THE NECESSITY ANALYSIS OF DISTRIBUTED FIBER-OPTIC TEMPERATURE MONITORING BY XIAMEN POWER CABLE ALARM CASE STUDY

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ABSTRACT
This paper introduces the application results of Distributed Fiber-optic Temperature Monitoring System (DTS) used in Xiamen Power utility for 220 kV power cable operation monitoring. In November 2007, one cross bonding box earthing problem caused by water leakage in a cable joint manhole was detected. In terms of the deployed DTS system this problem was resolved in time, successfully preventing the potentially serious large-scale cable faults. Thus to demonstrate the theory of DTS system for larger applications, this paper presents the reliability, sensitivity and usage of DTS in relation to the temperature monitoring.

KEYWORDS
Distributed Fiber-Optic Temperature Monitoring; Power Cable operation monitoring; Temperature Alarm; Cross Bonding; Short Circuit

INTRODUCTION
Xiamen is an island city of Fujian province, China. The power supply to this city is based on 5 circuits of 220 kV power lines, while 3 of them are mixed with overhead lines and power cable lines. In order to optimize the limited land resources, Xiamen has decided to replace the old overhead transmission lines with underground power cable lines gradually. Until May 2008, 243km power lines with voltage 110 kV-220 kV are in place, whereas 62km lines, approximately 26%, are represented by underground cables. With the granting of a series of Power Cable Lines Projects in FangHu district, the proportion of power cable lines is expected to further enhance, reaching at 35% in years. In these circumstances, the reliability of underground power cable lines has become vitally important for the entire power supply system in Xiamen. In order to better monitor the operating conditions of power cable lines, starting in 2005 Xiamen Power Utility has deployed a set of DTS systems (Distributed Fiber-optic Temperature Monitoring Systems) in 2005, equipping with the power rating system upon DTS as a pioneer in China.

The first DTS system was put into operation in 2005, with 4 channels monitoring two 220 kV lines, one 110 kV line, and one 10 kV line respectively (as shown in Figure 1). The monitoring results, as well as the corresponding temperature curve plotted in real-time, were accessible via the internal networks for the authorized personnel. In addition, the DTS system includes the capability to automatically update the maximum temperatures and locations in each channel via SMS to any designated mobile addresses. Valuation and testing results indicate that these features of DTS have improved the efficiency of power cable maintenance to considerable extents.

CABLE HIGH TEMPERATURE ALARM CASE AND URGENT SERVICE
On 2 November 2007, Xiamen cable maintenance engineers detected that the maximum temperature in a 220 kV line showed consecutively increasing trend on daily basis, according to the alarming SMS received from the DTS. Xiamen engineers reported this exceptional situation and started to check the history monitoring data log. On 7 November the increase rate of cable temperatures was doubled, which led to the temperature, at 18:00 on 12 November, to reach at 48°C. In terms of the above information engineers from the Power Transmission Department went for on-site check immediately. Initial detection showed that 30# man hole was filled with water, and the surface water temperature was 84°C, far exceeded the normal range. To deal with the situation immediate actions were taken to pump the water out from the hole for further cable system investigation. After two on-site investigations at 13 November and 14 November, it was found the faults were mainly attributed to the short circuit when water went into the cross-bounding box accidentally, which gradually heated up the surface water in the man hole. Based on the investigation results contingency plans were made and executed in due course, resulting in the decrease of surface water temperature started to decrease. After 3 hours the DTS reported that the temperature went below than the alarming threshold, reaching at 55°C as shown in Figure 2.1 and Figure 2.2. Simultaneously, senior engineers were allocated to resolve the water leakage problem of all joint boxes in man hole 30# as well.

Fig. 1  Power cable temperature monitoring system
The system has been in operation for 6 consecutive years, effectively prevented a high temperature issue on 13 November 2007.
Figure 3.1 shows the temperature trends in the period from 2 November to 12 November. Figure 3.2 presents the trend in the 48 hours after the monitoring alarm was triggered in. The trend, after 7 November, implies positive correlation between the rapid enhancement of the cable temperature as well as the increase of cable workload. At 18:00 on 12 November, the cable surface temperature reached at 48°C.

During the investigation the key point was to identify the cause of the exceptional temperature increase. Valuation results show that the increase is contributed by three main aspects: the heat generated by the cable operation, the magnetic interference and the water leakage. From the stance of cable system, the magnetic field generated by operating cable could influence the water temperature to some extent. Put another way, the heat could also be partially attributed to the insulation problem inside the cable, as well as the cable joint box caused by short-circuit current.

For the detailed investigation it was eventually determined that the most influential factor was the water leakage of the joint box. While water leaked into the joint box accidentally, short circuit took place which eventually heated up the water in the man hole. This argument was proven by the fact that the water temperature in the upper part of the water was constantly higher than the lower part.
TEMPERATURE EVALUATION IN THE WHOLE HANDLING PROCESS

Figure 5 shows the temperature measured by DTS during the whole urgent service process, from 10:00 of 3 November to 18:00 of 14 November. The whole period can be evaluated with 7 stages.

- **Stage 1:**
  10:00—12:00, 13 November 2007
  Water started to be pumped out, cable surface temperature dropped from 58°C to 43°C

- **Stage 2:**
  12:00—13:00, 13 November 2007
  Water pumping was paused for lunch, and cable temperature went up again from 43°C to 45°C

- **Stage 3:**
  13:00—14:00, 13 November 2007
  Forced ventilation from outside to man hole, and temperature went to normal from 45°C to 29°C

- **Stage 4:**
  14:00—19:00, 13 November 2007
  On-site investigation, with intermediate forced ventilation, and cable temperature was in the level of 30°C

- **Stage 5:**
  Overnight till 10:00, 14 November 2007
  Man hole was closed overnight, cable temperature increased back to 43°C. Second service is needed, this decision was made based on the measurement result.

- **Stage 6:**
  10:00—12:00, 14 November 2007
  Forced ventilation continue, and temperature reached at 29°C.

- **Stage 7:**
  After 12:00, 14 November 2007
  Temperature measurement result became stable at 29°C. Investigation was over.

The sensitivity of OFDR DTS technology used for this cable temperature monitoring case has been presented very well in this case. The case study clearly showed the small differences, even the temperature changes during lunch time and over night. In this case, Xiamen Power Company had taken the advantages of the OFDR DTS, and successfully solved the problem without the need to shut down the entire cable operation. This case also demonstrated that the DTS system is ideal for power cable operation monitoring.

**FUNCTIONS OF DTS USED IN POWER CABLE OPERATION MONITORING**

1. To give exact temperature data of the cable surface on time

This service case demonstrates that DTS technology is capable of monitoring power cable operations, especially in case of temperature fluctuations caused by the sudden changes of power cable operation surroundings or fiber break faults. In China, DTS had already been deployed in various circumstances for power cable operation monitoring alarms, including fire alarm, water leakage alarm, cable outer cover damaging alarm, and anti-theft guarding alarm.

This report introduces the application of DTS alarms in dealing with water leakage and resulting short circuit. In this case DTS system provided the accurate temperatures of the cables and the location of cable faults for engineers.
in time. In addition, the summary information, including the maximum temperature and location in the monitoring range, was sent to the designated engineers on daily basis by DTS which offered an efficient way to monitor the system even the engineers were not physically presented in the emergency scene.

2. To determine the safety margin of cable surface temperature

From the temperature graph, Xiamen engineers were informed that the safety margin of temperature should be around 29°C, as shown in Figure 5. Having all the temperature information around the man hole 30#, engineers were equipped with a clear target to execute the contingency plan for solving the identified problems.

The normal temperature near the man hole 30#

3. To determine a successful trouble shooting or service

On 13 November 2007, the urgent service was supposed to be finished. But overnight the DTS monitoring result indicated that another 15°C temperature increase was detected, exceeding the safety margin determined by DTS. Based on this measurement, the service team continued the service work on 14 November 2007 to investigate the cause of the temperature enhancement. After hours work the temperature stabilised at the range of 29°C, and DTS concluded that the service work was finished successfully.

CONCLUSIONS

This report provides the detailed analysis in regard with the cable operation monitoring offered by DTS system. In the Xiamen cable maintenance case introduced in aforementioned chapters, three main problems were identified by DTS. These included water detection in the man hole, the water leakage problem in the cross-bonding box, and the overheated cable surface temperature (55°C). While DTS system detected the emergency accident, accurate temperature measurements were provided for the designated engineers promptly. In terms of this information investigation group was formed and sent to the emergency scene and the overheated temperature issue was eventually resolved. It shall be noted that since the faults were identified and fixed on-line with the cable under operation, it did not cause any unnecessary power supply to shut down.

In summary, this case study gives the following conclusions:

1. DTS system had been successfully deployed in Xiamen to identify a short circuit problem in cable cross-banging box. This high temperature alarm enabled Xiamen Power Company to locate the source and solve the problem promptly without the need to shut down the entire cable system supply. After this case, the value of DTS system was largely appreciated in the industry. It is noticed that Xiamen has decided to install DTS systems for its entire 220 kV underground cable lines in the city.

2. Cable temperature monitoring is sensitive and accurate for cable operation monitoring and maintenance.

3. The real-time SMS function is largely perceived to be useful by operation engineers, effectively eliminating the need to visit the system physically while receiving prompt information updates on daily basis.

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