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Use of a coded voltage signal for cable switching and fault isolation in cabled seafloor observatories

Key words: Cabled seafloor observatories; Cable switching and fault isolation; Coded voltage signal; Maximum bit frequency

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Motivations

1. Cabled seafloor observatories play an important role in ocean exploration. In establishing a permanent, reliable, and robust seafloor observatory, a highly reliable cable switching and fault isolation method is essential.

2. Theories and methods of fault isolation for terrestrial electrical systems are not suitable for cabled seafloor observatories due to the specific nature of the submarine environment.

Main ideas

A coded voltage signal with a distinct sequence is employed as the communication medium to transmit commands through an existing power transmission path.

The analysis of the maximum bit frequency of the voltage signals guarantees the accuracy of command recognition.

A prototype based on the switching method is built and tested in a laboratory environment, which validates the functionality and reliability.

1. Switching system

Main components:

(1) two latch-type vacuum interrupters;

(2) four high-voltage diodes;

(3) controller;

(4) sample circuit.

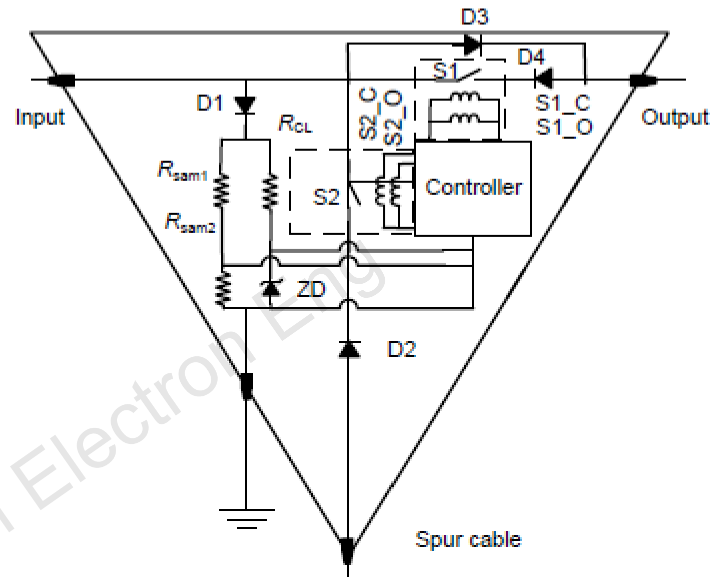


Fig. 4 Switching system based on the coded voltage signal

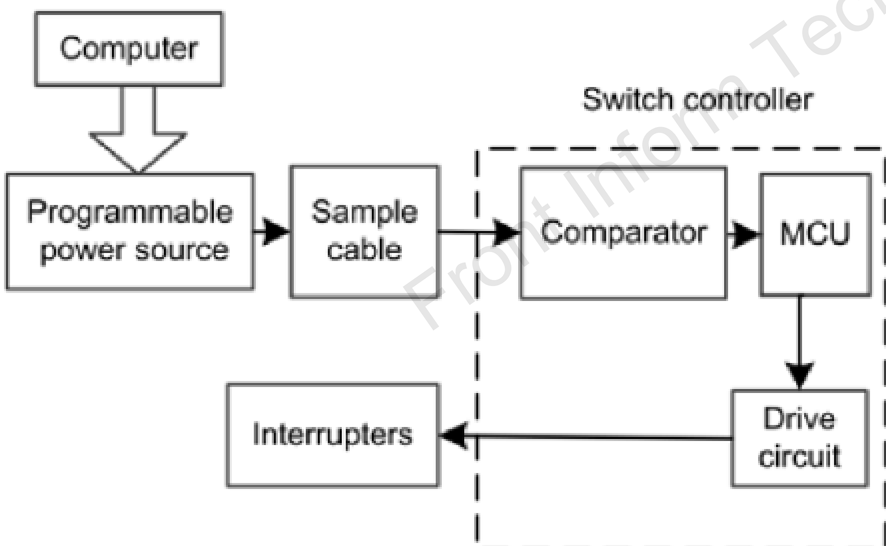


Fig. 3 Control logic of the proposed switching method

Characteristics:

(1) two voltage levels;

(2) working at each voltage level;

(3) tens or even hundreds of switching systems in a network.

2. Logic of command signal identification

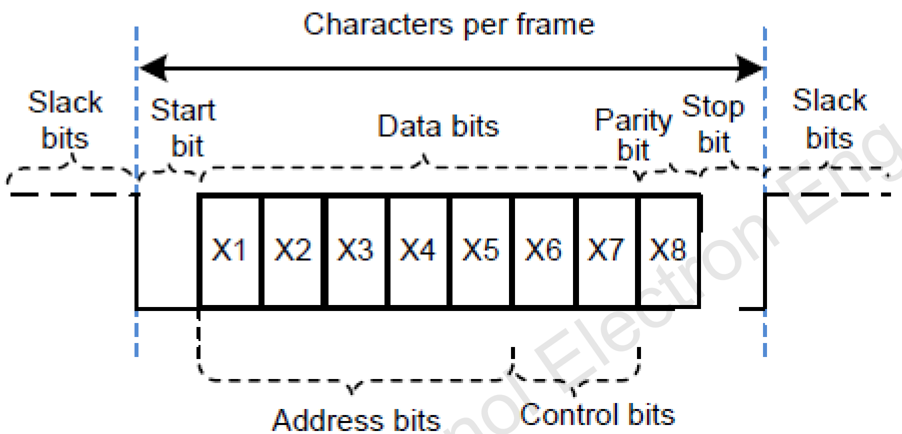


Fig. 5 Definition of the communication protocol

(1) Slack state:

1) slack bits: high voltage level with no command.

(2) Command identification:

1) start bit: a special flag bit to activate the switch controller;

2) address bit: the license to control a specific switching system;

3) control bit: indicating the final desired status of the interrupters;

4) parity bit: parity check;

5) stop bit: indicating that the command signal is over.

2. Logic of command signal identification

(3) Command identification:

1) motivating the controller with a falling edge;

2) receiving and counting bits;

3) receiving the stop bit;

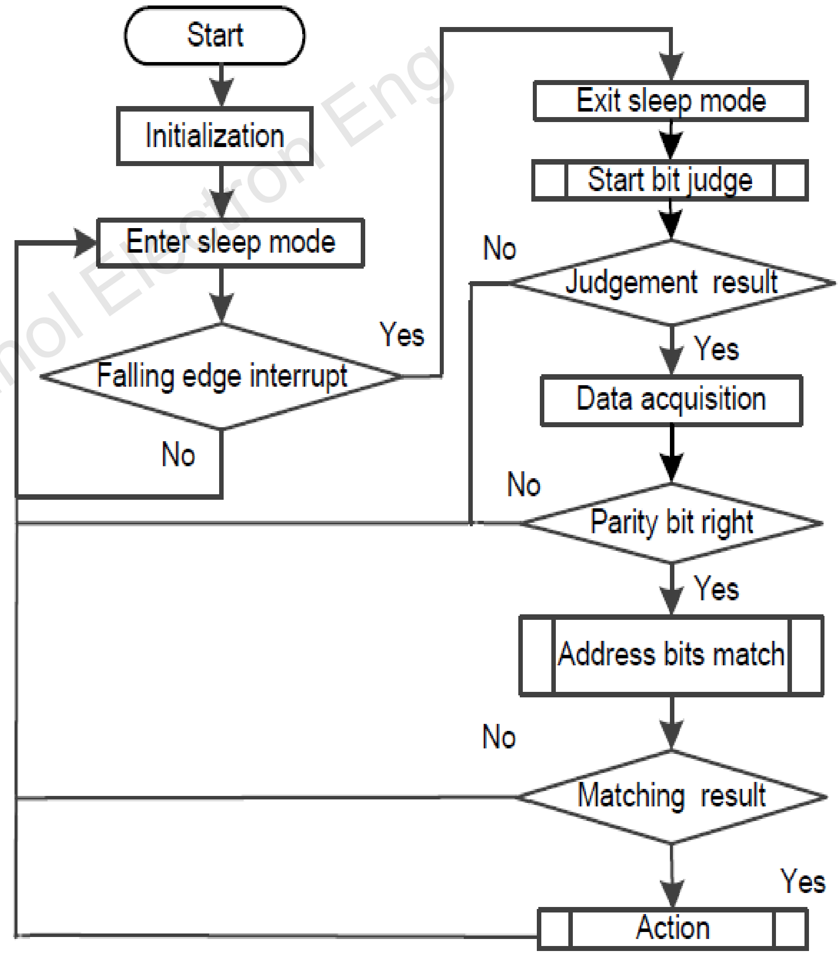
(4) Command response:

1) parity bit check;

2) address bit check;

3) interrupter configuration;

4) go back to sleep mode.



3. Simulation and analysis

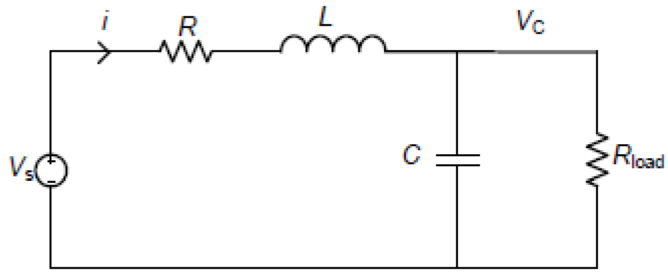


Fig. 8 RLC model simulating a 1000-km cable

$$\begin{cases} L\dfrac{\mathrm{d}i}{\mathrm{d}t} = V_S - iR - V_C, \\ C\dfrac{\mathrm{d}V_C}{\mathrm{d}t} = i - \dfrac{V_C}{R_{load}}, \end{cases} \qquad V_C = V_S \frac{R_{load}}{R_{load} + R}.$$

Parasitic parameters:

(1) resistance: 0.98 Ω/km

(2) inductance: 0.37 mH/km

(3) capacitance: 0.179 μF/km

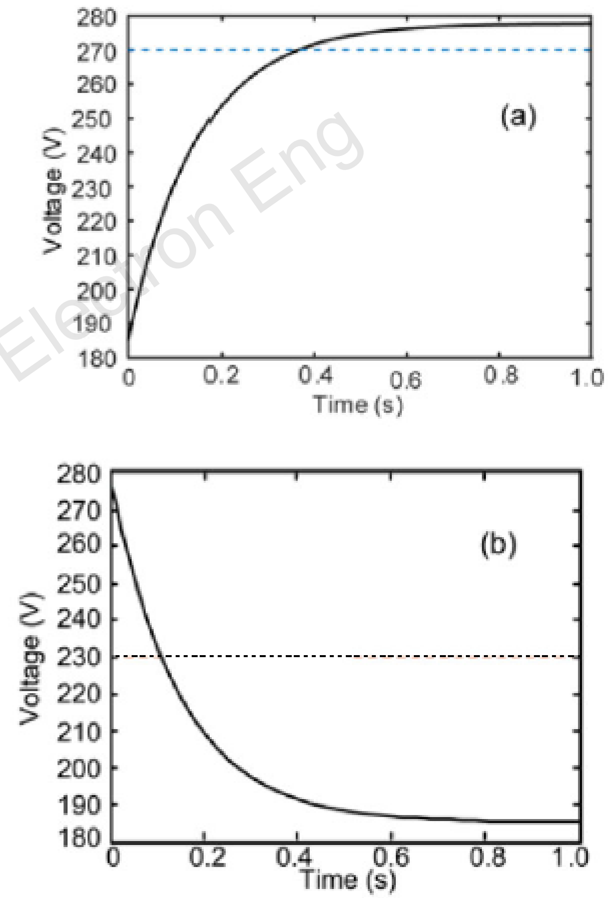


Fig. 9 Variation curves between two voltage levels: (a) 200 V to 300 V; (b) 300 V to 200 V

Major results

Each RLC mode simulates a 10-km submarine cable.

Voltage levels:

- High level: +300 V;
- Low level: +200 V.

	Cable	RLC model
Resistance	0.98 Ω/km	10 Ω
Inductance	0.37 mH/km	3.7 mH
Capacitance	0.179 μF/km	1.6 μF

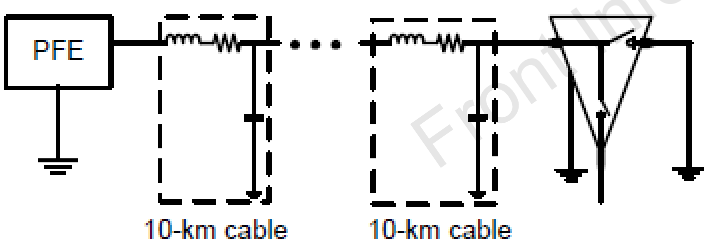


Fig. 11 Test platform with a 150-km model cable

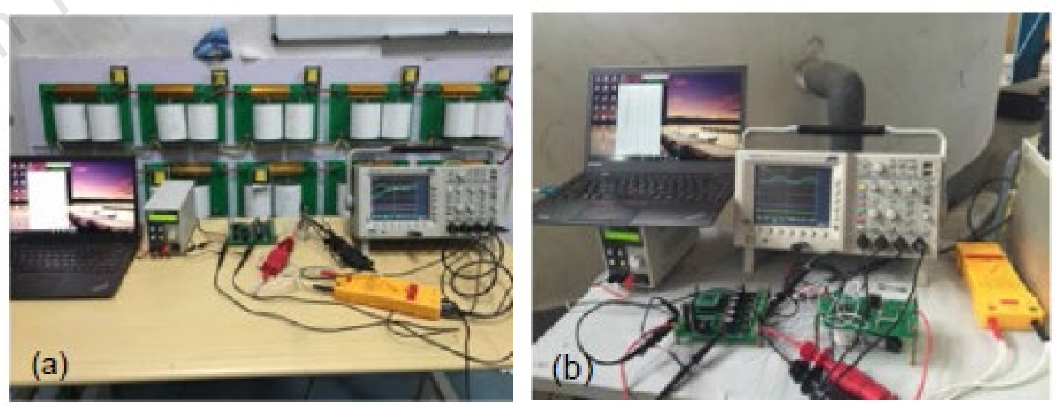


Fig. 12 Function test: (a) test with a 150-km model cable; (b) test with a practical 150-km submarine cable

Major results

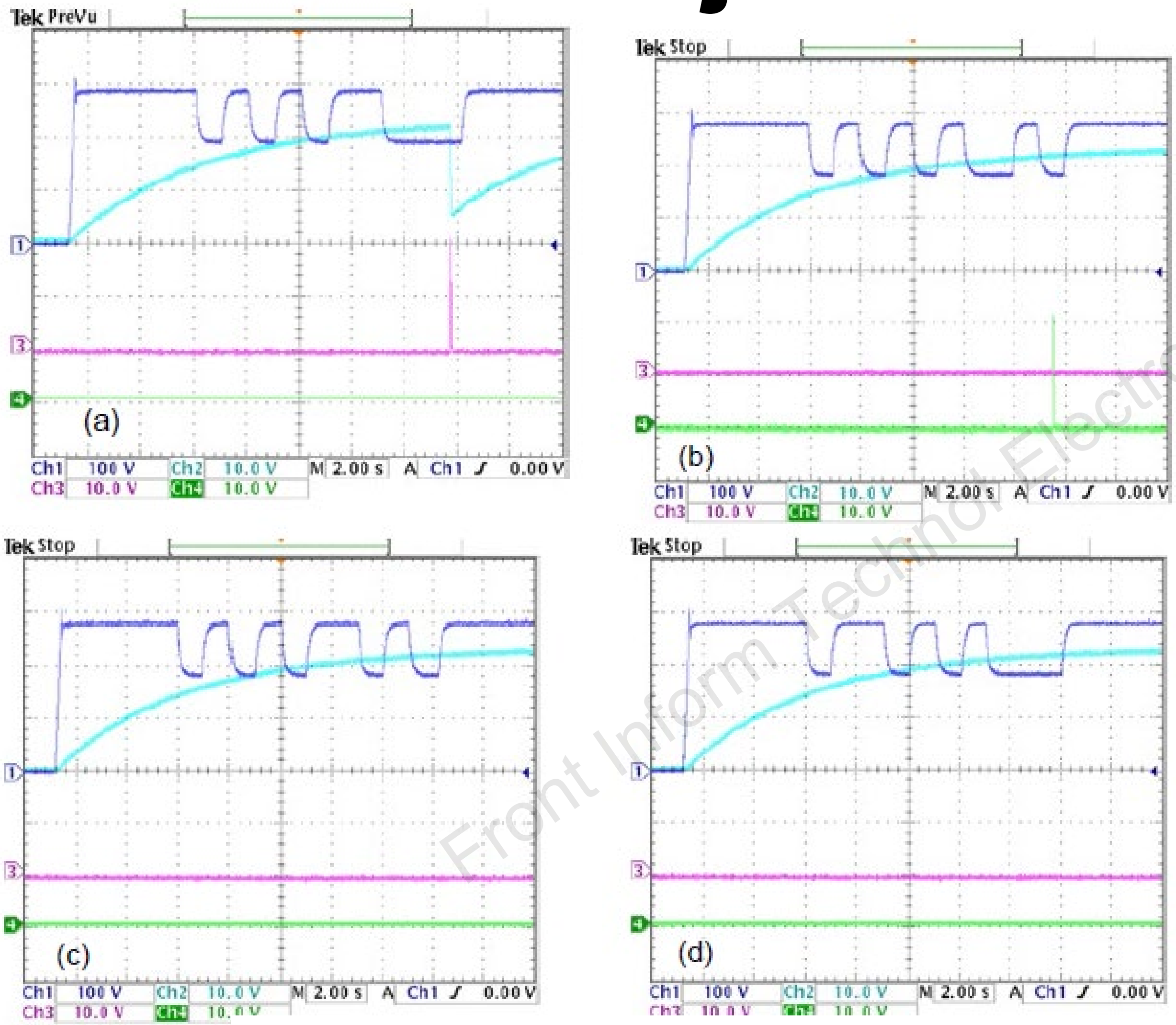


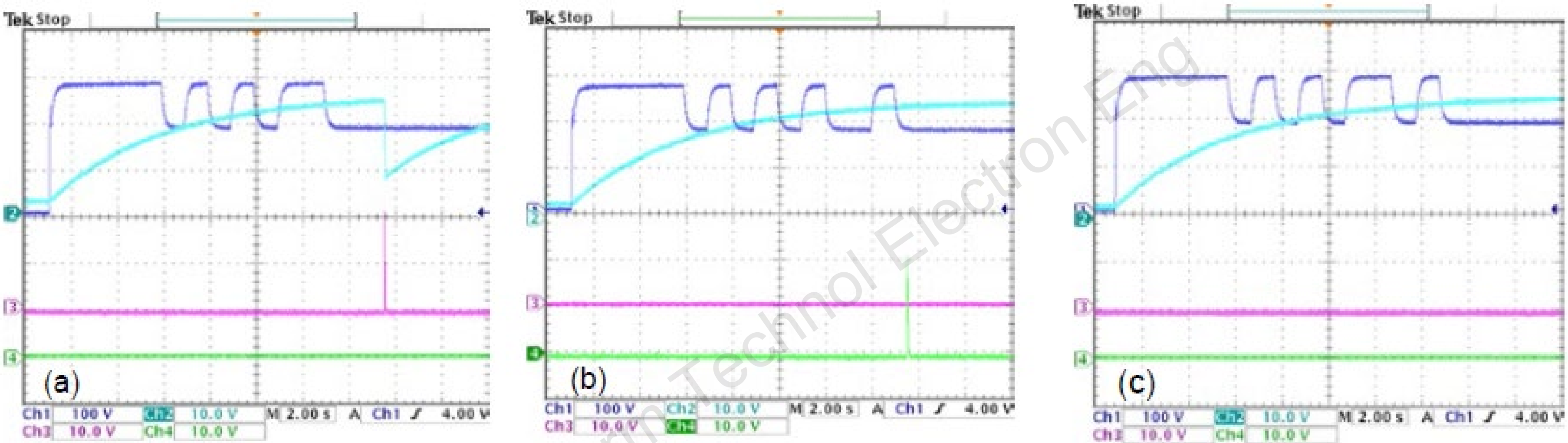
Fig. 13 Test results with a 150-km model cable: (a) command to a close interrupter; (b) command to an open interrupter; (c) command with a wrong parity bit; (d) command with non-corresponding address information

Channel 1 (blue line): The input command signals across the switching system.

Channel 2 (cyan line): The voltage across the energy-storage capacitor for the closing solenoid.

Channels 3 and 4 (red and green line, respectively): The voltage across the interrupter's closing and opening solenoids.

Major results



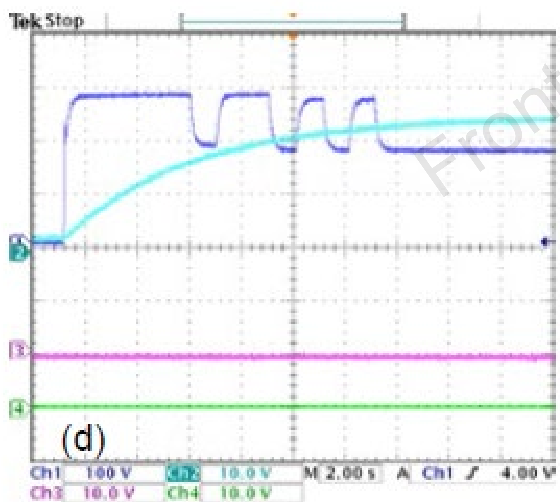


Fig. 14 Test results with a practical 150-km submarine cable: (a) command to a close interrupter; (b) command to an open interrupter; (c) command with a wrong parity bit; (d) command with non-corresponding address information

Conclusions

1. An active switching method for cable switching and fault isolation of cabled seafloor observatories based on a coded voltage signal was described in this study.

2. Operating at zero current and nearly zero voltage maximizes the lifetime of the interrupters.

3. The series of tests on the established prototype validated the functionality and reliability of the system.