An active node isolating method based on discrete-voltage intervention for seafloor observation network

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***Abstract*—Seafloor observation network is gradually acting as one of the most efficient methods to explore the ocean for its long-term, real-time, sustained presence. To establish a reliable, robust Chinese Experimental Ocean Observatory Network with two observation nodes along a 150-km electrical/optical submarine cable, an active node isolating method based on discrete-voltage intervention is proposed in this paper aimed at controlling specific node inserted in or cut away from the whole network. With the switching system, the network could operate at normal function with certain node's failure or routinely maintenance. The prototype of the switching system was setup and tested in laboratory to demonstrate active controllability.**

Keywords—seafloor observation network; active node isolating; discrete-voltage; insert in; cut away; prototype

I. INTRODUCTION

Ocean is attractive to human due to its biological diversity and the influence on global climate, geological activities and other global eco-system process[5]. The approaches human utilized to understand ocean are diversified, such as dive, ships, satellites, undersea vehicles moorings, battery powered instrument, seafloor observation network etc. Unlike the other approaches limited by the ocean observation conditions or the power, seafloor observation network is gradually acting as one of the most efficient methods to explore the ocean for its long-term, real-time, sustained presence[1]. Several experimental projects with a single node connected to shore through electrical/optical submarine cable have been built, such as Long-term Ecosystem Observatory(LEO-15)[4], Hawaii-2 Observatory(H20)[5], Hawaii Undersea Geo-Observatory (HUGO)[6], and Monterey Accelerated Research System (MARS)[3][7]. However, as multidiscipline put more and more attentions to the ocean research, the increasing demands accelerate the multi-nodes, regional cabled observation network's development. North East Pacific Time-Integrated Undersea Networked Experiments(NEPTUNE) Canada[2][10] is the first regional seafloor observation network in the true sense. Another regional network, Regional Scale Nodes(RSN)[8], was put into service in 2014. Chinese Experimental Ocean Observatory Network with two nodes is the first attempt to construct the regional network in China[14], which is the application field in this paper.

As for regional network, how to isolate a fault when it occurs is an non-ignorable issue. El-Sharkawi et al. and Lu proposed two cable switching methods to isolate the fault section for a ring or mesh-like network. They control the cable switching systems through the controller in the node and changing the input voltage's level and polarity, respectively[10][13]. Y. Chen proposed an actively controllable switching method for the tree topology seafloor observation network with discrete-current as the control commands[12]. Analyzing the advantages and disadvantages of these methods and considering the topology of Chinese Experimental Ocean Observatory network, an active node

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isolating method based on discrete-voltage intervention is proposed in this paper.

II. TOPOLOGY OF CHINESE EXPERIMENTAL OCEAN OBSERVATORY NETWROK

The topology of Chinese Experimental Ocean Observatory Network is shown in Figure 1. The network comprises an shore station(SS), a branching unit(BU) and two observation nodes along a 150-km electrical/optical submarine cable. In this system, BU is only a sealed case which splits the cable conductor into two branches without isolation switches. And observation nodes distributed at 75-km and 150-km locations are connected to the cable with a sealed case which separates the electrical conductor and optical fibers, respectively.

To manage cost, single conductor high-voltage direct-current transmission via seawater return technology has been applied in the system. SS feeds the cable with a negative constant voltage(-10KV) considering electrolytic corrosion and the demands of extensibility and high power[14]. However, the network is sensitive and may completely go to a system-wide shutdown due to a fault of the cable or specific node. Compared with the nodes, the cable is off-the-shelf commercial product and robust, so we assume that the cable is of no fault in the life time of the network while specific nodes may be maintained routinely or repaired when there is a fault. As the repair/maintenance time is usually as long as several weeks, the node should be cut away from the network to ensure that the other node could work at normal function. An active node isolating method configuring a switching system in the sealed cases between the cable and nodes is proposed aiming at controlling the node inserted in or cut away from the whole network.

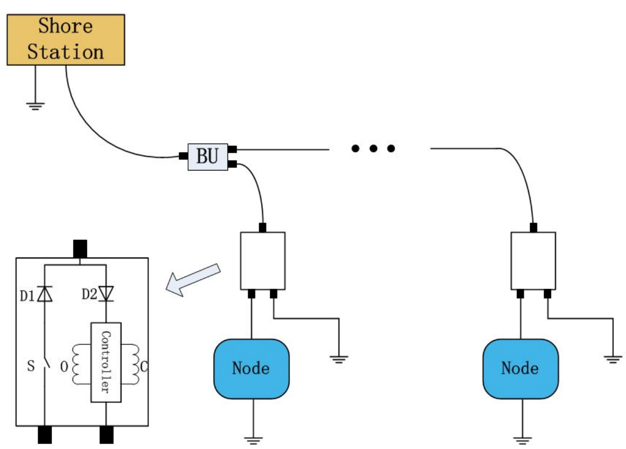

Fig. 1. The topology of Chinese Experimental Ocean Observatory network

III. DESIGN OF ISOLATING METHOD

Different from the terrestrial electrical system, ocean observation network works at a cold, high pressure, deep-sea extreme environment and the construction environment is bad. Thus, reliability is the first priority for the network due to the high cost for repair and maintenance.

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EI-Sharkawi et al. and Lu proposed two cable switching methods to isolate the fault section for a ring or mesh-like network[10][13]. Y. Chen made some changes for the two methods to make them fit for the tree topology[12]. As for the first method, the interrupters is controlled by the controller in nodes and operates at the high voltage(-10KV). However, There are no off-the-shelf interrupters applied in the terrestrial electrical system that have a good performance on switching off direct current at high voltage. Also, the large size determines these interrupters not fit for deep-sea application. As for the other method, all the switching actions are autonomous and they can't actively control specific node inverted in or cut away from the network. Y. Chen proposed an actively controllable switching for the tree topology seafloor observation network with discrete-current as the control commands[12]. The method is robust to network fault but not satisfy the extensity of constant voltage(CV) network. An active node isolating method based on discrete-voltage is proposed and presented in this section.

A. Design of switching system

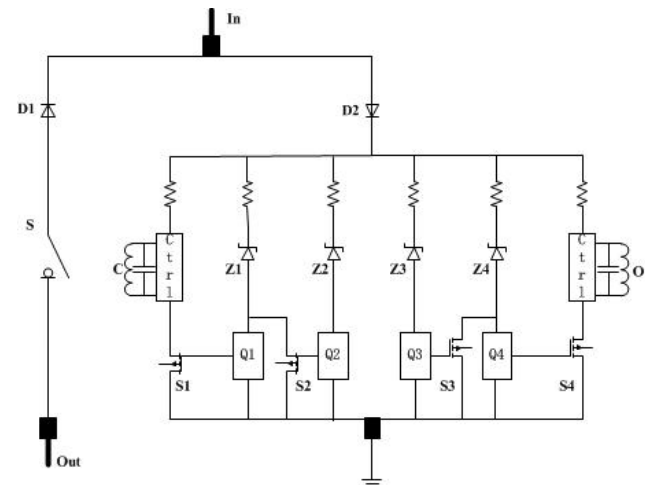

Fig. 2. Switching system circuit

The main components of the switching system are shown in Figure 2.

1) A latch-type vacuum interrupter(S) with a companion closing solenoid and opening solenoid is inserted in the route of the cable conductor and the node through a diode(D1);

2) Four zener diodes are arranged as the figure, connected to four drive units(Q1, Q2, Q3, Q4) which drive the four MOSFETs(S1, S2, S3, S4) on or off, respectively; Each one controller, one capacitor, three resistors, two zener diodes, two drive units, and two MOSFETs, constitute the switching circuit and set a operating voltage window as the comand voltage range. The two switching citcuits are connected in parallel to the cable conductor through a diode(D2);

3) The opening solenoid and closing solenoid are operated by one switching circuit, respectively.

The nodes start up only when the SS feeds voltage lower than -6KV while the switching system works at positive voltage. The design of two backward diodes(D1, D2) ensures that the nodes and the switching system work at different feeding mode. That means the latch-type vacuum interrupters operate at nearly zero current and zero voltage which improves the reliability of the switching system. As there is no communication configured before the node work due to the particularity of the marine environment and the infrastructure of the network, discrete levels of positive constant voltages are utilized as signals for the shore station communicating command information to the switching system. Different levels of voltage are corresponding to different command signals as shown in Table Ⅰ.

TABLE I. THE COMMAND SIGNALS

Nodes / Voltage	Node1	Node2
V_{1_C}	**Closed**	-
V_{1_O}	**Open**	-
V_{2_C}	-	**Closed**
V_{2_O}	-	**Open**

When fed with specific level of voltage, the corresponding switching circuit's controller powers the solenoid triggering the latch-type vacuum interrupter on or off while the other controllers don't work. Benefit from the control mechanism of the switching system, specific node can be inserted in or cut away from the network actively as required.

B. Operation mechanism

Based on the feature mentioned before, the network with the isolating method works at three modes: normal operation mode, configuring mode and fault location mode, as shown in Figure 3 .

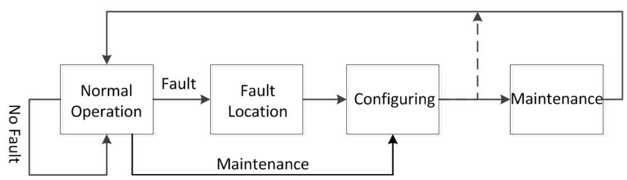

Fig. 3. Work logic of the network with the isolating method

1) Normal operation mode: The network is fed with a negative constant voltage (-10KV) from the shore station. The nodes work at normal function while the switching systems don't work.

2) Configuring mode: The network would go to configuring mode when a node needs to be inserted in or cut away from the network. In this mode, the shore station reverses the feeding voltage and feeds the network with a series of specific level positive voltages as command signals to control corresponding switching system. The interrupter latches to the specific position when the feeding voltage is in specific operating voltage window. Then the network goes back to normal operation mode with the node maintained. After the node's maintenance work is completed, the node connects back to the network. The nodes don't work due to the presence of the diode(D1) in this mode.

3) Fault location mode: The network would go to fault location mode if there is a node working at wrong status that too serious to start up the network normally. The node's fault can be determined and located with the Insulation Resistance Tester(IRF) at the shore station. The method is to open all the interrupters, then closing the interrupters and testing the insulation resistance according to priority. The presence of a fault insulation resistance would indicate the fault node. Then, the network goes to configuring mode to isolate the fault node.

C. Considerations

The controllable nodes number is limited by the three factors.

1) The active node isolating method proposed controls the node inverted in or cut away with different levels of voltage as the command signals. Each levels of voltage have a corresponding operating voltage window.

2) Limited by the property of the cable and component, the maximum allowance command voltage should be lower than 1KV.

3) Considering avoiding the presence of false operation, there is a voltage range Δ_V between each two adjacent operating voltage windows.

IV. LABORATORY TEST

The prototype of the switching system has been setup and tested in laboratory. A test platform composed of two switching systems(distributed at the 100-km and the 200-km location, respectively) , two latch-type vacuum interrupters and 200km cable(distributed RLC mode) is established to verify the function of the active node isolating method.

In practical application environment, the 150-km electrical and optical submarine cable has stray parameters of resistance (1 Ω /km), capacitance(0.179uF/km) and inductance (0.37mH/km). Here, 20 RLC sections(each modes 10km-cable) are used in this platform to mode 200-km cable and each section is composed of a serial 10 Ω resistance, a serial 3.7mH inductance and a parallel 1.6uF capacitance. The platform is shown in Figure 4.

A. Switching function test

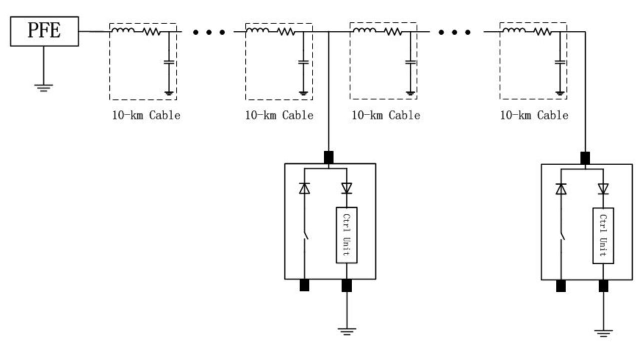

Fig. 4. Structure of test platform

To validate the function of the switching system, the command signals of the two prototype was set from 100V to

400V when they were setup. The voltage values for opening and closing the two interrupters were 125V, 175V, 325V, and 375V, respectively. And the actual corresponding operating voltage windows were [116,148], [161,190], [306,336], and [357,382], respectively.

The platform was fed with voltage commands of 125V, 175V,325V, and 375V in sequence with multimeter validating the corresponding interrupter operating accurately. The test results are shown in Figure 5,6.

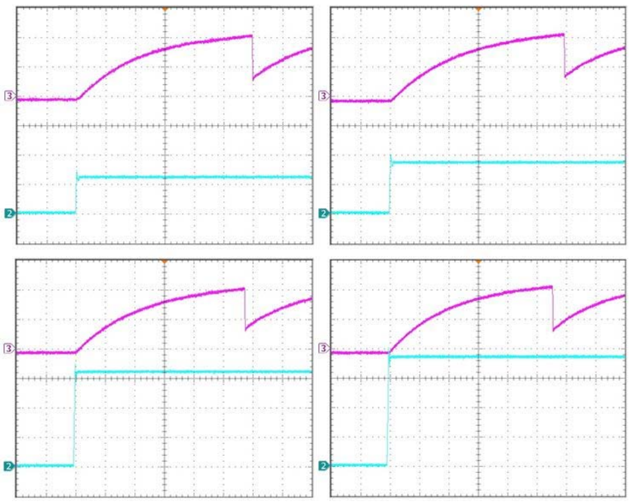

Fig. 5. Operation with the feeding voltage 125V, 175V, 325V, 375V

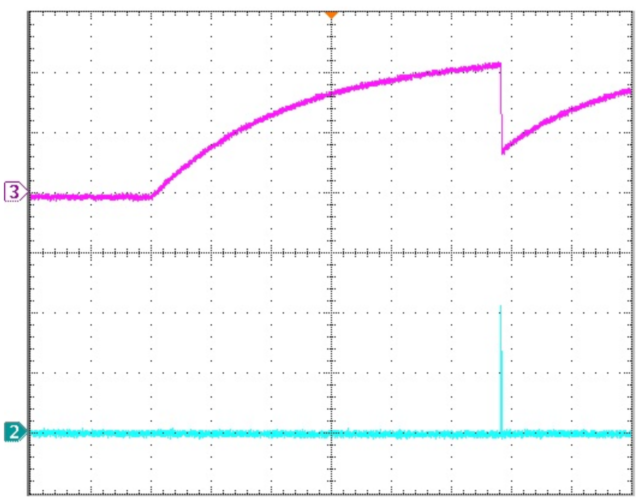

Fig. 6. Operation of solenoid with the feeding voltage 175V

As shown in Figure 5, the line 2 represents the input voltage across the switching system(100V/Grid). The line 3 represents the voltage across the capacitor(10V/Grid) which stores the energy for interrupter's solenoid to action. In Figure 6 , the line 3 represents the voltage across the capacitor(10V/Grid) and the line 2 represents the voltage across the corresponding interrupter's solenoid(10V/Grid).

B. *Disgussion*

As seen in Figure 5,6, when fed with a command voltage, the corresponding capacitor starts to store the energy and the voltage across the capacitor rise up slowly. When the voltage rise up to 22V, the energy stored in the capacitor is released to the solenoids, and the latch-type vacuum interrupter operates. The time the capacitor taken to store the energy is about 23s (4s/Grid), namely the response time of the switching system. Due to the difference of each switching circuits' components, the response times may be different in a small range.

In Figure 5, the input voltage of the switching system No.2 at 200-km location rise up to 375V in a very short time. The time is too short compared with the response time of the switching system that other switching circuits would not operate incorrectly.

There are many tests to be done before the switching method is put into practical application. Further test will be focused on the missing operation in the durability test and the overheating test. The switching method will also be tested with the true submarine cable if condition permitting.

V. CONCLUTION

An active node isolating method based on discrete-voltage intervention for seafloor observation network with the feature of briefness, controllability and reliability was presented in this paper. Laboratory prototype tests validated the actual feasibility of the method. Although this method is designed focusing on the topological structure of Chinese Experimental Ocean observatory Network to isolate the node, it also inspirations for creating a new BU switching method for regional seafloor network.

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