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China Electric Power Research Institute Test Report

CSM System Cable Temperature Monitoring and Emergency Load Calculation Validation Research

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Research institute: China Electric Power Research Institute

Research staff: Zhang Zhenpeng (Engineer) Liu Songhua (Engineer)

Meng Shaoxin (Senior engineer) Liu Hongbin (Technician)

Geng Xiaohua

Project Leader: Zhang Zhenpeng (Engineer)

Produced by: Zhang Zhenpeng (Engineer)

Reviewed by: Rao Wenbin (Senior engineer)

Approved by: Li Shusen (Professor)

Abstract

This research verifies the validation of emergency load calculation and cable temperature monitoring based on Cable Safety Monitoring (CSM) system developed by Bandweaver Technologies Co., Ltd.

The research includes: 1). Temperature monitoring test by Distributed Temperature Sensor (DTS); 2). Location test; 3). Validation research of the accuracy of real temperature of conductor under emergency load based on the temperature calculated by CSM system. In the research, cable was simulated operating in cable tunnel and buried underground, and CSM system calculates the emergency load when cable conductor temperature rising to 85℃ for 1h, 2h, 4h, and 12h. At cable test site of China Electric Power Research Institute, cable thermal circulation heating system is used to charge current and time on the target cable which is installed with conductor temperature thermocouple. Cable conductor temperature measurement system monitors the actual conductor temperature and analyzes the deviation between the actual value and calculated value (85℃) by CSM system to verify its accuracy.

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CSM System Cable Temperature Monitoring and Emergency Load Calculation Validation Research

1. Preface

CSM system, comprising DTS host and optical cable, is developed by Bandweaver Technologies Co., Ltd. to online monitor high voltage and ultra-high voltage cable lines. This system relies on DTS host to real time monitor the temperature of cable surface and by making use of these data, together with cable load current and cable structure parameters to calculate the conductor temperature. The CSM system can compute cable load capacity and then realize cable emergency load capacity prediction. Cable emergency load capacity refers to the maximum load current value of cable when temperature rises to 85-90℃ in certain period of time.

To verify the validity of CSM system, China Electric Power Research Institute first tests the accuracy and positioning of DTS host temperature monitoring, and then the emergency load capacity prediction of CSM system under simulated conditions.

2. Experiment

2.1. Main test equipment and test cable

2.1.1. Main test equipment

1). Cable conductor temperature measuring system: to realize the real time measurement of cable conductors. It comprises thermocouples for cable conductor temperature measurement, thermocouples for cable metal sheath temperature measurement, thermocouples for cable outer sheath temperature measurement, and temperature collection and record units.

2). Cable thermal circulation heating system: to heat current of test cable for cable load simulation purpose. It comprises straight-through transformer, regulator transformer and control unit.

3). Thermostatic waterbath

4). Double standard mercury thermometer (measurement range: 0-50℃, division value: 0.1℃; measurement range: 50-100℃, division value: 0.1℃)

2.1.2 Test cable

To meet the site demands and ensure the representativeness of test data, the experiment uses XLPE with its cross section at 2000mm^2 and rated voltage at 220kV. Please see Table 1 for the model, length, and structure parameter of the test cable.

Table. 1 Model, length, and structure parameter of the test cable.

Model		YJLW02 127/220 1X2000
Length (m)		17
Conductor	Material	Copper
	Diameter(mm)	55.4
Thickness of conductor sheath(mm)		2.1

Insulating layer	Material	XLPE
	Normal thickness	24.5
Thickness of insulating layer(mm)		1.2
Tape		Layer 1:Semi-conductive water-proof expansion tape Layer 2：Semi-conductive elastic expansion tape Layer3：Semi-conductive elastic and water-proof expansion tape
Metallic sheath	Material	Aluminum
	Thickness(mm)	3.3
	Depth of wrinkles(mm)	6.8
	Grain spacing(mm)	30.9
	Outer diameter(mm)	133.9
Outer sheath	Thickness(mm)	5.0
Outer diameter of cable(mm)		148.3

2.2. Contrast test of DTS temperature monitoring and positioning accuracy

2.2.1. Contrast test of DTS temperature monitoring accuracy

Coil 10m (normally not shorter than 10m) optical cable into a reel smaller than 150mm in diameter and put it into a thermostatic waterbath. Keep the thermometer and optical cable coil at the same horizontal plane. The thermometer shall be kept in middle of the coil but not touch upon optical cable, shown as in diagram 1.

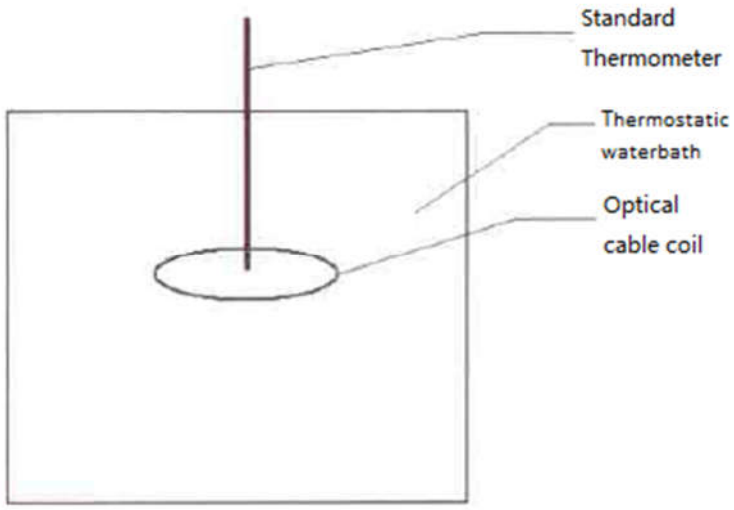


Diagram 1 Temperature measurement contrast test diagram

The contrast test is conducted in two conditions: room temperature-90℃ and 0℃-90℃. After the

water temperature stabilizes for 3mins, make records of the thermometer reading and the maximum and minimum reading from DTS host.

1). See Table. 2 for the contrast test result in room temperature-90℃ condition.

Table 2 Test result in room temperature-90℃ condition

Thermometer reading (℃)	Maximum reading on DTS(℃)	Minimum reading on DTS(℃)
35.8	35.9	35.7
44.8	45.0	44.8
54.9	55.1	55.0
65.0	65.4	65.2
74.9	75.3	75.2
84.3	84.6	84.5
90.1	90.3	90.0

2). See Table 3 for the contrast test result in 0℃-90℃ condition.

Table 3 Test result in 0℃-90℃ condition

Thermometer reading (℃)	Maximum reading on DTS(℃)	Minimum reading on DTS(℃)
5.7	6.0	5.5
10.8	10.9	10.5
20.4	20.4	20.2
30.5	30.3	30.2
40.3	40.3	40.0
50.7	50.7	50.6
60.7	60.8	60.7
70.6	70.9	70.7
79.9	80.2	79.9
90.2	90.4	90.1

2.2.2. Contrast test of positioning accuracy

Connect a 1000m optical fiber to DTS host, and heat it at 20m from the connecting end. Check the maximum temperature variation position on DTS software and mark this position as the starting point (coordinate zero). According to the meter mark on optical fiber, mark at 5m, 10m, 20m, and 500m from the starting point and heat these points to certain temperature (higher than room temperature). And then read the length data on DTS software relevant to temperature variation points. See Table 4 for the test data.

Table 4 Positioning accuracy test result

Length of optical cable(m)	Starting point, L1 (m)	Temperature vibration point on DTS, L2(m)	actual measurement length on DTS, L2-L1 (m)	Temperature at test point (℃)

5	32.4	37.5	5.1	46.2
10	51.7	61.9	10.2	51.0
20	65.9	86.2	20.3	51.6
500	12.7	513	500.3	52.4

2.3. Contrast test of emergency load current and cable conductor temperature in cable tunnel simulation

2.3.1. Cable and thermocouple installation

Cable is installed in cable tunnel in serpentine shape with optical cable fixed on its surface, shown as diagram 2 and 3.

Diagram 2 Cable simulation in cable tunnel

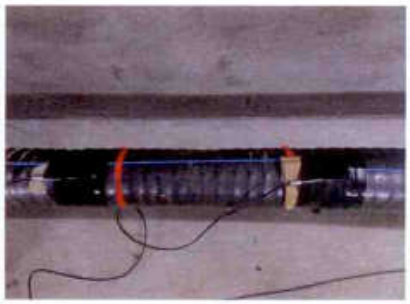


Diagram 3 Optical cable installation method

According to IEC standard, distance between conductor thermocouples should be at 0.5-1m, and in this test the distance is set at 0.8m and 1m. To provide sufficient data sample of cable conductor temperature, and avoid influence of uncertain factors including expansion and contraction in installation, three conductor thermocouples (normally more than three) are installed on test cables. In selecting samples, obviously unreasonable data shall be deleted, and any two or more could be selected for validation reference if there is no invalid samples.

In cable tunnel simulation, three thermocouples are installed at peak, trough, and in-between of the serpentine cable. Sheath temperature thermocouples (shown in diagram 4) are installed around each conductor thermocouple. To avoid overheat influence on conductor temperature measurement at the connection of cable conductor and aluminum row, three thermocouples are installed around middle of the cable, kept more than 5m from cable ends.

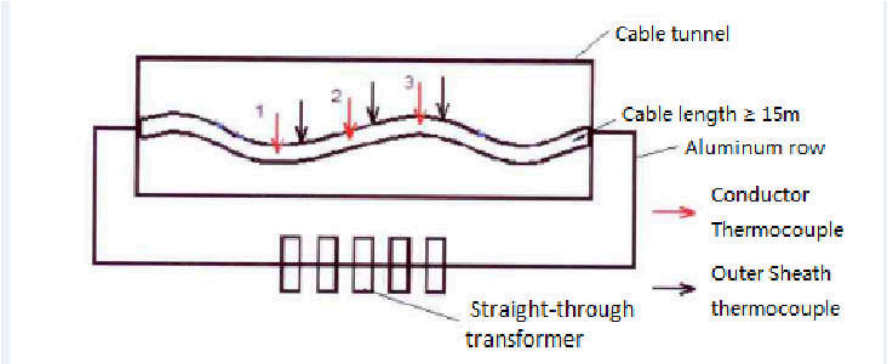


Diagram 4 Thermocouple place diagram in cable tunnel

2.3.2. Test procedure and charging scheme

1). 1h current charging

Get a test cable and record its current conductor temperature (59.5℃). Use CSM software to compute the current amount charged to the cable for 1h and get the cable conductor temperature rose to 85℃, its calculation result is 3180A. Charge 3180A current to this cable by thermal circulation system for 1h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 1h 3180A current charging, the actually measured temperature of cable conductor is 83.4℃ and 83.4℃, and CSM calculation is 84.8℃.

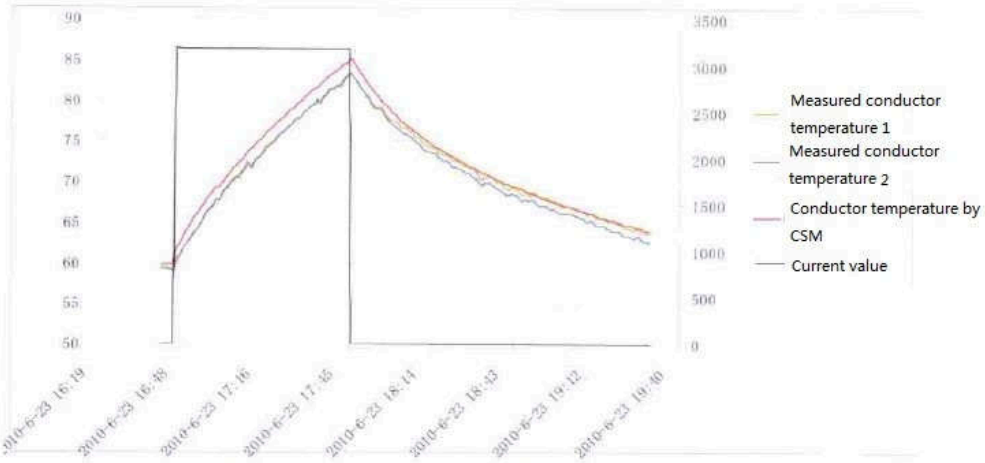


Diagram 5 Conductor temperature graph with 1h current charging in cable tunnel simulation

2) 2h current charging

Get a test cable and record its current conductor temperature (59.0℃). Use CSM software to compute the current amount charged to the cable for 2h and get the cable conductor temperature rose to 85℃, its calculation result is 2730A. Charge 2730A current to this cable by thermal circulation system for 2h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 2h 2730A current charging, the actually measured temperature of cable conductor is 83.5℃ and 83.2℃, and CSM calculation is 85.2℃.

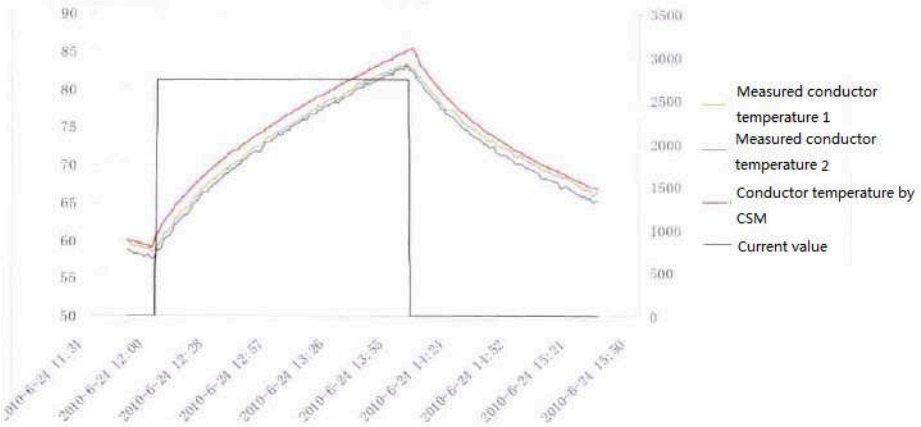


Diagram 6 Conductor temperature graph with 2h current charging in cable tunnel simulation

3) 4h current charging

Get a test cable and record its current conductor temperature (60.5℃). Use CSM software to compute the current amount charged to the cable for 4h and get the cable conductor temperature rose to 85℃, its calculation result is 2370A. Charge 2370A current to this cable by thermal circulation system for 4h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 4h 2370A current charging, the actually measured temperature of cable conductor is 87.1℃ and 86.7℃, and CSM calculation is 86.2℃.

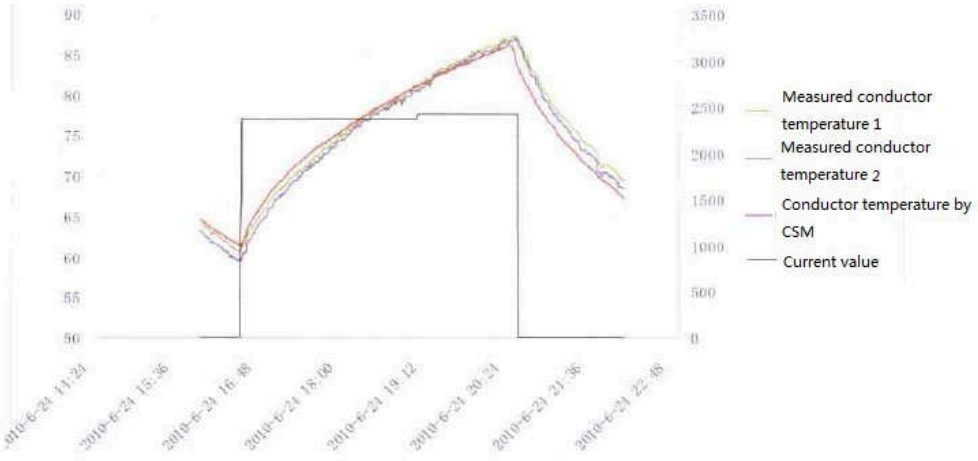


Diagram 7 Conductor temperature graph with 4h current charging in cable tunnel simulation

4) 12h current charging

Get a test cable and record its current conductor temperature (56.3℃). Use CSM software to compute the current amount charged to the cable for 12h and get the cable conductor temperature rose to 85℃, its calculation result is 2100A. Charge 2100A current to this cable by thermal circulation system for 12h, and record the actually measured and calculated temperature of conductor. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 12h 2100A current charging, the actually measured temperature of cable conductor is 83.1℃ and 83.3℃, and CSM calculation is 84.7℃.

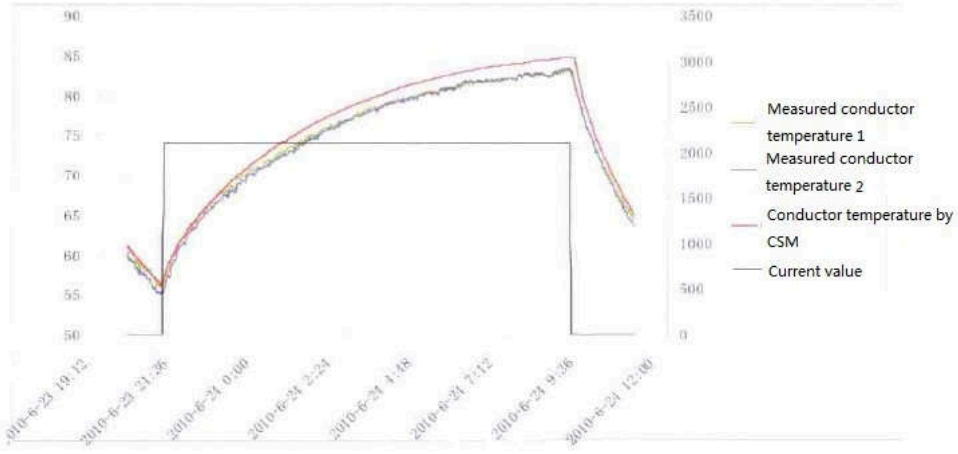


Diagram 8 Conductor temperature graph with 12h current charging in cable tunnel simulation

2.4. Contrast test of emergency load and conductor temperature for buried test cables

2.4.1 Cable and thermocouple installation

The test cable is buried in a U shape with burial depth at 1m. The optical cable is fixed on the surface of cable.

Diagram 9 Cable burial simulation

Diagram 10 Optical cable fixation on test cable

According to IEC standard, the distance between conductor thermocouples should be at 0.5-1m, and in this test the distance is set at 0.8m and 1m. To provide sufficient data sample of cable conductor temperature, and avoid influence of uncertain factors including expansion and contraction in installation, three conductor thermocouples (normally more than three) are installed on test cables. In selecting samples, obviously unreasonable data shall be deleted, and any two or more could be selected for validation reference if there is no invalid samples.

Under burial condition, three thermocouples are installed at bottom and bending positions of the U-shape cable. Sheath temperature thermocouple (shown in diagram 11) is installed around each conductor thermocouple. To avoid overheat influence on conductor temperature measurement at the connection of cable conductor and aluminum row, No. 1 and 2 thermocouple are installed around the middle of the test cable, kept more than 5m from the conjunction of two ends. No. 3 thermocouple is installed around the minimum bending radius, kept more than 3m from the conjunction.

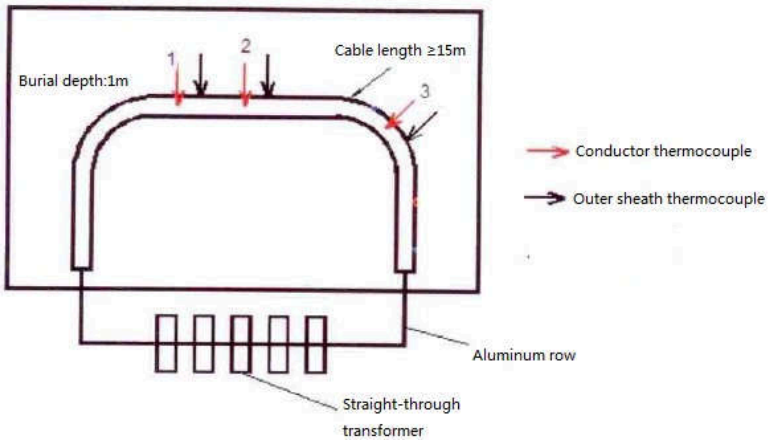


Diagram 11 Thermocouple installation diagram in cable burial condition

2.4.2 Test procedure and current charging scheme

1). 1h current charging

Get a test cable and record its current conductor temperature (65.5℃). Use CSM software to compute the current amount charged to the cable for 1h and get the cable conductor temperature rose to 85℃, its calculation result is 3060A. Charge 3060A current to this cable by thermal circulation system for 1h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 1h 3060A current charging, the actually measured temperature of cable conductor is 87.0℃ and 83.7℃, and CSM calculation is 84.5℃.

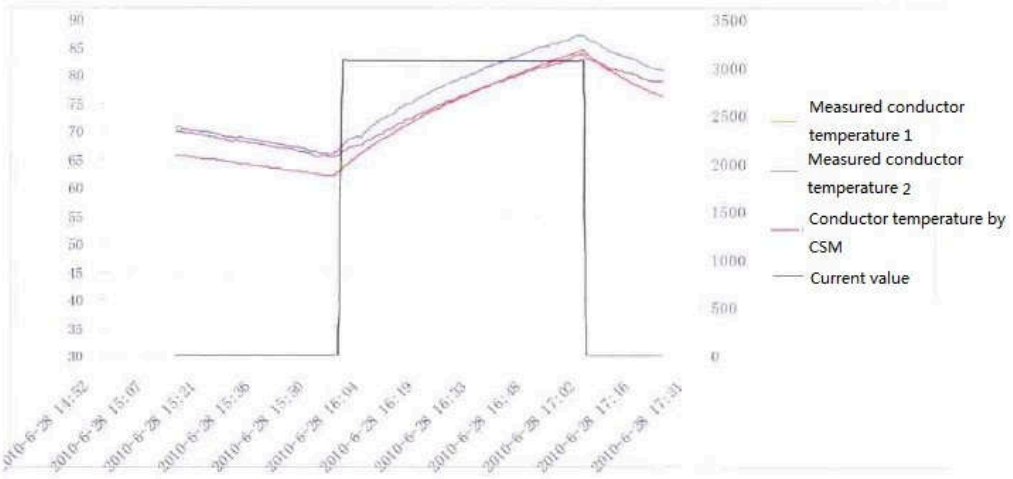


Diagram 12 Conductor temperature graph with 1h current charging in cable burial simulation

2) 2h current charging

Get a test cable and record its current conductor temperature (31.0℃). Use CSM software to compute the current amount charged to the cable for 2h and get the cable conductor temperature rose to 85℃, its calculation result is 3360A. Charge 3360A current to this cable by thermal circulation system for 2h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 2h 3360A current charging, the

actually measured temperature of cable conductor is 86.8℃ and 83.8℃, and CSM calculation is 84.7℃.

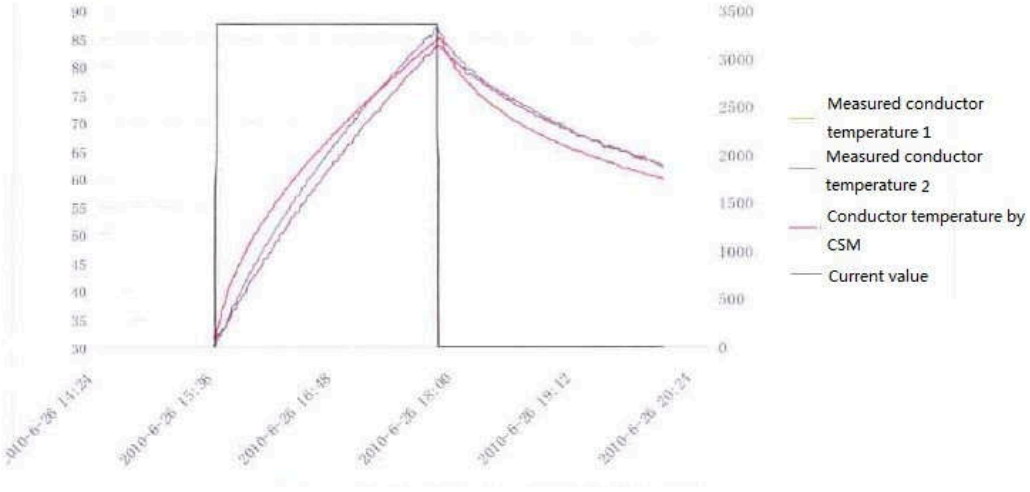


Diagram 13 Conductor temperature graph with 2h current charging in cable burial simulation

3) 4h current charging

Get a test cable and record its current conductor temperature (40.2℃). Use CSM software to compute the current amount charged to the cable for 4h and get the cable conductor temperature rose to 85℃, its calculation result is 2680A. Charge 2680A current to this cable by thermal circulation system for 4h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 4h 2680A current charging, the actually measured temperature of cable conductor is 86.9℃ and 83.6℃, and CSM calculation is 84.6℃.

Diagram 14 Conductor temperature graph with 4h current charging in cable burial simulation

4) 12h current charging

Get a test cable and record its current conductor temperature (33.1℃). Use CSM software to compute the current amount charged to the cable for 12h and get the cable conductor temperature rose to 85℃, its calculation result is 2200A. Charge 2200A current to this cable by thermal circulation system for 12h, and record the actually measured conductor temperature and the one calculated by CSM. Plot a graph of the two temperature values.

The target temperature of charging current is 85℃.In the test, after 12h 2200A current charging,

the actually measured temperature of cable conductor is 87.0℃ and 84.6℃, and CSM calculation is 85.7℃.

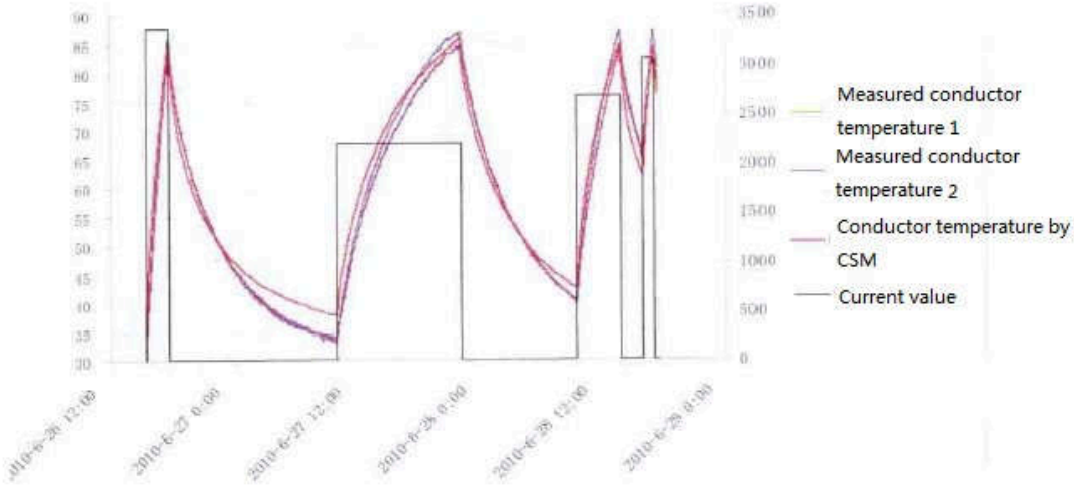


Diagram 15 Conductor temperature graph with 12h current charging in cable burial simulation

3. Data analysis

3.1 Data analysis of DTS temperature and positioning test

3.1.1 Data analysis of DTS temperature test

Table 5 Contrast test data of DTS temperature test

Thermometer reading(℃)	Difference between maximum DTS reading and thermometer reading (℃)	Difference between minimum DTS reading and thermometer reading (℃)
10	0.1	-0.3
20	0	-0.2
30	-0.2	-0.3
40	0	-0.3
50	0	-0.1
60	0.1	0
70	0.3	0.1
80	0.3	0
90	0.2	-0.1

After a comprehensive comparison and analysis of DTS and thermometer measurement under room-90℃ and 0-90℃ conditions, it's concluded that the deviation between DTS and thermometer measurement is ≤±0.3℃ in 0-90℃ test。

3.1.2 Data analysis of DTS positioning test

Table 6 Contrast test data of DTS positioning test

Actual measuring length of optical cable (m)	Deviation between actual measuring length and DTS measurement (m)	Temperature at tested position(℃)
5	0.1	46.2
10	0.2	51.0
20	0.3	51.6
500	0.3	52.4

The test results indicate that the DTS positioning accuracy is within 0.1m when the measurement optical cable ranges 5m; 0.2m when the optical cable ranges 10m; 0.3m when the optical cable ranges 20m; 0.3m when the optical cable ranges 500m.

3.2 Result analysis of conductor temperature measurement in cable tunnel condition

Table 7 Test data of conductor temperature in cable tunnel condition

Emergency load time (h)	1	2	4	12
Emergency load (A)	3180	2730	2370(2.5h) 2430(1.5H)	2100
Expected conductor temperature (℃)	85	85	85	85
Measured conductor temperature1 (℃)	83.4	83.5	87.1	83.1
Measured conductor temperature 2 (℃)	83.4	83.2	86.7	83.3
CSM calculated conductor temperature (℃)	84.8	85.2	86.2	84.7
Deviation between expected temperature and measured temperature 1 (℃)	-1.6	-1.5	2.1	-1.9
Deviation between expected temperature and measured temperature 2 (℃)	-1.6	-1.8	1.7	-1.7
Deviation between expected temperature and CSM calculated temperature (℃)	-0.2	0.2	1.2	-0.3

From this table, it can be seen that constantly charging certain time (1h, 2h, 4h, and 12h) of current to test cable in cable tunnel condition, the deviation between actually measured temperature and calculated (and expected) temperature (85℃) is smaller than 2.0℃. At the 4h test, owing to the fluctuation of power grid, a variation of 60A current occurred and led to an

increase of 1-2℃ of conductor temperature.

3.3 Result analysis of conductor temperature measurement in cable burial condition

Table 8 Test data of conductor temperature in burial condition

Emergency load time (h)	1	2	4	12
Emergency load (A)	3060	3360	2680	2200
Expected conductor temperature (℃)	85	85	85	85
Measured conductor temperature1 (℃)	87.0	86.8	86.9	87.0
Measured conductor temperature 2 (℃)	83.7	83.8	83.6	84.6
CSM calculated conductor temperature (℃)	84.5	84.7	84.6	85.7
Deviation between expected temperature and measured temperature 1 (℃)	2.0	1.8	1.9	2.0
Deviation between expected temperature and measured temperature 2 (℃)	-1.3	-1.2	-1.4	-0.4
Deviation between expected temperature and CSM calculated temperature (℃)	-0.5	-0.3	-0.4	0.7

By above data, it can be included that when cable is buried in a 1m deep condition, constantly charging certain time (1h, 2h, 4h, and 12h) of emergency load to test cable, the deviation between actually measured temperature and calculated (and expected) temperature (85℃) is smaller than 2.0℃.

4. Conclusion

Above tests shows that in 0-90℃ test condition, the absolute deviation between thermometer reading and DTS measurement is ≤0.3℃, and the absolute deviation of positioning accuracy is≤0.3m.

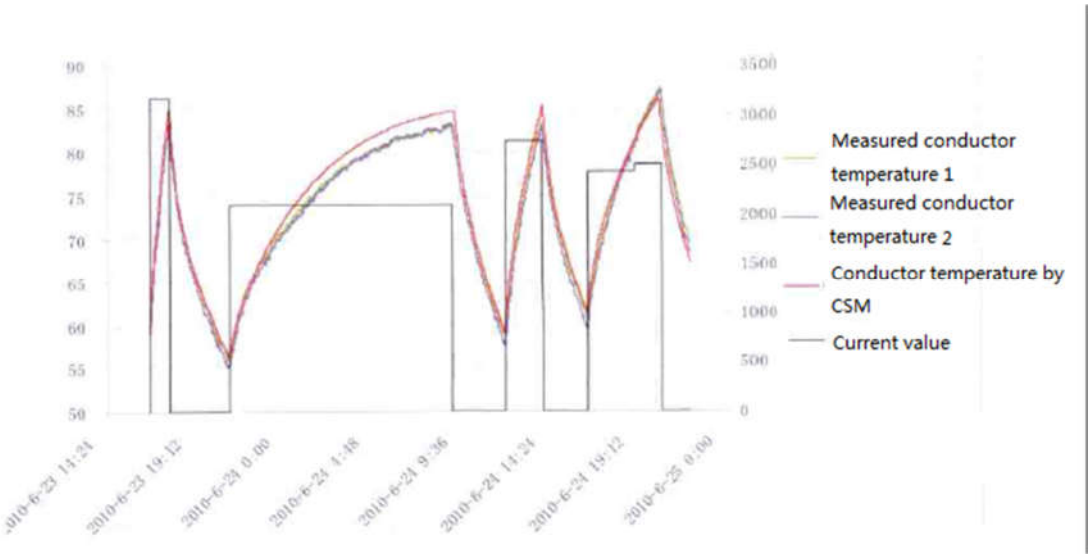
In tests, CSM system makes use of sheath temperature measured by DTS to compute the emergency load amount charging for 1h, 2h, 4h, and 12h to get conductor temperature rise to 85℃ by mathematic model and analysis program. Then charge the calculated current for relevant time to test cable and compare the deviation among the measured conductor temperature with the one calculated by CSM and expected value (85℃).

1). In cable tunnel condition, charging 1h, 2h, 4h, and 12h current to the test cable, the deviation (absolute value) between the measured conductor temperature and the value calculated by CSM and expected value (85℃) is smaller than 2.0℃.

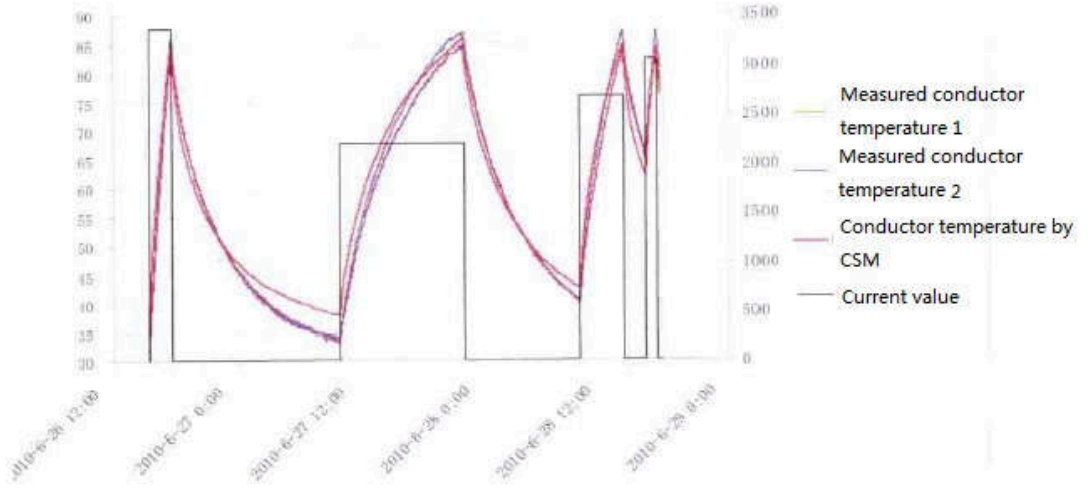
2). In cable burial condition, charging 1h, 2h, 4h, and 12h current to the test cable, the deviation (absolute value) between the measured conductor temperature and the value calculated by CSM and expected value (85℃) is smaller than 2.0℃.

Appendix A

Graph of current against cable conductor temperature in cable tunnel condition



Graph of current against cable conductor temperature in cable burial condition

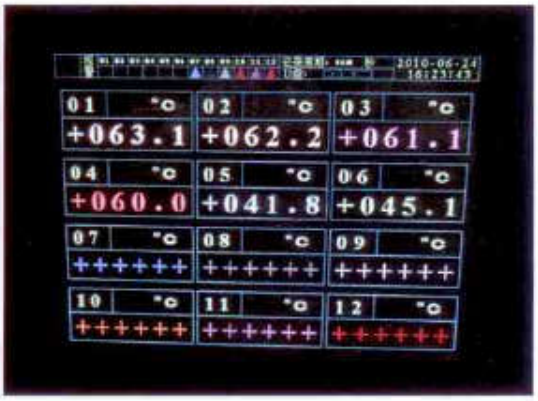


Appendix B

Cable tunnel simulation

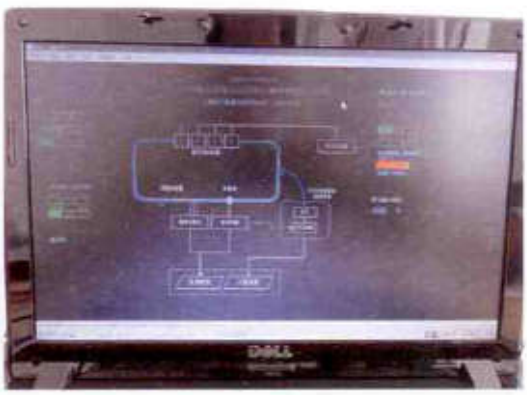
Cable burial simulation

CSM calculation interface



Interface of cable conductor temperature calculation and sheath temperature measurement

DTS host of CSM system



CSM operation interface