Power System Research for Cabled Seafloor Scientific Observatory

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Abstract. The power supply system, which is totally discussed in this paper, is of special importance for the daily operation of the cabled seafloor scientific observatory. Based on the unique features of the power supply system of the cabled seafloor scientific observatory, this paper proposes the solution of parallel direct current power supply, which is suitable for the underwater environment. According to special application environment of power supply system, this paper determines the maximum voltage and current that can be applied to the transmission system of the cabled seafloor scientific observatory.

Introduction

The vast ocean area, comprising roughly 71 percent of Earth’s surface, is rich with resources and energy [1]. The ocean is an important part of the global ecological system which the mankind depends on for living and the important basic resources for sustainable economic and social development. There are many ocean observation tools, such as ocean research vessel, oceanographic buoy, ROV, AUV and glider. However, these tools are limited by energy and have difficulties in information transmission. In order to detect and understand the physical, chemical, biological, and geological functions of ocean systems better, America, Canada and Japan have established seafloor scientific observatories, which can achieve the long-time, continuous, real-time ocean observation [2]. Seafloor scientific observatory will become an international research focus in the field of marine science and technology gradually.

Cabled seafloor scientific observatory (CSSO) is one of the seafloor observatory networks, which realizes the network power-supply and the information transformation. IN CSSO, the observation equipment will not be confined by its own power source, and can transmit the real-time observation data to the shore station. The power supply system connects the underwater observation equipment and the State Grid by fiber-optic/power cable in CSSO, ensuring a continuous power supply and the normal operation of the observation equipment [3]. This paper analyses the characteristics of cabled seafloor scientific observatory power system, and proposes a power supply solution suitable for CSSO.

The characteristics of CSSO power supply system

The goal of CSSO is to build a regional, long-term, real-time marine observation platform, which can realize the measurement and multidisciplinary research in different time scales, from a few seconds to decades, and different spatial scales from a few microns to several thousand meters.
Japan proposed the scientific submarine cable network named ARENA in February 2002 [4]. ARENA network will be planned to encircle the Japanese Island and contain many observation nodes within 45km intervals. North-East Pacific Timer-series Undersea Network Experiments (NEPTUNE) is a planned cabled network consisting of 3000 km of fiber-optic/power cable on the seafloor, which encircles the Juan de Fuca tectonic plate beneath the Northeast Pacific Ocean [5,6]. ESONET was proposed by the European commission. The aim of ESONET is to monitor the submarine terrain around Europe from the abyss to the continental shelves [7]. ESONET proposes a network of 11 regional observatories for the scientific goal in a unique natural environment. In summary, power supply system requires not only supplying remote power but also distributing electrical energy for observation equipment. The power supply system is different from the terrestrial counterpart in many ways. The characteristics of CSSO power supply system are as follows, 1) the harsh power transmission environment, the fiber-optic/power cable is used as an underwater power transmission carrier so that the cable must have a good performance of corrosion resistance, insulation and stability, 2) long-distance power transmission, similar to the terrestrial transmission network, the transmission distance underwater is hundreds of kilometers, 3) numerous observation equipment, power should be reasonably allocated for the equipment, which is similar to the terrestrial distribution network.

**DC or AC**

Two kinds of long-distance transmission mode are high voltage alternating current (HVAC) and high voltage direct current (HVDC). With the development of technology, HVDC transmission technology is fully developed. Compared with HVAC, HVDC has irreplaceable advantages in terms of submarine cable transmission.

The electric performance parameters of submarine cable are as follow, conductor resistivity \( R=0.387 \Omega/km \), conductor capacititivity \( C=0.213 \mu f/km \), conductor inductance \( L=0.438 mh/km \). The equivalent model of submarine cable is shown in Figure 1. Assuming that the cable length is 100km and the frequency of ac is 50HZ, resistance, capacity and inductance of submarine cable is \( R=38.7 \Omega \), \( X_c = 149.52 \Omega \), \( X_l = 13.75 \Omega \) respectively. Inductive reactance value is small and its power loss is negligible, but it can lead to the current phase lag. Because the seawater is used as a transmission circuit, there is a larger capacitance between submarine cable and seawater. If the mode of transmission is AC, the power loss will be serious. On the contrary, DC transmission can improve the transmission efficiency of the power, which is not influenced by capacitive reactance and inductive reactance.

![Figure 1: The equivalent model of submarine cable](image)

The transmission power of AC can be described by equation:

\[
P = \frac{V_1 \cdot V_2}{X_{12}} \sin \delta
\]  

(1)

Where

- \( P \) is the transmission power
- \( V_1 \) is the voltage of sending end
- \( V_2 \) is the voltage of receiving end
- \( \delta \) is the phase difference of \( V_1 \) and \( V_2 \)
- \( X_{12} \) is the equivalent reactance of \( V_1 \) and \( V_2 \)
If $\delta=90^\circ$, $P = P_M = \frac{V_1 V_2}{X_{12}} \sin \delta$, $P_M$ is the static stability maximum values of transmission lines.

When there is a small disturbance in system, it is likely to make $\delta > 90^\circ$, and leads to the system instability. With the transport distance extended, the equivalent reactance $X_{12}$ will increase and the transmission power will reduce. DC transmission circuit is not affected by the phase difference $\delta$ and has a better stability than AC transmission systems.

Therefore, CSSO uses DC transmission to provide power for the scientific equipment. DC transmission reduces the cost and loss of the transmission circuit, and improves stability of the transmission circuit.

**Series or Parallel**

In order to achieve regional, real-time ocean observation, CSSO needs to configure a variety of observation equipment. The primary problems are how to connect observation equipment and allocate power. There are two kinds of connection ways of observation equipment: series and parallel. A series connection of the sources and loads is used in CSSO, and shore power supply unit uses the method of constant-current to supply.

Series power supply mode is shown in Fig2. Power Branching Unit (PBU) mainly includes the current-to-current converter. The output currents are equal to the input current, $I_1 = I_2 = I_3$, where $I_1$ is the input current, $I_2$ and $I_3$ are the output current. The voltage relationship of PBU can be written as, $V_1 = V_2 + V_3$, where $V_1$ is the input voltage, $V_2$ and $V_3$ are the output voltage. The structure of PBU is very complex, and is prone to fail.

![Series power supply mode](image)

**Figure 2: The series power supply mode**

A parallel connection of the sources and loads is used in CSSO, and the shore power supply unit uses the method of constant-voltage to supply. Parallel power supply mode is shown in Fig3. Observation equipment is connected in parallel by Branch Unit (BU). The output voltages are equal.
to the input voltage, $V_1 = V_2 = V_3$. The current relationship of BU can be written as, $I_1 = I_2 + I_3$. Branch Unit does not include current converter, and the structure is simple.

Figure 3: The parallel power supply mode

Figure 4: Current and voltage values in a series power system

Figure 5: Current and voltage values in a parallel power system

The power delivery efficiency of series and parallel power supply modes are calculated and compared [8]. The loads are connected in series (Fig.3) or in parallel (Fig.4). For the series and parallel cases, the source voltage is 10kV, the source current is 10A, and the source power is 10kW. The cable resistance is 500Ω to the first load, and 100Ω between the next two loads. The parallel connection delivers 30kW to loads. The series connection delivers 30kW to loads. The efficiency of parallel is higher than series power system. CSSO generally supplies power in parallel.
Maximum voltage and current

CSSO uses seawater as a transmission circuit. Due to the awful environment of ocean, the value of current and voltage should be chosen properly. In selecting the transmission voltage of the power system, the following factors should be considered: the cost and volume of auxiliary equipment, submarine cable insulation, and the environmental effects. Correspondingly, the following factors should be considered in selecting the transmission current of power system: the transmission loss, the useful life of sacrificial anode.

The rated voltage of observation equipment is commonly 24V or 48V. Seafloor junction box needs to install DC/DC transformer. If the transmission voltage is too high, the cost and volume of DC/DC transformer will increase, and unnecessary economic loss will be caused. The transmission voltage is restricted by submarine insulation performance. The transmission line is a powerful source of electromagnetic field that could threat marine life and humans or even destroy ships communication. High electric potential should not be used. Considering the factors above, a level of 10kV could be used for the transmission voltage [8].

A large value of current may cause the cable to overheat and reduce the lifetime of the insulation of submarine cable. If the cable is long, the voltage drop between the source and the load may be excessive. The voltage may be lower than the starting voltage of DC/DC transformer. Because the sea is used as conductor, the depletion rate of sacrificial anode is directly proportional to the current value. The current value of CSSO should be selected as 10A [8].

Power supply system verification

The power supply system has been successfully applied in CSSO of Chinese Academy of Sciences. The CSSO consists of the shore station, the junction box, the observation equipment, and the submarine cable. The output voltage of the shore station is 10kV which provides reliable and stable electricity for observation system.

Conclusion

Combining with the characteristics of terrestrial power system, the paper puts forward the characteristics of CSSO power system. According to the special application environment of the power system, DC and parallel for power supply system is proposed for CSSO. The power supply system has the characteristics of low energy consumption, high power efficiency and the stability of electricity supply. It is easy to realize branch and extend functionality of CSSO. In addition, it has strong fault tolerance, and protects other systems from the fault which is isolated. The output voltage is 10kV, and the output current is 10A. The power supply system has been verified in CSSO of the Chinese Academy of Sciences.

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