sensors are connected to the J-MUX with underwater mateable connectors to make sensors and J-MUXes replaceable. As the sensor technology develop(s rapidly, it is important to be able to use state-of -the-art sensors. The connection and maintenance can be done with Remotely Operated Vehicles (ROVs) on the seafloor without using a cable ship. As number of cable ships is limited and their operation cost is not so cheap, this feature is also important for actual operation and maintenance of the scientific cable network.

Power feeding system

The ARENA network will use conventional underwater telecommunication cable for its principal portion, as these cables are widely used and have high quality and reliability. The typical underwater telecommunication cable has up to 8 fiber pairs and single power feeding line.

In the conventional underwater telecommunication cable systems, electric power is supplied to the underwater repeaters by two Power Feeding Equipment (PFE) located at the both end of the cable. The supply current flows through the power feeding line in the cable, and the return current flows through sea water. The current is controlled to keep the constant value. This power system is robust against cable faults, because when the cable is broken at any point and the power feeding line shunts to sea water, the output voltages of the PFEs will automatically vary so that the voltage at the fault point becomes ground voltage. The power feeding circuit in the underwater repeater is very simple. Basically it consists of zenar diodes that are inserted in the power feeding line. The electric power is extracted from both terminals of zenar diodes. The electric circuit is electrically floated, it is easily isolated from sea water by surrounding them with insulator. As the electric potential of all the electric parts is at almost the same level, there is no risk of corona discharge. Devices having high breakdown voltage are not required and the circuit can be made compact and economical. However as it is difficult t divide a constant current into two constant currents, the conventional power feeding system can not easily be used for mesh-like cable network. Therefore the authors analyze three possible power feeding method and compare them, (1) Constant Voltage (CV) power feeding, (2) modified Constant Current (CC) power feeding and (3) hybrid power feeding.

In order to simplify the analysis, an engineering model of power feeding network was assumed as depicted in Figure 4 imaging the northeastern portion of the cable network in Figure 1. Observation nodes are inserted in the cable with an interval of 50km, and its total number is 66. Trunk1 and trunk2 are connetced by Power Branching Unit (P-BU).

Table 1 shows number of observatories in the network of Figure 4 and power consumption of each observatory. Transmission equipment and DC/DC converters are placed in B-MUX. Geophysical observatories that include monitoring of earthquake are distributed with interval of 25km. The average of the power consumption of each node is 277W.

When designing power feeding system, the following points should be taken into consideration, (1) reliability, (2) cost, (3) robustness against cable fault, (4) stability, (5) size and weight and (6) power consumption.

Higher reliability is required for the underwater equipment, but the reliability and cost are sometimes inconsistent with each other. Moreover the underwater power system for ARENA is so complicated that it is not realistic to develop supremely reliable device in which only qualified parts are used like underwater repeaters for telecommunication underwater cable system. The practical way to get higher reliability is to minimize the extent to which any break affect by detaching the fault point.. System redundancy is also important to increase the reliability of the whole system while keeping the moderate development cost.

The same protection strategy can be applied for the robustness against cable fault. In case of constant current supply system, a single cable shunt fault does not interrupt power feeding. In case of constant voltage supply system, the fault cable portion should be detached from the other portion, and the extent to which a cable fault affect should be minimized. Fault point localization is also important.

Size, weight and power consumption of the underwater device should also taken into consideration to develop a realistic device that can be deployed and recovered from 6,000 meter water depth. Switching regulator having high conversion efficiency and high input voltage should be developed.

Constant voltage power feeding system

The advantage of the CV system is that the power can easily be sent to the mesh-like cable network, but some countermeasure against cable shunt fault is required.

Figure 5 is an example of underwater power feeding system for observation nodes. This power system regulates electric power for sensors and the other underwater devices. In this scheme, dual switching regulators are used to get higher reliability. In the regulator, plural converters are connected to share the input high voltage and to increase redundancy. Even if one converter were broken, the regulator would be able to supply enough power. The similar plural converter system was selected in the VENUS system and also proposed for the NEPTUNE system(5).

An electrical switch is placed in series of the switching regulator, that separate regulator when an excess current flows due to some fault. This switch should also be controlled by a

Table1 Estimated number of observatories and power consumption

	Average power (W)	Number of observatorie	Subtotal (W)
Geophysical observatory	15	132	1,980
Downhole observatory	69	2	138
Oceanographical	121	10	1,210
Geodetic observatory	11	43	473
Array sensors	4	2	8
Camera observatory	212	2	424
AUV station	60	10	600
Acoustic tomography	60	4	240
Transmission and power system	200	66	13,200
Total			18,273

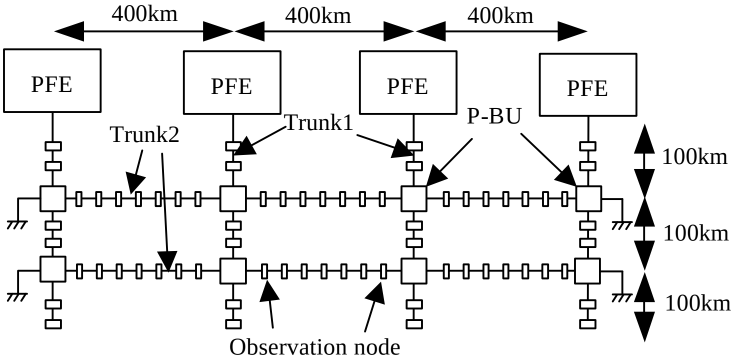

Figure 4 Engineering model for power feeding system

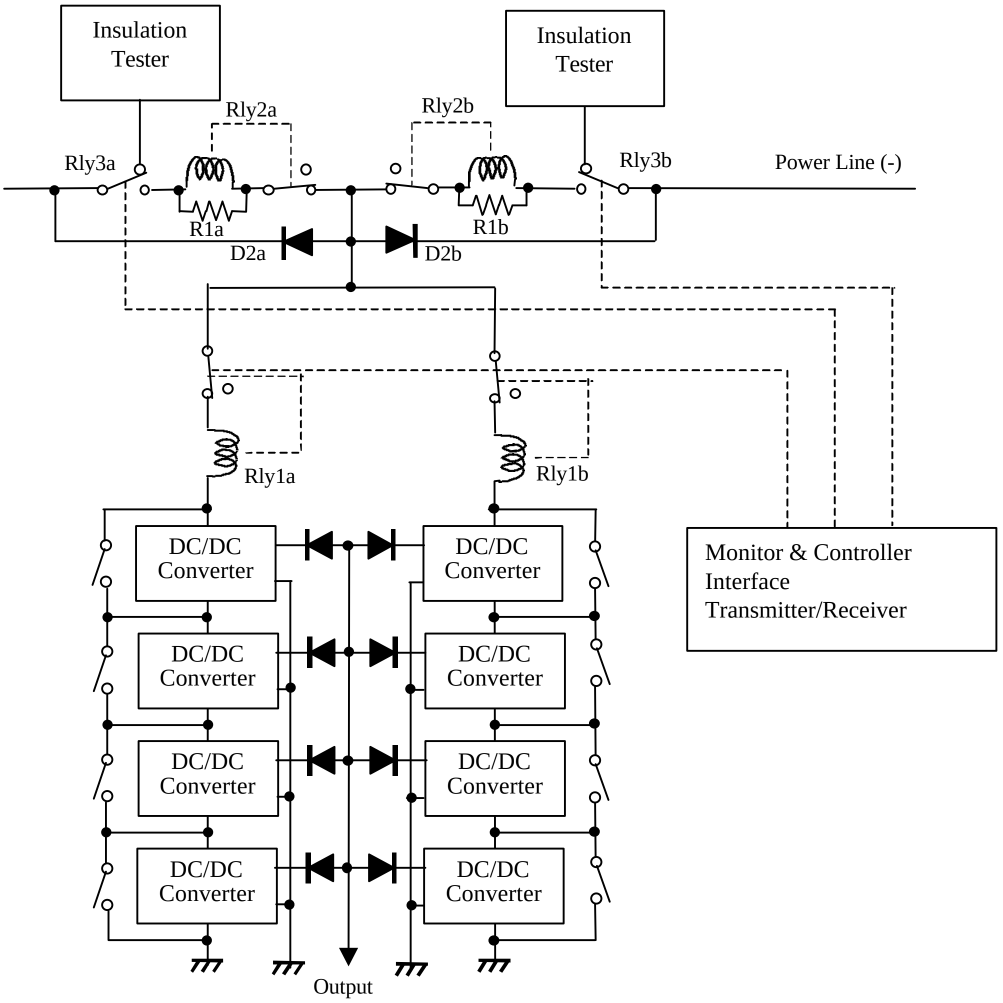

Figure 5 One model for a power regurator at Branch-MUX of CV system

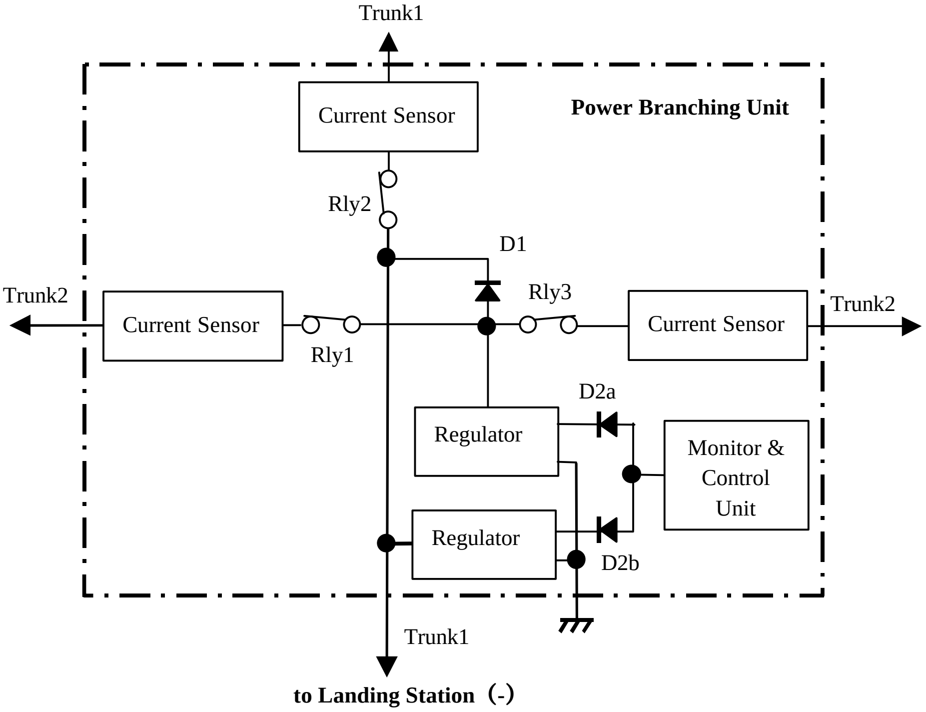

Figure 6 One model for a power branching system at P-BU of CV system

command sent from land stations for test and maintenance.

When shunt fault occurs in the main power feeding line, electric relay Rly2a or Rly2b will be activated to detach the fault portion. When the right hand cable broke, relay Rly2b will be activated, and when left hand cable broke, relay Rly2a will be activated. In this case, power supply to the regulator will be done through the diode D2a or D2b. Register R1a and R1b are used to adjust the sensitivity of the relays. By adjusting the sensitivity of the relays in each observation node, in the order that the right hand observation node has the more sensitive relay Rly2b and the less sensitive relay Rly2a, the relay most close to the fault point will be activated. The fault point can be separated from the other portion of the cable network, and the power can be supplied to all the normal observation nodes from PFEs at both end of the cable.

A concept of a power branching system for P-BU of CV power feeding system is shown in Figure 6. In this figure, trunk1 is connected to the landing station, and trunk2 is connected to the other P-BU. In case excess currents were detected with the current sensors, relays (Rly1, Rly2, Rly3) would detach the troubled cable section. The relays should also be controlled from land stations. As the trunk1 and the trunk2 are connected by a diode D1, even if the trunk1 were shunt to sea water, trunk2 would be fed through the other P-BU.

Assuming the three PFEs or three trunk1s in the right hand in Figure 4 are failed and only the PFE at the left end is alive, and assuming the output voltage of the PFE is 4,053V, the output current of the PFE becomes 6.46A. It is also assumed that the averaged power consumption of each observation node is 277W, efficiency of DC/DC converters in B-MAX is 80%, and the resistance of the underwater cable is 0.7Ω/km. The voltage at the far end of the cable from the PFE becomes 2,000V. As the rated maximum voltage of the conventional underwater telecommunication system is about 10kV, power feeding with 4,053V and 6.46A is feasible. The proposed CV power feeding system is robust against faults of PFE and cable.

Constant current power feeding system

As mentioned in the previous section, the CC power feeding system is robust against cable breaks and suitable for power feeding to underwater repeaters. Moreover as the repeater circuit is floating against sea water, a cable fault point can be located by measuring DC resistance between the power feeding line and sea water in case of shunt fault, or by measuring capacitance between the power feeding line and sea water in case of open cable fault. However the constant current can hardly be divided into two constant current. Therefore when applying CC power feeding system to the cable network depicted in Figure 4, dual cable network depicted in Figure 7 will be necessary.

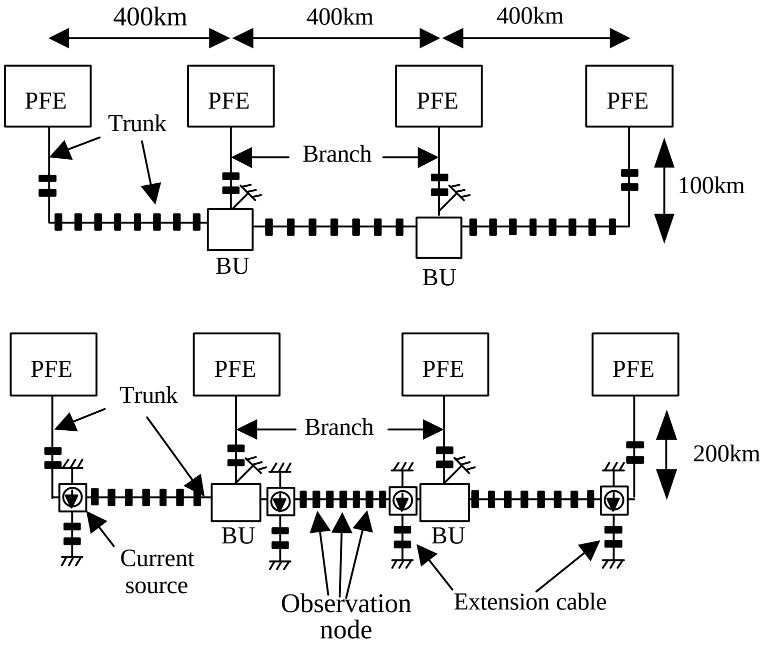

Figure 7 Cable network architecture using CC power feeding technology

Trunks and branches are connected with conventional Branching Units (BUs). Usually high-voltage relays are used in these BUs to switch the connection. These relays connect two of the power lines with each other, and the third line (usually branch line) is connected to sea earth. In case of cable fault, the connection is switched so that the broken line is detached and the normal two lines are connected with each other. Power feeding can be resumed through the normal two lines. The switching relays in BUs can be controlled by the start-up procedure of power feeding, and no special controller is needed.

In order to supply electric power to the extension cables, current sources, that is DC/DC converters operating in CC mode, are inserted in the trunk.

As it is difficult to input directly constant current into DC/DC converters, zenar diodes are inserted in the input stage of DC/DC converters. This causes power-loss and lower the conversion efficiency. Especially when the load is lower, most input power is consumed at the input zenar diode, that causes heat dissipation issue. Figure 8 shows one solution for this issue. In this solution, inputs of plural DC/DC converters are connected in series and outputs are connected in parallel. When the load is low, some of the input zenar diodes are shunted with the relays so that corresponding DC/DC converters do not work in order to increase the efficiency.

If one of the PFE failed, the other PFE will supply power to the whole system.

Although cables nearby landing stations are doubled, the CC power feeding system has many advantages and its relating technology is matured, it is still one of the options. Assuming the average power consumption of the observation node is 277W, efficiency of the DC/DC converters is 0.7, resistance of the cable is 0.7Ω/km, and supply current is 3A, the

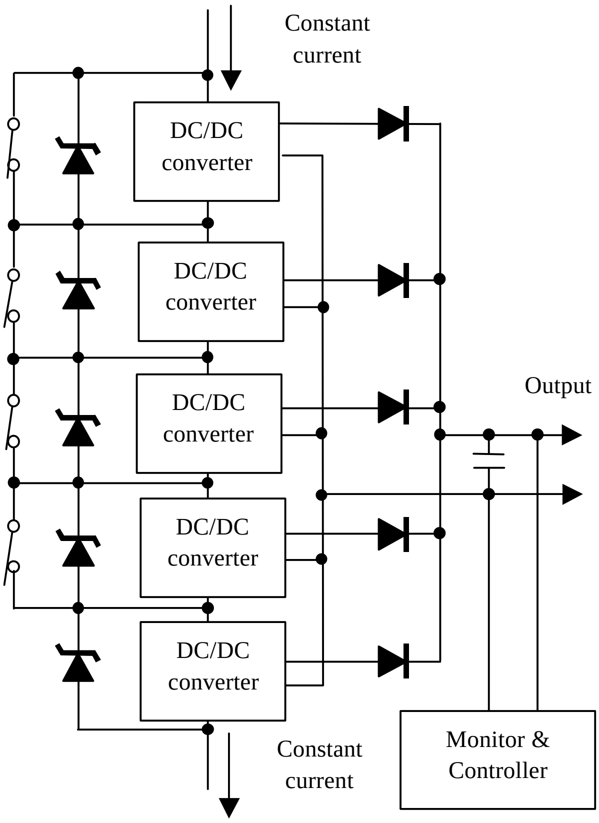

Figure 8 an example of block of P-BU for CC power feeding system

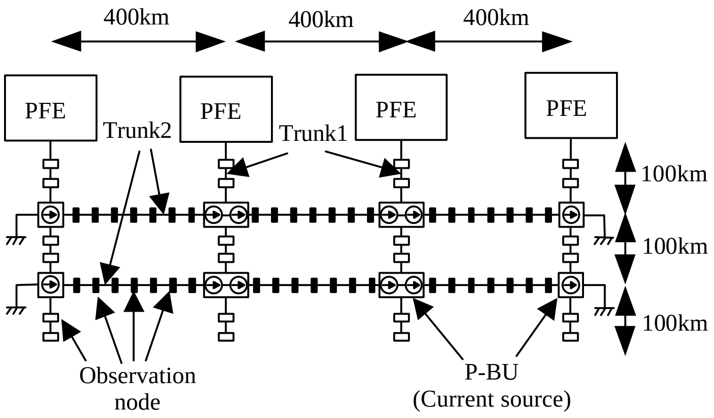

Figure 9 Cable network architecture using hybrid power feeding technology

supply voltage at the PFE becomes 8.8kV for the lower network in Figure 7 even when three of the PFE fails and only one PFE at the right or left end is alive.

Hybrid power feeding system

Hybrid power feeding system uses CV power feeding for trunk1 and CC power feeding for trunk2 as depicted in Figure 9. CC mode has various attractive advantages as mentioned in the previous section. DC/DC converters in P-BUs supply electric power to trunk2 in CC mode. As the input of the DC/DC converters are constant voltage, the conversion efficiencies can be kept high even in case of low load. Assuming the average power consumption of the observation node is 277W, number of nodes is 7, efficiency of the DC/DC converters is 0.7, resistance of the cable is 0.7Ω/km, and supply current is 1A, the output power of the current source in the P-BU becomes 2.3 kW. In this system, when one of the current sources in P-BUs fails, a current source at the opposite end of the section backups the failed current source as in the case for CC power feeding system. In this case, the output power of the current source becomes 4.6kW. If the cable shunt fault happens in trunk2, the system continues to supply power to observatories like the CC power feeding system. Heat dissipation, size and reliability of the current sources in P-BUs are issues to be considered, but the hybrid power feeding system is robust against cable faults similar to CC power feeding system. Hybrid power feeding system is one option for the scientific cable network.

Conclusions

The outline of the feasibility study on the scientific underwater cable network that was done with ARENA working group was described. Three power feeding system were analyzed and compared. Each system has its own advantages and disadvantages. The most suitable technology to be selected for the real system will differ depending on the size and required power of the network. When the basic architecture and the power required for the system are finally determined, the most suitable power feeding system will be selected.

The ARENA group continues the feasibility study. A detailed system design will be done when an actual project starts. The presented system may be changed according to further feasibility study and the detailed system design. The ARENA group is also doing other feasibility studies on system architecture, communication system, data protocol, timing, deploy and recovery operation, and reliability. These will be presented elsewhere.

The proposed cable network should be used multidisciplinarily as mentioned above. Therefore the network should be open to various sensors and many researchers. The network will work as an infrastructure, and should have a standard interface for sensors. Recently, based on ARENA group's work, a committee was organized in IEEE Oceanic Engineering Society Tokyo Chapter. The committee is open to anyone who has as interest in scientific underwater cable network. The authors think international co-operation is also important.

Acknowledgment

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