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.

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
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. proposed a CV power feeding system for NEPTUNE.

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) receives electric power from PFEs (Power Feeding Equipment) on the landing stations, and provides electric power to the laterally stretching cables.

Table 1 Estimated number of observatories and power consumption

<table>
<thead>
<tr>
<th>Geophysical observatory</th>
<th>Average power (W)</th>
<th>Number of observatories</th>
<th>Subtotal (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downhole observatory</td>
<td>69</td>
<td>2</td>
<td>138</td>
</tr>
<tr>
<td>Oceanographical observatory</td>
<td>121</td>
<td>10</td>
<td>1,210</td>
</tr>
<tr>
<td>Geodetic observatory</td>
<td>11</td>
<td>43</td>
<td>473</td>
</tr>
<tr>
<td>Array sensors</td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Biological observatory</td>
<td>212</td>
<td>2</td>
<td>424</td>
</tr>
<tr>
<td>AUV station</td>
<td>60</td>
<td>10</td>
<td>600</td>
</tr>
<tr>
<td>Acoustic tomography</td>
<td>60</td>
<td>4</td>
<td>240</td>
</tr>
<tr>
<td>Transmission and power system</td>
<td>200</td>
<td>66</td>
<td>13,200</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>18,273</td>
</tr>
</tbody>
</table>

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.
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 underwater 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 de constant current is switched with switching devices S\textsubscript{11} and S\textsubscript{12}, and fed into the transformer. The output of the transformer is rectified and filtered. The level of the input

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 configuration of a current source that will be placed in the PBU
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 ef-
ciency 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 con-
sumption so as to be put in a small pressure tight housing.

In order to address these issues, the authors have made a proto-
type 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 volt-
age 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

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 elec-
tric power of low voltage from high input voltage. In this scheme,
dual switching regulators are used to increase redundancy and reli-
ability. 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 sensi-
tivities 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. Dyn-
amic 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 branch-
ing 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 observa-
tion nodes is 80%, and the resistance of the underwater cable is 0.7Ω/
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.
5. HYBRID POWER FEEDING SYSTEM

Hybrid power feeding system uses CV power feeding for trunk- and CC power feeding for trunk-c. The hybrid power feeding system utilizes 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 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 faults 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 electric 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 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

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

(1) Submarine Cable Network of Next Generation”, Proc. of Scientific Submarine Cable 03, 2003


