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Novel Current toCurrent Converter for Mesh-like Scientific Underwater Cable Network

- Concept and Preliminary TestResult -

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***Abstract*-A novel seafloor observation system using underwater cable network named ARENA has been proposed by the technical committee of IEEE OES Japan Chapter. ARENA has mesh-like cable network and deploys a variety kind of sensors on the seafloor two-dimensionally. It can supply electric power and communication line to sensors on the seafloor, and enables long-term, continuous monitoring that can not otherwise be realized.**

One of the most challenging issues to realize a mesh-like cable network is power feeding. In this paper, a new current to current converter that branches a dc constant current into two dc constant currents is proposed. Preliminary experiments using a prototype show promising results. Results of the computer simulation of the current to current converter coincide with the experimental results.

I. INTRODUCTION

Ocean has deep relation with human life, and it is very important to know the nature of the ocean and utilize the ocean. Cabled observatories are the most secure way to enable continuous and long-term observation on the seafloor. In Japan, eight cabled observatory systems have been developed [1]. The objectives of these systems are monitoring of earthquakes and disaster mitigation. In 1999 multipurpose cabled observatories with many kinds of sensors were constructed by H20 [2] and VENUS [3] project. In these projects, decommissioned underwater telecommunication cables were utilized.

Recently related technologies such as underwater telecommunication cable technology, Internet technology and computer technology evolve very rapidly. Wavelength Division Multiplex (WDM) technology and optical amplifier technology provide us extremely high data-transmission capacity and flexible network easy to expand. Internet technology makes it possible to construct flexible data network between observatories and researchers in laboratories. These evolutions in the related field make it possible to develop a new kind of versatile and flexible scientific underwater cable networks.

In the USA and Canada, NEPUTUNE [4] project was initiated and new cabled observatory systems are to be constructed in the Monterey Bay [5] and Victoria Lake [6]. The NEPTUNE is multidisciplinary system, and has mesh-like cable topology. In Europe, ESONET [7] project was also proposed.

Considering the above situations, IEEE OES Japan Chapter organized a technical committee on the scientific submarine cables. The purpose of the committee is to conduct a technical feasibility study on the scientific use of underwater cables. The committee was established in February 2002, and published a technical white paper in January 2003.

The proposed scientific submarine cable-network[8] is named ARENA (Advanced Real-time Earth monitoring Network in the Area). The ARENA can be used not only for seismology but also for many scientific fields[9] such as geodynamics, geophysics, geochemistry, oceanography, marine environmentology, ecology, biology and development of mineral resource.

The ARENA has the following features. (1) Mesh-like cable network configuration covering vast research area, (2) Over 66 observation nodes with 50km intervals, (3) Robust against failures, (4) Wideband optical transmission system capable of transmitting plural HDTV (High definition Television) signal and synchronizing signal with accuracy of one microsecond, (5) System extensibility and (6) Exchangeability of sensors.

In ARENA, underwater telecommunication cables will be used for trunk cables, because they have supreme reliability and very long lifetime. Their configuration is simple and their cost is moderate. 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 seawater. This feature strongly restricts the feasible power feeding system.

For the conventional underwater telecommunication cable system, Constant Current (CC) 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 to all the cable from the both ends. 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.

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(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 have compared three systems [10], that is (1) CC power feeding system, (2) Constant Voltage (CV) power feeding system, and (3) hybrid system that comprises CC power feeding system and CV power feeding system. In the NEPTUNE system, CV power feeding system is being considered [11]. In the feasibility study of ARENA, a new current to current converter was proposed that enabled to apply CC power feeding system to mesh-like cable network.

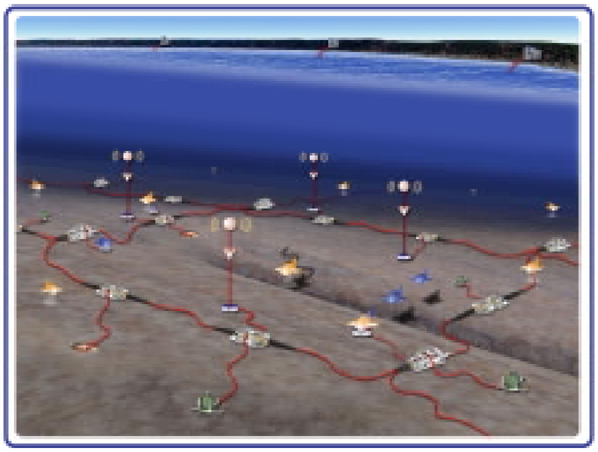
Fig.1 Artistic illustration of ARENA

In this paper, a new a new current to current converter proposed in the feasibility study will be described. The current to current converter is the key device for the CC power feeding system. Results of preliminary experiments using a prototype and results of the computer simulation of the current to current converter show the promising features of the current to current converter.

II. BASIC REQUIREMENT

In order to simplify the analysis, an engineering model of the power feeding network depicted in Fig. 2 was made. Observation nodes are inserted in the trunk cable with intervals of 50km. Power Branching Units (PBU) connect trunk-r and trunk-c.

Plural observatories can be installed in an observation node. Table 1 shows number of observatories in the network 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.

PBUs receive electric power from landing stations and branch the power to trunk-c. Current to current converters that are major parts of the power supply unit are placed in the PBUs. As two PBUs are placed at the both end of trunk-c, two power supply units can provide electric power to a trunk-c. Although it is possible for two power supply unit to share the output power, it is desirable that one power supply unit can provide all the electric power to trunk-c in order to increase redundancy and

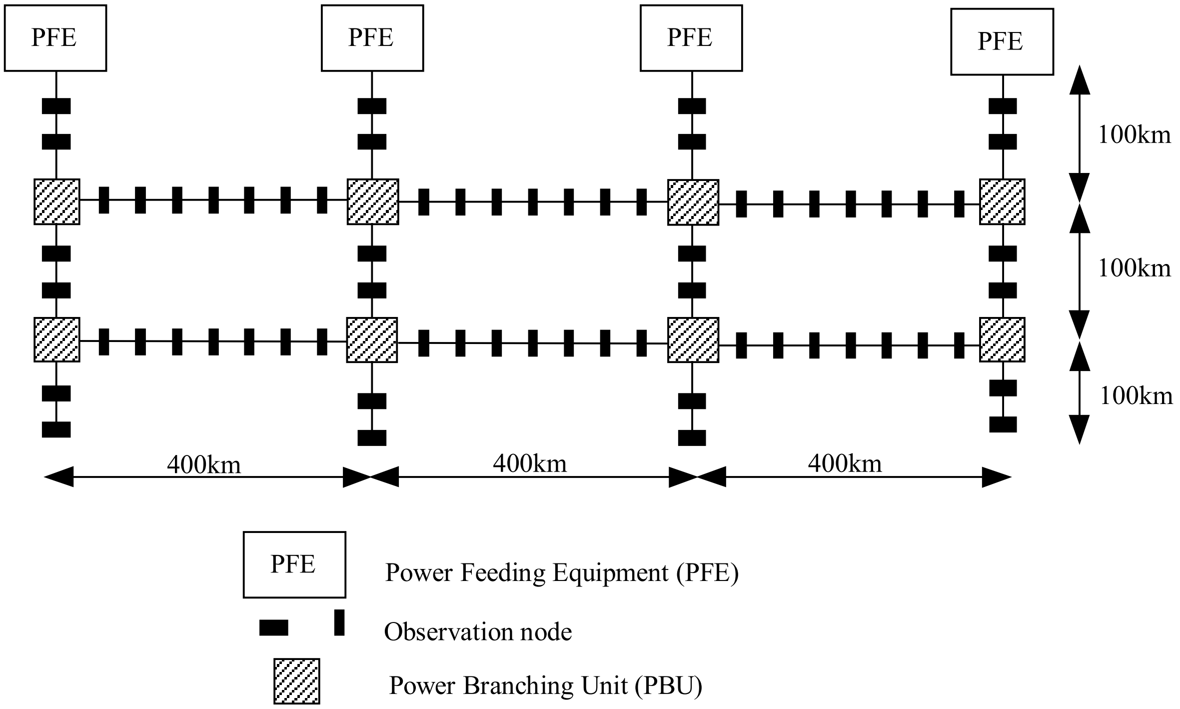

Fig. 2 Engineering model of the power feeding network

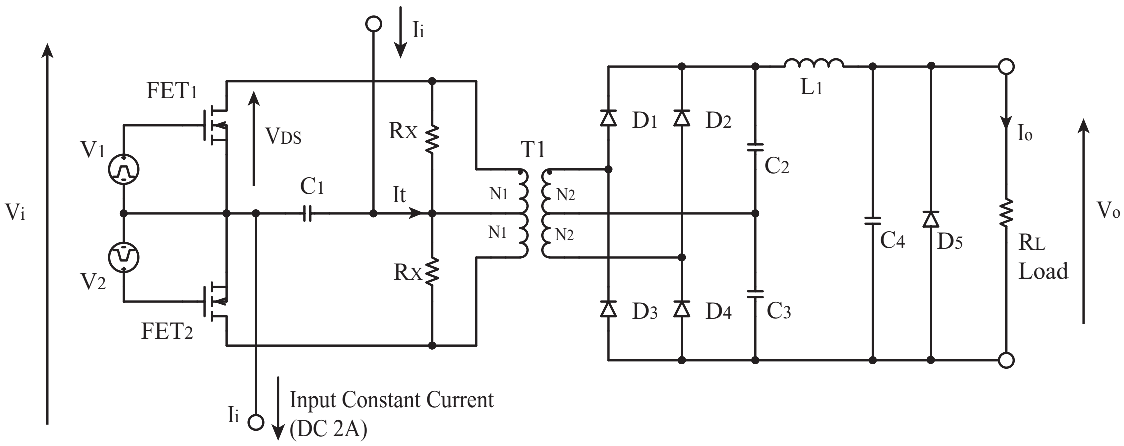

Fig.3 Circuit Diagram of the power supply for computer simulation

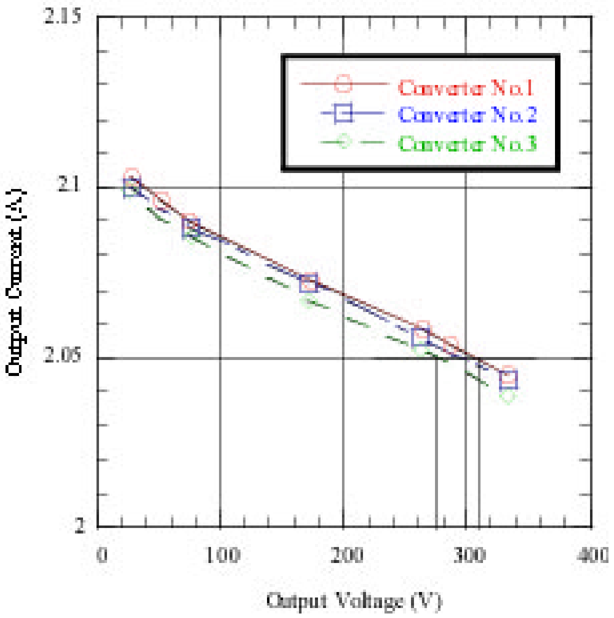

Fig.4 The output characteristics of the thee prototype of the C-C converter

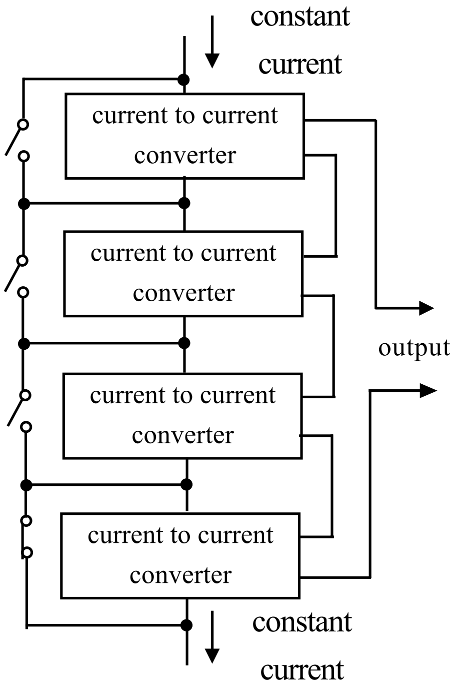

Fig.5 Typical configuration of a current source that will be placed in th PBU

reliability. Assuming the electric resistance of the trunk-c is 0.7Ω/km and the current is 2.6A, the required output power of the power supply unit becomes 3.9kW. It is also assumed that the average power consumption of the observation node and number of observation nodes are 277W and 7 respectively.

The other requirements for underwater power supply units are (1) high reliability, (2) lower cost, (3) robustness against cable faults, (4) long term stability, (5) small size and lower weight and (6) lower power consumption.

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. For ARENA, the reliability of the underwater power unit is secured by increasing the redundancy. Robustness against cable faults is one of the important features of CC power supply system. The other requirements, i.e. stability, size, weight and power consumption are issues to be addressed in the further study.

III. BASIC EXPERIMENTS AND COMPUTER SIMULATION

Fig.3 shows the proposed basic circuit of the current to current converter. The input dc constant current is switched with switching devices FET1and FET2, and fed into the transformer. The output of the transformer is rectified and filtered. The level of the input 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.

Fig.4 shows the measured current-voltage characteristics of the outputs of three current to current converters. 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. 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.

Fig.5 shows a typical configuration of a current source. Their inputs and outputs are connected in series to heighten the output power. One of three 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 converters in Fig.4 are connected in series and the output current is 2.05A, the output voltage of the three converters are between 275V and 310V. In order to realize the output power of 3.9kW, eight converters should be connected serially.

Fig.6 shows a model in which three converters are connected in series. Each converter is represented by an ideal constant current source Ii and an output resistance Ri. Output voltage Vi of each converter depends on Ii and Ri. If the difference between each Ii and Ri is larger, the difference between the output voltage of the converters becomes larger, and each converter can not share the output power. Therefore, it is important that the Ii and Ri of all converters match with each other. As Ii and Rx depend on coupling coefficients, loss of cores, and resistance of FETs, it is important to evaluate the relation between the output characters and the deviation of these values. Therefore, the authors conducted computer simulations of the converter for the evaluation.

B. Model of Computer Simulation

The simulation was done by using a general-purpose circuit simulation software. The model for the simulation was based on the prototype converter shown in Fig. 3. The accuracy of the simulation deeply depends on the model of the transformer. The linear core model was selected for the transformer T1, because its magnetic flux density was far lower than that of the saturation level. In the linear model, a transformer was represented by tow inductances corresponding to each winding and the coupling coefficient. The measured inductances were used for the simulation, and the coupling coefficient was calculated from the leakage inductance. Resistance Rxs in the primary of the transformer shown in Fig.3 represent the loss in the ferrite core. In addition, these resistances also represents transitional switching loss of the FETs.

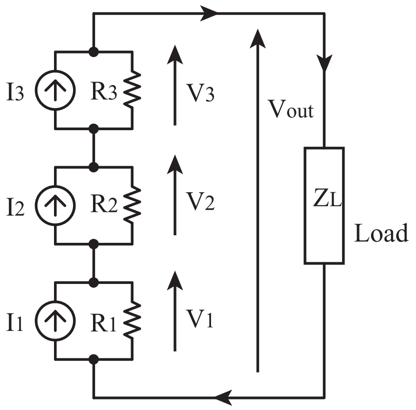

Fig.6 Output model of C-C swiching regulators

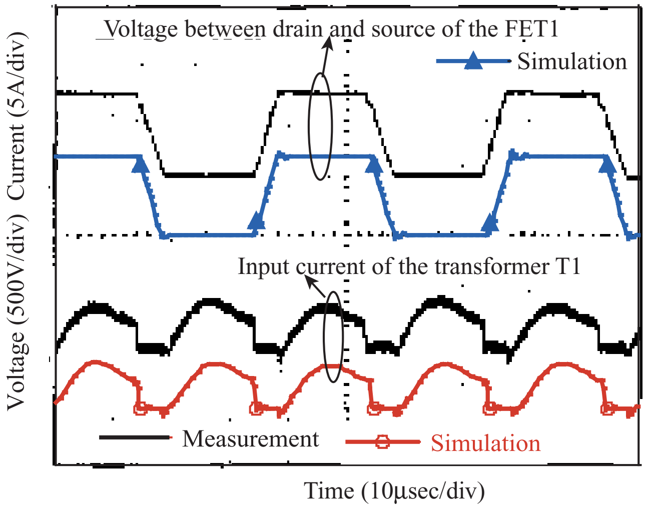

Fig.7 Comparison of observed waveform and result of simulation

C. Result of Computer Simulation

Fig. 7 shows the comparison between observed waveforms and simulation results. The upper two waveforms in this figure show the source-drain voltage of the FET1 in Fig.3, and the lower two waveforms in the figure show the current Ii that flow into the transformer.

The coupling coefficient of the transformer used in the simulation was selected so that the calculated current waveform coincided with measurements. The coupling coefficient obtained

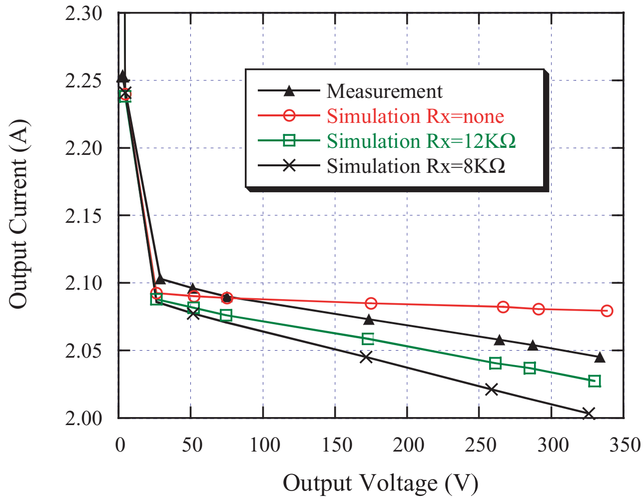

Fig.8 Load regulation calculated by computer simulation when changing registers representing the loss

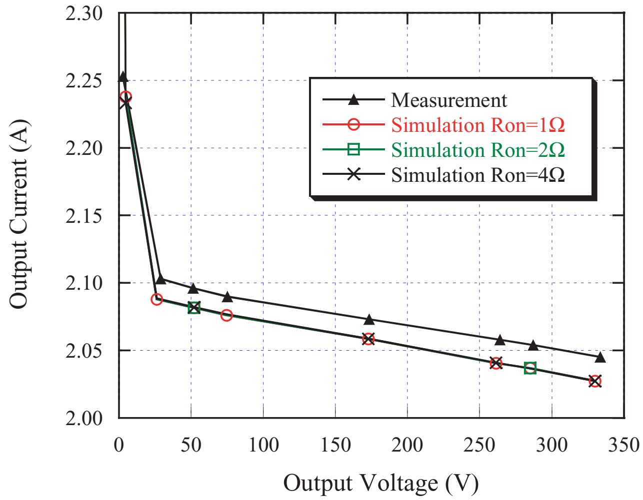

Fig.9 Load regulation calculated by computer simulation when changing on-resistance of FETs

thus was 0.992, that shows good conformance with the measured value of 0.994.

That the simulated waveform well coincides with the measured waveforms shows the simulation model is reasonable.

D. Characteristics of the current to current converter

Fig.8 shows the relation between output characteristic and Rx representing the loss of the transformer and FETs.

The output characteristics with Rx of 12KΩ coincide well with the measured characteristics. It is also clear that the deviation of resistance affects the output characteristics.

Fig.9 shows the output characteristic when the on-resistance of FET(Ron) is changed. It is clear that on-resistance of FET does not affect the output characteristic.

As the converter is driven with constant current, the on-resistance does not affect the input current and the output characteristics. The winding resistance of the transformer does not affect the output characteristics for the same reason. However, these resistances deteriorate the efficiency of the converter.

Fig.10 shows the output characteristic of the converter when the coupling coefficient of the transformer was changed. This figure shows that coupling coefficient has little influence on the output characteristic assuming it is larger than 0.99. For a common transformer, the coefficient of coupling of 0.99 or more is reasonable value.

E. Efficiency of the current to current converter

The efficiency of the converter is shown in Fig.11. Neither the drive circuit nor the control circuit is included in this calculation. The simulation and the measurement show good correspondence in higher voltage region. A little difference is shown in the lower voltage region.

The efficiency of 95% is obtained in higher voltage region. The detail of the loss in the higher voltage region is shown in Table 2. The loss with Rx represents the loss of the core and the

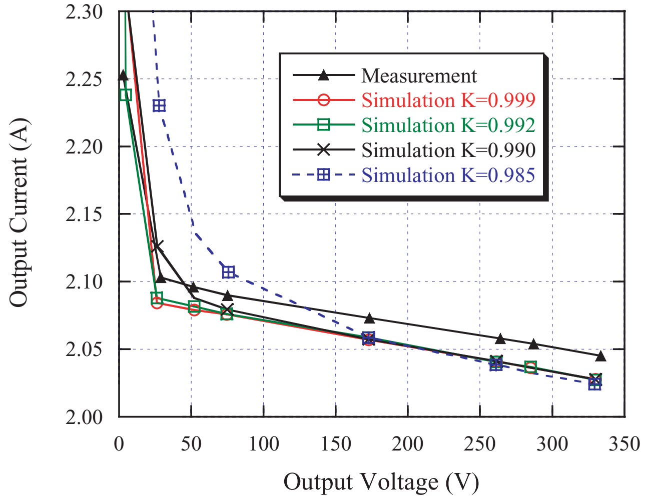

Fig.10 Load regulation calculated by computer simulation when changing coupling coefficent

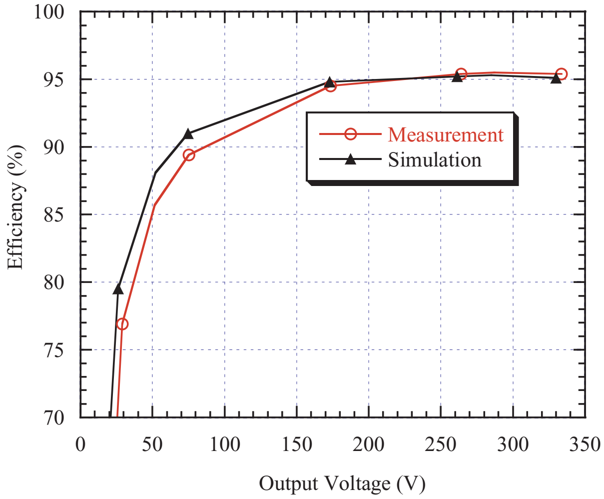

Fig.11 Efficiency of the current - current converter

switching loss of FET. The loss of the core is estimated to be about 3W by calculating using the magnetic flux density in the transformer. Therefore, it is clear that the switching loss of FET is dominant.

IV.CONCLUSIONS

CC power feeding system has many advantages for the underwater cable systems. However it was not easy to adopt CC power feeding system to mesh-like cable network, as it was difficult to branch a constant current into two constant currents. The authors have proposed a new current to current converter that makes the CC power feeding to mesh-like cable network feasible.

Three prototypes of the current to current converter were developed and compared with the computer simulation. The comparison shows good conformance, that shows the validity of the simulation.

In order to obtain higher output power, plural converters should be connected in series. In this case, the output characteristic of the converters should match with each other. Three prototypes show well matched output characteristics, that indicate promising possibility of the proposed current to current converter. It also confirmed that high conversion efficiency of 95% is available in higher voltage region.

As there are no feedback loop that stabilize the output characteristic, it is important to evaluate the output characteristics and its stability. The results of simulations show that on-resistance of FET and coupling coefficient has little influence on the output characteristics. On the other hand, it becomes clear that loss of the core and switching loss have larger influence on the output characteristics. The authors will do analysis and evaluation of the influence of these losses and their stability.

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Table 2 Details of the loss
(Output volatge:330V)

On-resistance of FET	6.3 W
Power loss of Rx	20.7 W
Rectifier diodes	3.2 W
Winding resistance	1.3 W
Other loss	3.6 W
Total	31.4 W

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