Feasibility Study on Power Feeding System for Scientific Cable Network ARENA

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ABSTRACT

Power feeding system is the most challenging technical issue to realize a mesh-like underwater cable network for scientific use. IEEE OES (Institute of Electrical and Electronics Engineers Oceanic Engineering Society) Japan Chapter organized a committee on the underwater cable-network for scientific seafloor monitoring, and conducted a technical feasibility study. In this paper, outline of the proposed power feeding system will be presented. In the feasibility study, three systems were proposed and compared, namely, (a) constant current (CC) power feeding system, (b) constant voltage (CV) power feeding system, and (c) hybrid system that consists of constant voltage feeding subsystem and constant current feeding subsystem. As a result of the feasibility study, the authors think the CC power feeding system is the most promising system for the proposed scientific cable network. The authors also proposed a new current to current converter that is the key devise for the CC power feeding system.

1. INTRODUCTION

IEEE OES Japan Chapter organized a committee on the underwater cable-network for scientific seafloor monitoring, and conducted a technical feasibility study. The proposed scientific submarine cable network was named ARENA. The outline of ARENA is described by Shirasaki et al.[1] The committee was established in February 2002, and published a technical white paper in January 2003. Forty-five engineers with various backgrounds from private companies, universities and research institutes participate in the committee. The committee consists of the steering committee, the power feeding working group, the data transmission working group and the underwater subsystem working group. The underwater subsystem working group handled the configuration of the underwater system, reliability, construction and maintenance. The detail of the data transmission system is described by Yoshida et al.[2] In this paper, outline of the proposed power feeding system will be presented.

Figure 1 shows the envisioned future scientific cable network around the Japanese archipelago. As many massive earthquakes occur on plate boundaries, the route of the cable network is located near plate boundaries. It is desirable to locate many seismometers two-dimensionally with interval of 20-50km in order to precisely monitor earthquakes. Therefore the proposed cable network has mesh-like configuration.

For the underwater telecommunication cable system, CC (Constant Current) power feeding system is used, because it has following advantages.

(1) It is robust against cable shunt faults. As electric power is usually supplied from both end of the cable, even if the cable is broken at one point, the electric power can be continuously supplied from the both end. Only the electric potential distribution of the cable changes.
(2) It is easy to electrically isolate underwater electric circuits from seawater, as there is no sea earth brought into electric circuits.
(3) In case of a cable shunt fault, the fault point can easily be localized with measuring the dc resistance between the power feeding line and the sea earth.

Figure 1 Envisioned scientific cable network ARENA

However, it was not easy to supply electric power to a mesh-like underwater cable-network with CC power feeding system, as there was no device reported to branch constant currents. Therefore

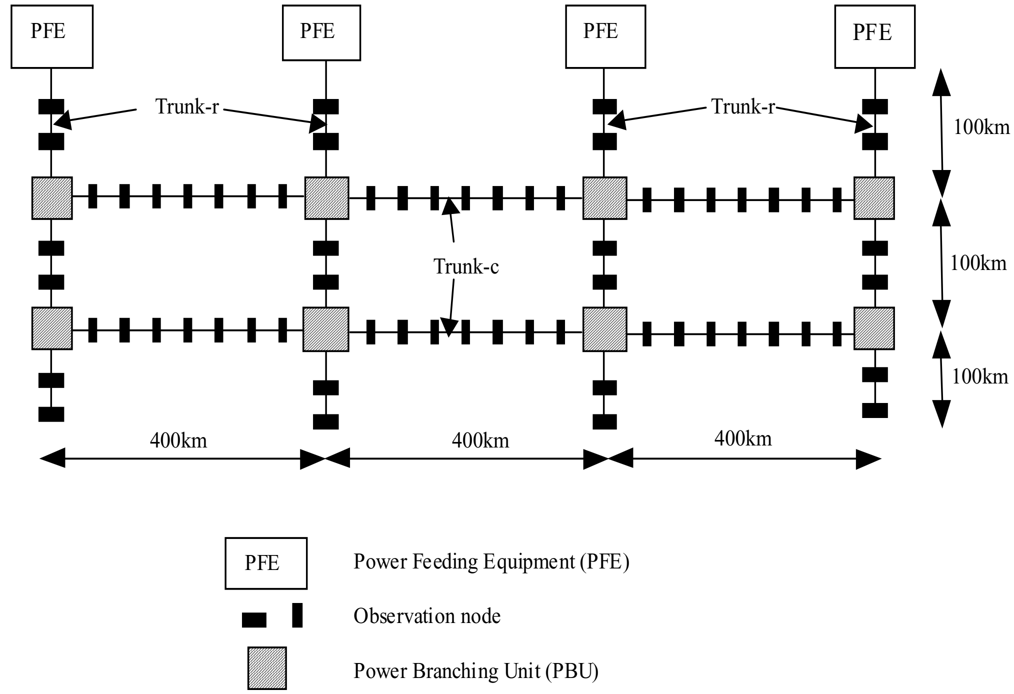

Figure 2: Engineering model of ARENA

This engineering model was made to analyze the power feeding system. In this model, the network has four landing point and mesh-like topology corresponding to the off Sanriku area in Figure 1 where two backbone cables are placed on both side of the plate boundary. 66 observation nodes are placed with 50km intervals. PBUs (Power Branching Unit) receive electric power from PFEs (Power Feeding Equipment) on the landing stations, and provide electric power to the laterally stretching cables.

Table 1 Estimated number of observatories and power consumption

	Average power (W)	Number of observatories	Subtotal (W)
Geophysical observatory	15	132	1,980
Downhole observatory	69	2	138
Oceanographical observatory	121	10	1,210
Geodetic observatory	11	43	473
Array sensors	4	2	8
Biological 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

a new power feeding system is required to be developed.

In the feasibility study, we had compared three methods, which are (1) CC power feeding system, (2) CV power feeding system, and (3) hybrid power feeding system that consists of CV power feeding subsystem and CC power feeding subsystem. Kirkham et.al[3] proposed a CV power feeding system for NEPTUNE.

As a result of the feasibility study, the authors think the CC power feeding system is the most promising system for the proposed scientific cable network. The authors also proposed a new current to current converter that is the key devise for the CC power feeding system.

2. BASIC REQUIREMENT

In order to simplify the analysis, an engineering model of a power feeding network depicted in Figure 2 was made. It corresponds to the northeastern portion of the cable network in Figure 1. Observation nodes are inserted in the trunk cable with an interval of 50km, and its total number is 66. Power Branching Unit (PBU) connects trunk-r and trunk-c.

Table 1 shows number of observatories in the network of and estimated power consumption of each observatory. Geophysical observatories that include seismometers and tsunami sensors are distributed with an interval of 25km. The average of the power consumption of a node is 277W.

The configuration of the underwater cable is one of important factors that has a great impact on the power feeding system. From a viewpoint of cost and reliability, the authors have chosen to use underwater optical telecommunication cables. They have been used widely and have very long lifetime and supreme reliability. Their configuration is simple and their cost is appropriate. All the related technique and tools for construction and repair works are available. However there is only one electric conductor in the underwater optical telecommunication cable and the return current flows in the sea-

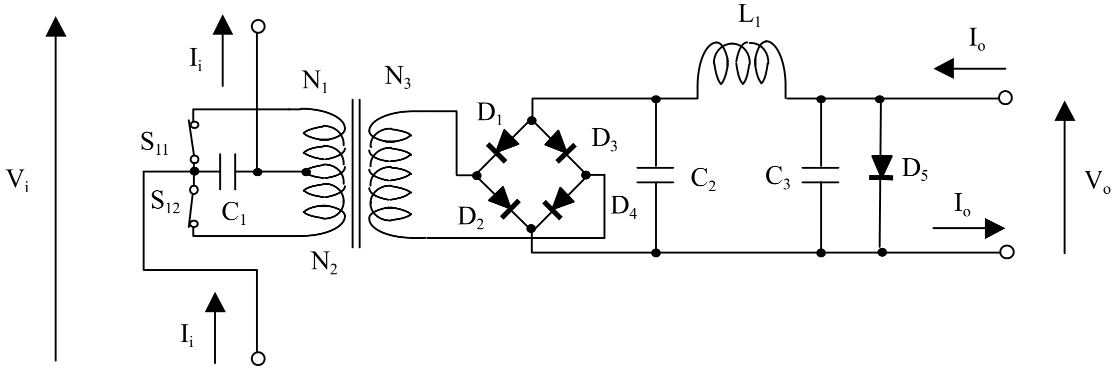

Figure 3 Basic circuit of the current to current converter

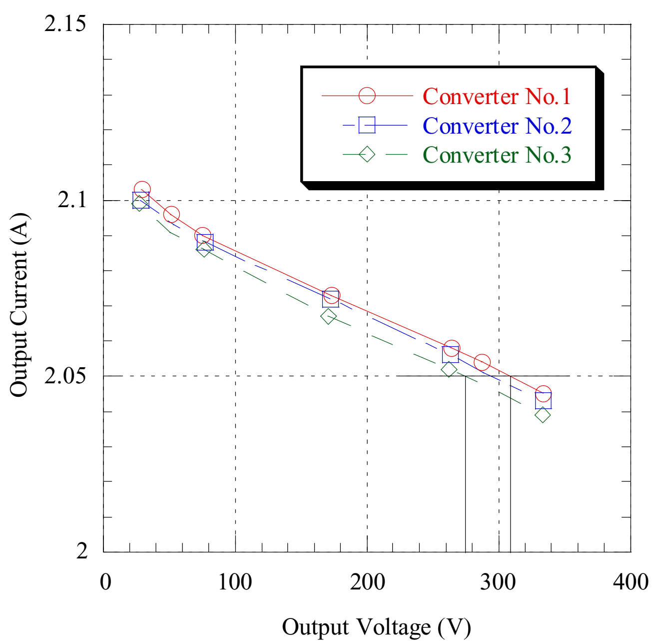

Figure 4 The output characteristics of three prototype of the current to current converter

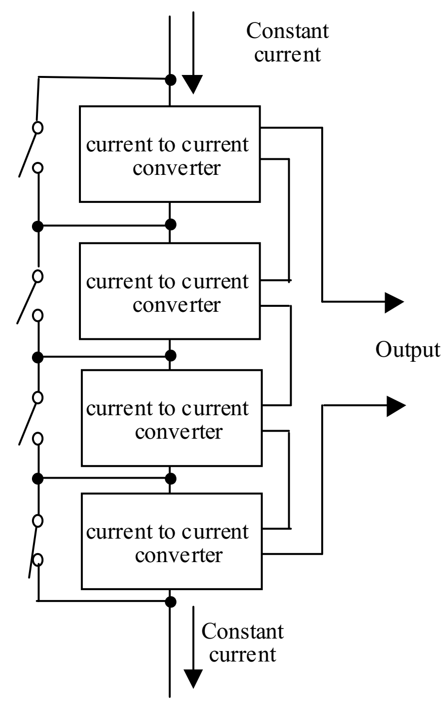

Figure 5 A typical configurarion of a current source that will be placed in the PBU

water. This feature strongly restricts the feasible power feeding system.

When designing power feeding system, the authors took the following items into consideration, (1) reliability, (2) cost, (3) robustness against cable fault, (4) stability, (5) size and weight of enderwater equipments and (6) power consumption of underwater equipments.

Higher reliability is required for underwater equipments, but reliability and cost are inconsistent with each other. Moreover the underwater power system for ARENA is so complicated that it is not realistic to use only such qualified parts as those used in underwater repeaters for underwater telecommunication cable system. The practical way to realize a highly reliable and robust system is to increase redundancies. Another practical way is to minimize the extent to which impact of a break extends.

One of the advantages of the mesh-like network architecture is that each observation node can be accessed from plural landing stations. This means even if a break in cable interrupts power feeding and data transmission, all observation nodes will be able to be accessed from other landing stations, and the network will continue to work. In order to secure the operation when a cable fault occurs, the fault point should be localized from landing stations.

Size, weight and power consumption of the underwater equipments should also be taken into consideration to develop a realistic device that can be deployed to and recovered from 6,000 meter water depth.

3. CONSTANT CURRENT POWER FEEDING SYSTEM

As described in the introduction, although CC power feeding system has many advantages, it was hard to branch a constant current. In the feasibility study, a new current to current converter was proposed that enabled to branch a constant current.

Figure 3 shows the proposed basic circuit of the current to current converter. The input dc constant current is switched with switching devices S_{11} and S_{12}, and fed into the transformer. The output of the transformer is rectified and filtered. The level of the input

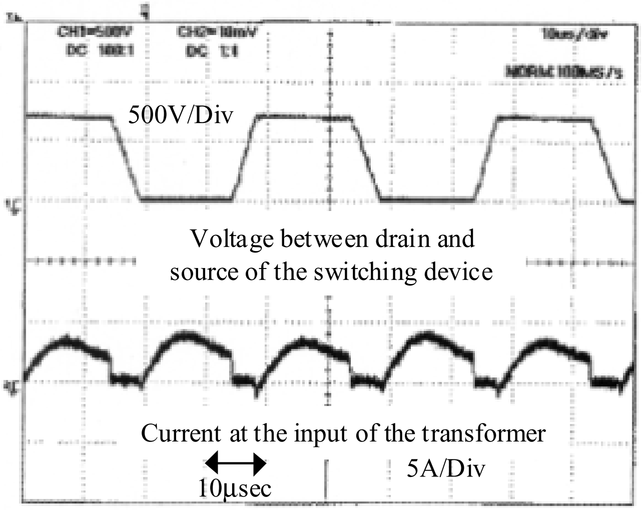

Figure 6 Observed waveform of the current to current converter

current and number of windings of the transformer determine the level of the output current. As this basic circuit is very simple and there is no feedback loop, high reliability and high conversion efficiency can be expected. However there are following issues to be considered.

(1) Is it possible to switch a dc constant current while retaining the reliability of the switching device?
(2) Is it possible to connect plural current to current converters in series to increase the output power?
(3) Is it possible to start up power feeding without making excess inrush current?
(4) Is it small and does it have high reliability and low power consumption so as to be put in a small pressure tight housing.

In order to address these issues, the authors have made a prototype of the basic circuit and evaluated its performance. Figure 4 shows the current-voltage characteristics of the outputs of three current to current s. The characteristics of the three converters are very similar to each other. This means that these three converters can be connected in series to increase the output voltage and power as explained later. It can also be confirmed that as the converters have high output impedance of about 5.6kΩ, it can be used as a current source.

Figure 5 shows a typical configuration of a current source in which four current to current converters are used. Their inputs and outputs are connected in series to heighten the output power. One of four converters is a spare and its input is shunted. When one of the working converters fails, its input will be shunted and the spare converter will be activated. Assuming the three tested converters are connected in series and the output current is 2.05A, the output voltage of the three converters are between 275V and 310V.

Figure 6 shows an example of the waveform of the converter. In this case, as the transient time of the switching is not optimized, the waveform is not sharpened. Although the efficiency is about 90% when the output voltage is 300V, it can be improved by optimizing the switching waveform.

All these results show that the proposed current to current converter has promising features. The authors will continue the study on the current to current converter.

4. CONSTANT VOLTAGE POWER FEEDING SYSTEM[(4), (5)]

The advantage of the CV system is that it is easy to branch electric power. However there are also some technical issues to be considered. These issues include,

(1) How to localize fault points of underwater cables.
(2) How to detach a shunt fault portion of underwater cables.
(3) Is it possible to develop a DC/DC converter with high input voltage small enough to be put in a pressure tight housing?

Figure 7 is the proposed configuration of the underwater power source for each observation nodes. This power source regulates electric power of low voltage from high input voltage. In this scheme, dual switching regulators are used to increase redundancy and reliability. In the regulator, plural converters are connected to share the input high voltage and also to increase redundancy.

Relays Rly1a and Rly1b are placed in series with switching regulators. These relays will be activated and latched when excess current flows due to faults, and protect the converters. They are able to be controlled by a command sent from landing stations for test and recovery.

When a shunt fault occurs in the trunk cable, electric relay Rly2a or Rly2b will be activated to detach a shunt fault portion. When the rightward cable shunted to seawater, surge current will flow leftward from the shunted point assuming the polarity of the feeding voltage is negative. It will flow through Rly2b and diode D2a, and will activate relay Rly2b to detach the rightward cable. Electric power will be supplied continuously through leftward cable and the diode D2a to the regulators. If left-hand cable breaks, relay Rly2a will be activated. Register R1a and R1b are used to adjust the sensitivity of the relays. By adjusting the sensitivity of the relays so that sensitivities of relay Rly1bs increase and sensitivities of relays Rly1as decrease when it goes to the right, the relay most close to the fault point will be activated first. The fault portion can be separated from other portions of the cable network, and the power can be supplied to all the normal portions from PFEs at both end of the cable. Dynamic analysis of the surge current due to cable shunt fault and protection circuits is needed to ensure the behavior of the above protection system.

Figure 8 shows the proposed configuration of a power branching system in PBU for CV power feeding system. In this figure, trunk-r is connected to the landing station, and trunk-c is connected to the other PBUs. When a current sensors detects an excess current, relays (Rly1, Rly2 and Rly3) will detach the faulted cable section. The relays should be latched and also be controlled from landing stations. As the trunk-r and the trunk-c are connected through a diode D1, even if the trunk-r is shunted to seawater, trunk-c will be fed through the other PBUs.

Assuming the three PFEs in Figure 2 are failed and only the PFE at the left end is working, and assuming the output voltage of the working PFE is 4,053V, the output current of the PFE and the voltage at the far end of the cable become 6.46A and 2,000V respectively. It is also assumed that efficiency of DC/DC converters in the observation nodes is 80%, and the resistance of the underwater cable is 0.7W/km. 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.

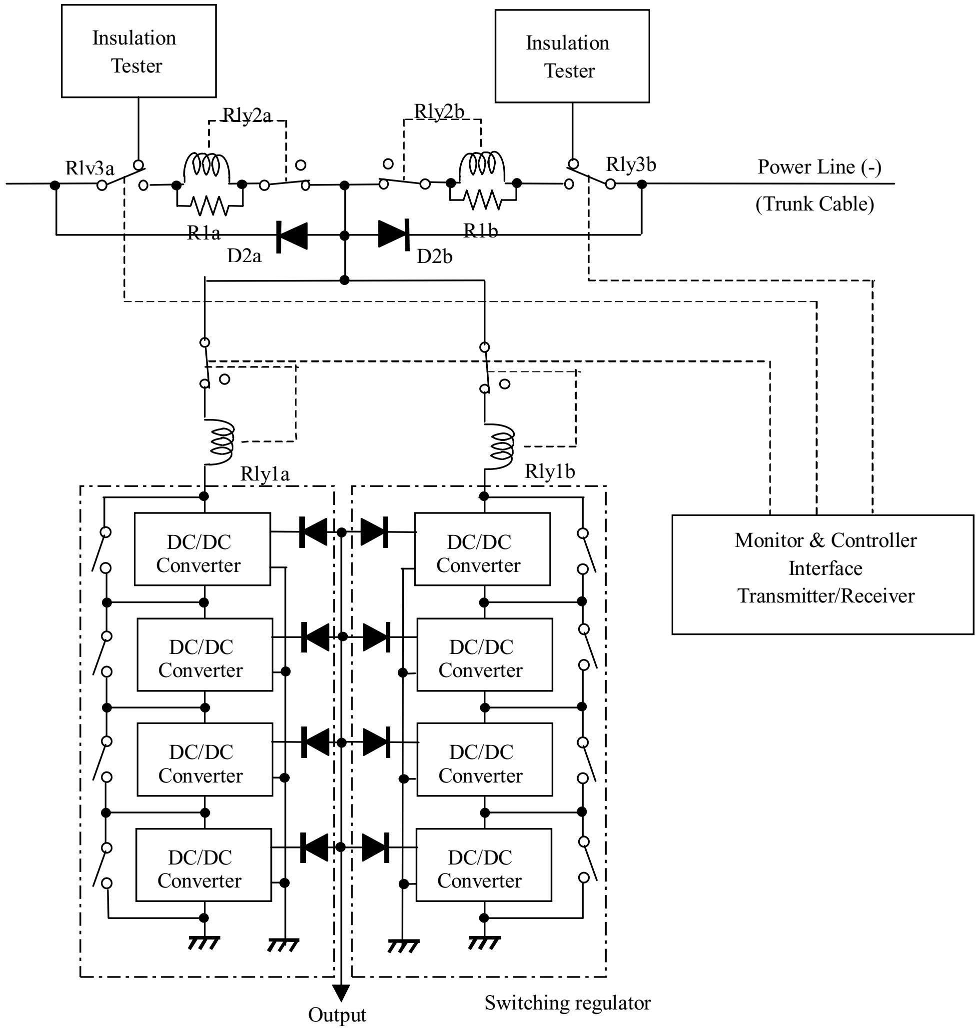

Figure 7 Proposed configuration of the underwater power source for each observation nodes

5. HYBRID POWER FEEDING SYSTEM[(4), (5)]

Hybrid power feeding system uses CV power feeding for trunk-r and CC power feeding for trunk-c. The hybrid power feeding system utilizes the both advantages of CV power feeding system and CC power feeding system. In the hybrid system, conventional DC/DC converters are placed in PBUs. These DC/DC converters are used in constant current mode. However two kinds of power sources with CV input and with CC input for observation nodes are required. This disadvantage increases the development and maintenance cost.

6. CONCLUSIONS

The feasibility study on the scientific underwater cable networks are conducted by a committee on the underwater cable-network for scientific seafloor monitoring organized by IEEE OES Japan Chapter. Basic requirements are described to do the feasibility study efficiently. Three power feeding systems were analyzed and compared. Each system has its own advantages and disadvantages.

The CC power feeding system is conventionally used for underwater telecommunication cable system, and has many advantages such as robustness against cable shunt fault and easiness to isolate electric circuits from seawater. However it was not easy to branch a constant current. The authors proposed a new current to current converter for the CC power feeding system, and conducted preliminary experiments using a prototype. The results show the promising feature. The authors will continue the study on the current to current converter.

The CV power feeding system has an advantage that it is easy to branch eclectic power. However there are also some technical issues to be considered including measures against cable shunt faults and development of a power source with high input voltage. Basic configurations for PBUs and power sources for underwater observation nodes are proposed.

The hybrid power feeding system utilizes the both advantage of CV power feeding system and CC power feeding system. However two kinds of power sources with CV input and CC input are required for the hybrid system. This disadvantage increases the development and maintenance cost.

REFERENCES

(1) Y. Shirasaki, M. Yoshida, T. Nishida, K. Kawaguchi, H. Mikada, K. Asakawa and members of committee on the submarine cable-network for scientific seafloor monitoring organized by IEEE OES Japan Chapter, ARENA : A Versatile and Multidisciplinary Scientific

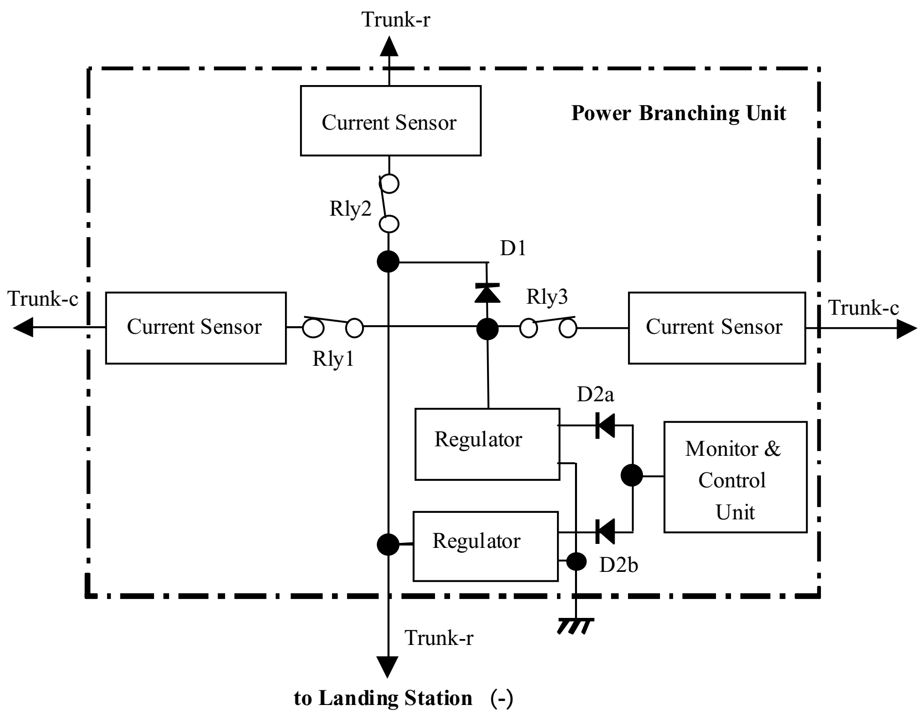

Figure 8 Proposed configuration of a power branching system in a PBU for CV power feeding system

Submarine Cable Network of Next Generation", Proc. of Scientific Submarine Cable 03, 2003

(2) M. Yoshida and Y. Hirayama, "The Data Transmission System for the Real-time Seafloor Monitoring Cable Network", Proc. of Scientific Submarine Cable 03, 2003

(3) H. Kirkham, et. al., "The design of the NEPTUNE Power System", Proc. of OCEANS 2001, 2001

(4) Y. Shirasaki, T. Nishida, M. Yoshida, Y. Horiuchi, J. Muramatsu, M. Tamaya, K. Kawaguchi and K. Asakawa, "Proposal of Next-generation Real-time Seafloor Globe Monitoring Cable-network", Proc. of OCEANS 2002

(5) K. Asakawa, J. Muramatsu, M. Aoyagi, K. Sasaki and K. Kawaguchi, "Feasibility Study on Real-time Seafloor Globe Monitoring Cable-network - Power Feeding System -", Proc. of Underwater Technology, pp.116-122, 2002