Study on the damage analysis of 110kV cable structure

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Abstract. The market application value of power cables has gradually emerged with the development of various industries. Cable laying is a basic project in the construction of power grid and a key part of power engineering construction, and a key content of power engineering construction, which is related to the safe and reliable operation of the entire power grid. With the laying process of power cable, the metal sheath is subjected to structural damage such as extrusion deformation. This paper takes a 110kV cable line as an example, The case of cable damage was introduced in detail, and targeted measures were proposed based on the defects caused by the damage. At the same time, the structural analysis of the cable damage is carried out, and the structural analysis and simulation are performed, and the partial discharge test is performed on the damaged portion of the insulation to obtain the stress received when the cable is recessed, and the partial discharge signal detected by the damage of the insulating shielding layer is collected. Provide reference for staff related to power cables.

1 Introduction

As an important part of power transmission and distribution in the power system, power cables are usually laid in the soil or in the space of buildings, ditches or tunnels, which are not easily affected by the surrounding environment or climate conditions, and can carry out stable performance transmission with high security. In recent years, cable failures have affected the reliability of power supply. The reason is attributed to insulation damage [1-3]. With the expansion of the application scope of high voltage single core power cable in China, more and more cable metal sheath induced voltage problems appear gradually. The rise of induced voltage will cause personal safety, and the insulation layer will also be broken down; especially when the cable line is short circuited, subjected to switching overvoltage or lightning overvoltage, a high induced voltage will be generated on the metal sheath, in turn, the current carrying capacity of the cable will be reduced, and even the outer sheath insulation may be damaged or cause cable line operation accidents. Therefore, the metal sheath plays an important role in the power cable. In the process of power cable transmission, once the line has a short-circuit fault, the short-circuit current can flow through the metal sheath as its flow path. In this way, the heating phenomenon generated by the large current flowing through the magnetic core can be avoided, thus reducing the risk of cable insulation damage, and at the same time, the metal protection of the cable The sheath also plays a shielding role, and the metal sheath has a profound impact on the safety and reliability of the power supply of the cable [4,5]. This paper analyses the cause of external force damage of 110kV cable line in a certain area, carries out mechanical simulation analysis and partial discharge test, analyses the test results, and provides reference for the operation and maintenance management of transmission cable in the future.

2 Causes of cable damage by external force

In the process of China's large-scale construction, the threat to the safety of urban construction is also highlighted[6]. The influence of external force accident on the cable is various, such as causing damage to the personal safety of construction personnel on site, leaving hidden danger of safety accident to the cable system, significant decline in the overall health level of the equipment, endangering the safe power supply of the power grid and a series of adverse social effects, etc., the main factors causing external force damage of the cable are as follows.

2.1 External causes

Mainly by the municipal, construction and construction departments in the supervision and management of many problems, management confusion, municipal departments mining, maintenance information published lag and other factors.

(1) Urban construction has been in the development, municipal engineering, road excavation and underground railway construction, the operation environment of the cable is quite complex, the power cable is always in a relatively dangerous environment, greatly increasing the possibility of external force damage accidents.

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(2) Non electric construction personnel are lack of awareness of cable protection. For large construction projects, the process is different, and the construction team often changes. Because the construction units do not pay attention to the effective protection of cables and ignore the rules and regulations, sometimes the location of power cables is unknown during construction. Through the so-called "experience", only when external force accidents occur, can they contact the cable operation management department for emergency repair. What's more, after the cable is damaged by excavation, the cable is buried. Some construction units are clear about the buried cables and have signed agreements with the operation Department. However, due to the internal management confusion or the early termination of the construction period, the relevant agreements are violated, which leads to external accidents.
(3) Some large-scale urban construction projects "layered subcontracting" led to internal management confusion and unclear responsibilities. Finally, after the accident, the power department could not receive the information in time, which delayed the repair time and caused huge losses.
(4) The construction units of many urban construction projects do not examine the documents carefully. According to the working procedures, the construction unit shall call on relevant pipeline units such as gas, water, electricity and heat to hold a coordination organization meeting before construction. Due to the lack of construction supervision, the information about the pipeline position on the construction site should be accurately announced, especially for the pipe jacking construction, excavation and maintenance construction information, but many construction units have not yet prepared for work. In recent years, municipal construction and cable line have developed rapidly, and the relevant cable drawing data lags behind the actual situation, and the drawings are usually inaccurate and not accurate clear and inconsistent situation. In this case, if the construction unit does not consult the cable data and blindly uses machinery for construction, the threat to the power cable will undoubtedly increase.
(5) In the construction, the cable operation unit should send relevant personnel to the site to track, remind and check, so that once problems are found, they will be solved in time to prevent cable damage accidents caused by external forces. Most of the cable damage caused by external force is caused by various municipal construction, and the construction information can only be obtained after a few days, and the blind spot in these days is exactly one of the factors leading to external force damage. For pipe jacking engineering, it is a huge safety hidden danger to the safe operation of the cable.

2.2 Internal causes

It is mainly due to the poor operation of cable engineering management system, and the management of construction and completion data is not in place.
(1) Not paying enough attention to the cable operation management, many projects do not work seriously. The drawings are seriously missing, and there are many potential hazards of the line, which affect the safe operation of the cable. The important reason for the cable external force accident is this, and for the construction unit, it causes certain potential safety problems.
(2) The lack of high-voltage cable operators, coupled with the lack of business responsibility, inspection is not in place, easy to miss, affecting the effective inspection. In addition, the problem of theft is repeated, and some equipment is stolen, which leads to the external damage of the cable.
(3) Many urban construction projects need to relocate high-voltage cables at the construction site. However, due to the lack of close cooperation between various departments, the focus of work is different, and there is no good coordination, resulting in many opportunities for relocation and protection of cables.

2.3 Other causes

One of the important factors of uncontrollable cable damage is that the power sector has no strict and effective protection measures and management measures. There are no effective sanctions against the units concerned. The protection means are very limited. After the cable is damaged by external force, the destroyer cannot be punished. Therefore, the occurrence of external force accident is highly uncontrollable.

3 External force damage cases of 110kV cable

3.1 cable damage by external force

During daily inspection, the cable team found that the buried pipe section of 110kV cable line was damaged by construction machinery, and the buried pipe section of the cable line was damaged by external force. It is found that a damaged cable buried pipe, about 1.1m long and about a third of the circumference wide, had a depression on the surface of the cable sheath due to external extrusion impact. The sheath depression is 0.8mm after measurement. As shown in Figure 1 and Figure 2.

Fig. 1. buried tube after mechanical damage.

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Fig. 2. Outer sheath depression

3.2 Defects case

According to the "grading standard of transmission equipment defects", the damage to the insulation shielding layer is classified as "major". As shown in Figure 3 and Figure 4, the aluminium sheath and insulation shield of 110kV cable line are damaged. The impact dent damage occurs at the body of the cable, and the metal sheath and internal insulation shield are damaged by the impact. The stress concentration generated by the depression reduces the fatigue life of the cable structure, and the existence of the depression also reduces the yield strength of the cable structure [7-13]. In summary, the static strength and fatigue life of the existing cable structure in the sag area have a significant impact on the power supply reliability of the cable. According to the standard, the defect and the insulation shield layer are rated as "significant" and should be locally strengthened for maintenance and replacement.

Fig. 3. Damaged aluminum sheath

Fig. 4. Damaged insulation shield

3.3 Simulation

As the buried pipe section of the cable was damaged by water supply emergency repair construction machinery, the inspection found that a damaged cable buried pipe, about 1.1m long and about one third of the circumference, had a depression on the surface of the cable outer sheath. It can be inferred that the cable section is subject to external impact. This simulation simulates the steel ball with M = 4kg, releases the steel ball at the height of 0.5m, 1m, 1.5m, 2m, 2.5m and 3m, and observes the sag and stress of the cable under the impact of the steel ball. As shown in Figure 5, the sag and stress distribution of the cable under the height of 2m are shown.

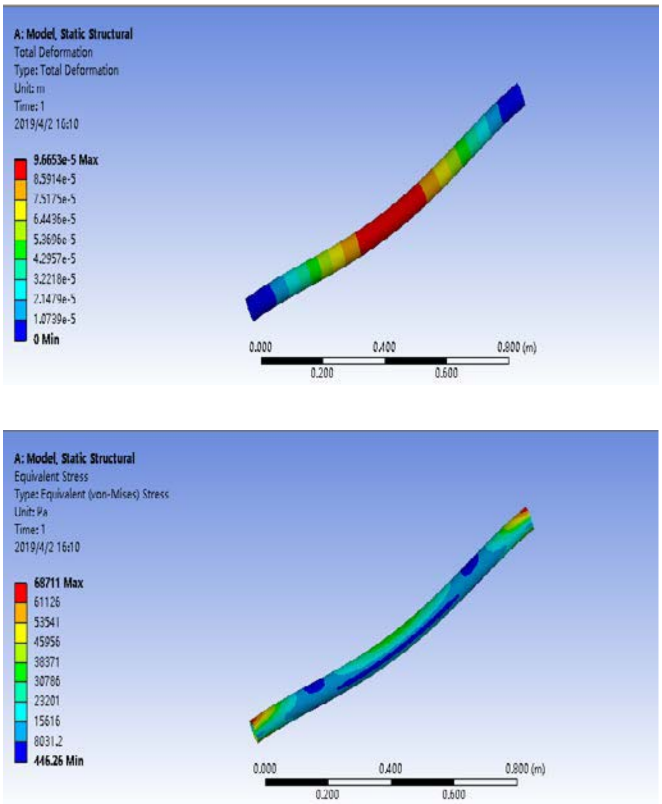

Fig. 5. Cable depression and stress distribution at a height of 2m

According to the simulation results, the cable sag and stress distribution of 4kg steel ball at different heights are obtained. As shown in Table 1.

Table 1. Cable sag and stress distribution at different heights

Height (m)	depression (mm)	Stress (kPa)
0.5	0.024	17.18
1	0.048	34.35
1.5	0.073	51.53
2	0.097	68.71
2.5	0.12	85.88
3	0.145	102.98
19.25	0.809	575.45

It can be seen from the table that when the steel ball with 4kg is released at the height of 0.5m, 1m, 1.5m, 2m, 2.5m and 3m, the cable sag and stress distribution at different heights are obtained. When the height is 0.5m, the maximum value of depression is 0.024mm and the maximum value of internal stress is 17178pa. When the height is 1 m, the maximum value of the depression is 0.048 mm and the maximum internal stress is 34 355 PA. When the height is 1.5m, the maximum value of depression is 0.073mm, and the maximum internal stress is 51533pa.When the height is 2m, the maximum value of the depression is 0.097mm and the maximum internal stress is 68711pa. When the height is 2.5m, the maximum value of depression is 0.12mm and the maximum internal stress is 85888pa. When the height is 3m, the maximum value of depression is 0.145mm and the maximum internal stress is 1.03×10^5Pa.

4 Partial discharge test

The partial discharge of the cable does not cause leakage. At this time, the insulation layer does not have penetrating damage. There is insulation barrier between the partial discharge area and the cable core, that is, the power system is still in normal operation. The damage of partial discharge to the insulation layer is similar to the corrosion process. At the beginning, the partial discharge area is very small and the discharge is very weak. If the partial discharge is allowed to exist for a long time, the discharge will be carried out as the area expands gradually, the damage to the insulation layer is gradually aggravated, which eventually leads to the penetrating damage of the insulation layer. Once the insulation layer is damaged, it will cause serious power system failure. In order to avoid power accidents, the insulation condition of cables must be monitored in advance. Partial discharge will have a process from small to large, so partial discharge generally does not cause the insulation layer to be broken down immediately, but if partial discharge exists for a long time, the insulation performance of cable will gradually decrease. In order to reduce power failure, it is necessary to detect in time. There is a close relationship between partial discharge and cable insulation defects, so the cable insulation condition can be judged according to the characteristics of partial discharge. These characteristics may be different for different equipment insulation. In the process of cable laying, the metal sheath is easy to be extruded and deformed, resulting in insulation damage. Compared with conventional non-destructive test parameters, partial discharge can well reflect the cable insulation state [14,15]. Some international authorities believe that cable partial discharge is the external manifestation of cable insulation deterioration, and is the most effective method to judge cable insulation status.

4.1 test application

(1) Necessity of partial discharge test

The advantages of XLPE cable lie in conductivity, transmission capacity, quality, operation and maintenance. So it is widely used in various fields. According to the requirements of relevant electrical test standards, the newly completed cables need to undergo AC voltage withstand test. However, the AC voltage withstand test only tests whether the overall performance of the cable is intact and whether it can withstand the expected test voltage value. The monitoring and diagnosis methods of local damage and damage that may occur in the test process of the cable are still lacking. After AC voltage withstand test, the possibility of partial discharge defect still exists. If the cable with internal defect continues to operate, it will bring hidden danger to the safe operation of power grid. Therefore, it is necessary to combine partial discharge detection technology with AC withstand voltage test, which will give more comprehensive consideration to the insulation state of the cable, conduct a more in-depth evaluation of the cable insulation condition, and identify the cable damage. To ensure the safe and reliable operation of the power grid.

(2) Test object

The 110kV cable line damaged by external force is XLPE high-voltage cable line. Due to the external force damage, the aluminium sheath and insulation shield of the cable line have produced depression. The model is YJLW03-Z 64/110 single core, and the cross-sectional area of cable conductor is 400mm2. A 16m cable line with damage point is intercepted at the site. In order to analyse the damage severity, partial discharge detection is carried out.

4.2 test analysis

This test instrument adopts series resonance withstand voltage test system, model: MSR700-21000, DDX digital partial discharge detector, model: DDX-7000, to test 110kV cable line damaged by external force. Partial discharge is used to indicate the severity of partial discharge of high-voltage cable. To test the partial discharge of high-voltage cable, the test system must be calibrated first. After testing, the amplitude of partial discharge signal is compared with the calibration information, and the value of partial discharge is calculated to judge the damage degree of partial discharge. Among them, the background signal of not closing the cable is 1.6pC, and the background signal of closing with cable is 2pC. When the voltage is raised to 70kv, the partial discharge signal is 5pC, and when the voltage is increased to 96kV, the partial discharge signal is 18pC, as shown in Figure 6.

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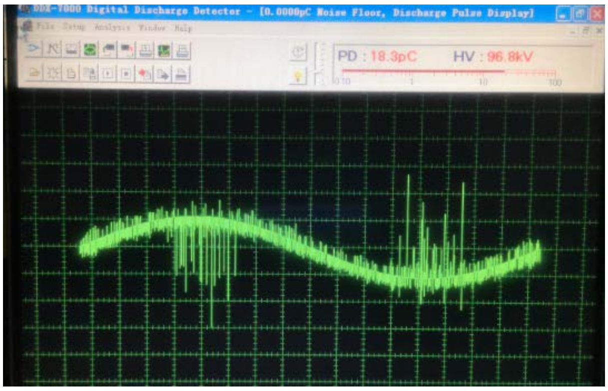

Fig. 6. 96kV partial discharge diagram

When the voltage is increased to 112 kV, the partial discharge signal is 50-70 pC. as shown in Figure 7, the partial discharge signal is 69.4 pC when the voltage is increased to 112.6 kV.

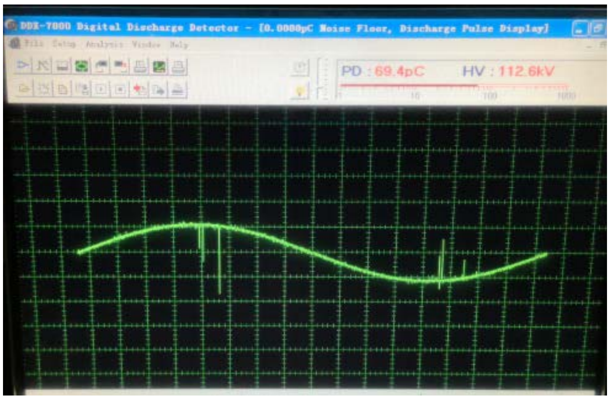

Fig. 7. 112kV partial discharge diagram

As shown in Figure 8, when the voltage is increased to 113.5kv, the partial discharge signal is 65.6pC.

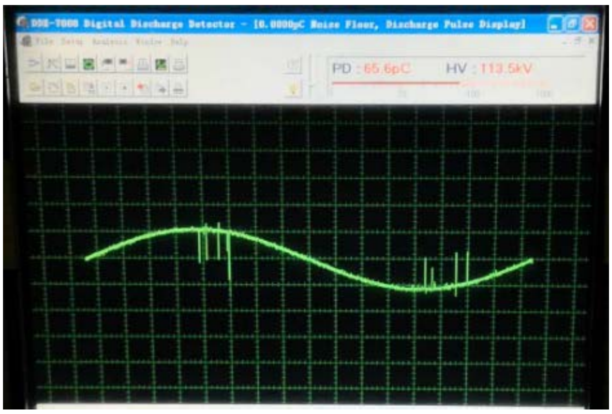

Fig. 8. 112kV partial discharge diagram

When the voltage is increased to 160kV, the partial discharge signal is between 53-70pC. As shown in Figure 9, when the voltage is increased to 158.7kV, the partial discharge signal is 63.5pC.

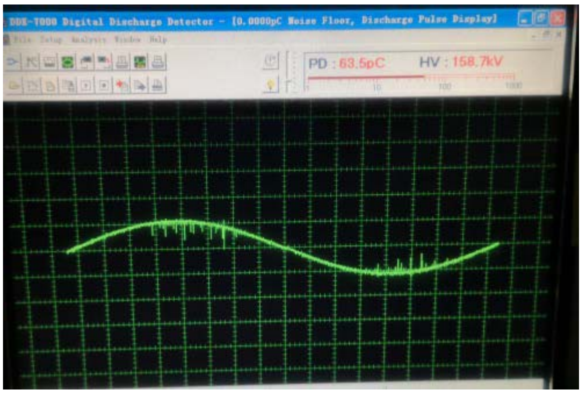

Fig. 9. 160kV partial discharge diagram

As shown in Figure 10, partial discharge signal of 53.2pC appears when the voltage is raised to 160.1kv.

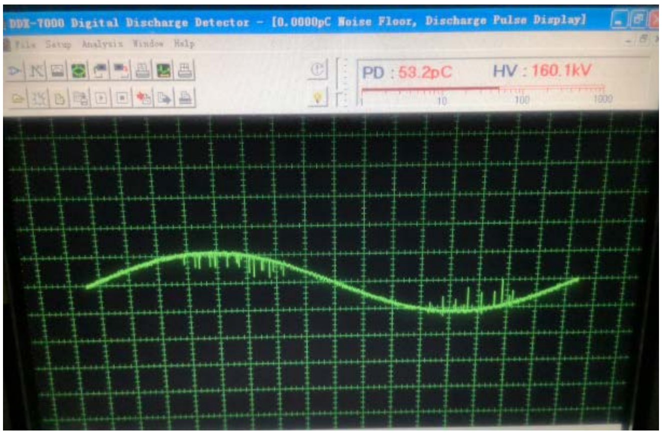

Fig. 10. 160kV partial discharge diagram

4.3 cause analysis

In the insulation body of cable, it is sensitive to external interference. In the process of manufacturing and processing, bubbles and other related impurities will always exist, which makes the breakdown strength of this area reduce and discharge phenomenon is easy to occur. Due to the effect of electric field, partial discharge occurs in some areas inside the insulator. Sometimes partial discharge does not penetrate the whole cable. Relevant local measurement specifications also mention the definition of partial discharge, which is a partial bridging discharge phenomenon. However, no matter what kind of partial discharge is, it is a potential hidden danger to the safe operation of the cable. It is not conducive to the stable operation of power system. The high-voltage cable body is cut open, and it is found that there are signs of discharge on the surface of the cable. The cross-section of the cable damaged by external force is shown in Figure 11. The location of partial discharge is one of the plane of the cable. This part of the cable has shown a non-circular angle. The air gap is formed at the junction of the metal sheath and the cable insulation shield due to the non-circular corner at the insulation part, and partial discharge occurs in the air gap under the action of voltage.

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According to the laboratory measurement, the structural dimensions of the cable insulation core depression are as follows: the normal outer diameter of the insulated core is 65.2mm, the minimum outer diameter of the depression is 64.3mm, and the hollow area of the insulated core is 39 × 27mm (length × width). The average insulation thickness of cable is 17.8 mm, and the minimum insulation thickness at depression is 17.0 mm. It can be seen that the damage of insulation shield of 110kV cable is more than 0.8mm.

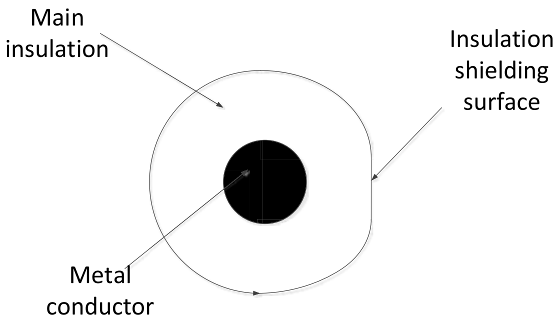

Fig. 11. Schematic diagram of the fault cable

5 Conclusion

The metal sheath is of great significance to the safe and stable operation of the cable. Once the metal sheath is damaged by external force, such as depression and other structural damage, the local overheating of the cable will occur, and the power supply reliability of the whole cable will be seriously affected. Therefore, in order to ensure the safe and stable operation of the cable, it is necessary to prevent the structural damage of metal sheath due to extrusion deformation. In this paper, for 110kV cable line, it is found that the damage of insulation shield of 110kV cable is more than 0.8mm. The simulation analysis of the cable shows that the stress can reach 575.45kpa. Partial discharge test was carried out to detect the partial discharge signal inside the cable. When the voltage was increased to 160.1kV, partial discharge signal of 53.2pC appeared. In AC withstand voltage test of high voltage cable, partial discharge test technology is applied in cable insulation diagnosis. The partial discharge test technology can be used as a technical means of high voltage cable test, which is helpful in cable test and cable management. This can also provide reference for the relevant personnel of cable laying construction.

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