Research on Key Technologies of High Voltage Power Cables in Smart Grid

Yun Guo, Minhu Xu, Yubo Shen*, Rong Cao, Kexin Zhang and Xiangyu Zhao
State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute, Harbin 150040, China

*Corresponding author email: yubo_shen@sgcc.com.cn

Abstract. Smart grid, high voltage, power cable, key technology, fault diagnosis.

Abstract. The paper discusses important issues such as high-performance materials, electrical tree aging, space charge, insulation structure and technology, and cable operation detection in cable research and development. It is believed that DC cables will be used in power transmission for a long time in the future. It will receive more and more attention, but it is also facing the problems of insulation reliability and the development of new materials due to space charge and nonlinear temperature characteristics. The paper analyses the main reasons for the failure of power cables in the smart grid, and proposes several advanced power cable fault diagnosis technologies, and studies their principles and applications in order to improve the efficiency of fault diagnosis of the smart grid and protect the power grid. Operational reliability.

Keywords: Smart grid, high voltage, power cable, key technology, fault diagnosis.

1. Introduction
At present, with the rapid development of the national economy and the continuous increase in power grid demand, most of the high-voltage transmission lines are laid underground or in the air, and different types of high-voltage transmission cables are increasingly used in various sectors of the national grid. Once the high-voltage cable fails, it is very likely that the circuit will be interrupted, which will have a great impact on citizens and enterprises, and in serious cases will cause major safety accidents. Therefore, it is very important to perform fault detection on high-voltage cables in time. Currently, cable fault detection mainly includes: grounding detection, short circuit detection, disconnection detection, etc. However, the detection of cables is very difficult, because in addition to overhead cables, they may also be laid underground or even in the sea. This is a severe challenge to the detection of high-voltage cables. Water tree aging and metal shielding damage are common phenomena in XLPE cables. When there is moisture inside the insulator in the cable, the aging phenomenon of the formation of dendritic defects in the insulator due to the local concentration of the electric field is called water tree. In a high temperature environment, the water tree branches will undergo significant oxidation, which will increase the water absorption and conductivity, and ultimately lead to thermal breakdown; in a low temperature environment, the water tree branches will
be oxidized or converted into electrical branches for a long time [1]. The smart grid system mainly refers to the topological analysis of the power network system based on the SCADA information, and clarifies the content of the fault and the specific fault point. The entire fault repair process involves a lot of logical judgments, and a complex mathematical model needs to be established to quickly locate the fault and accurately deal with it. Power cable fault diagnosis technology has become one of the main technologies of the current power grid system, so it is necessary to discuss power cable fault diagnosis technology.

2. Key technological breakthroughs and research hotspots in the development of cables

In the more than 100 years of cable development, engineers and researchers have carried out a series of studies around the goals of higher voltage, greater capacity, higher stability, and greater transmission distance. For example, in 1960, a large number of extruded cables were put into urban underground power transmission. At that time, people thought that this kind of insulation would not need to be replaced for 100 years, but within a few years, a large number of failure reports were received. It was discovered that a large number of tree-like channels appeared in the cable insulation. In 1968, it was confirmed that the main problem affecting the operating stability of extruded cables was dendritic aging. The use of anti-electric tree aging XLPE materials and a 3-layer co-extrusion process effectively solved this problem, which enabled the rapid development of XLPE cables from the 1990s to the present [2]. With the deepening of the understanding of the characteristics of space charge in insulating materials, the use of flexible DC transmission to avoid the situation of polarity inversion, so that the problems caused by space charge are alleviated, and XLPE cables can be gradually used in actual DC transmission projects.

3. Aging analysis of power cable lines

Common transmission lines are mainly composed of three parts: insulation layer, conductor layer and protective layer. For long-running power cables, the protective layer and insulation layer will often be aged or damaged. Under normal circumstances, the insulation paper of the body, joints and terminal parts of the oil-filled cable is often immersed in the insulation oil, which is not prone to aging. When the cable is deformed or the insulating layer and protective layer are broken or leaked under the interference of external forces, the insulating effect of the oil-filled cable will be greatly reduced, which is very likely to cause a major safety accident. The charged insulating oil will react with moisture and other substances in the air, causing aging, etc., further reducing the insulating effect.

Damage to the metal shielding layer and aging of the water tree are the most common fault conditions for XLPE cables. When the insulating part of the cable is doped with moisture, the dendritic aging damage based on the local concentration of the electric field in the insulator is called water tree. When exposed to a high temperature environment for a long time, the water tree will gradually oxidize, the water absorption effect will be greatly enhanced, the conductivity will gradually increase, and thermal breakdown may eventually occur; when the water tree is in a long-term low temperature environment, due to oxidation and transformation, the water branches will further turn into electric tree branches. Some scholars have explained the effect of space charge in a quantitative way. They believe that the cumulative effect of the charge emission at the tip of the needle under a strong field destroys the local area of the material to form micro-cracks and leads to electrical dendrites [3]. They also summarized the above hypothetical electrical dendritic initiation the pattern is shown in Figure 1.
4. Cause analysis of cable failure

Cable faults can be roughly classified into the following categories. Figure 2 shows the classification diagram of cable fault causes.

4.1. Mechanical damage

Mechanical damage is the main cause of cable accidents. When the mechanical damage is minor, the cable can continue to run, but the damaged part will develop into a fault point after long-term operation, causing an accident [4]. The main causes of mechanical damage to cables are:

4.1.1. The cable installation quality is not high. The cable is bruised during installation, excessive bending of the cable damages the cable, excessive mechanical traction during the laying process strains the cable, etc.

4.1.2. The cable is damaged by external force. Construction work on the cable path or near the cable directly damages the cable under the action of external force.
4.1.3. *The metal Armor layer of the cable is damaged.* The metal Armor layer is severely damaged by external force or corrosion.

4.1.4. *Damage caused by natural phenomena.* The natural stroke of the cable causes damage to the cable installed on the cable nozzle or bracket; for example, the expansion of the insulating rubber in the intermediate joint or terminal head causes the shell or cable sheath to burst; the cable is damaged due to land settlement [5].

4.2. *Insulation drops of cable insulation*
The main reasons for the decline of cable insulation are: water in the cable insulation layer due to improper cable termination or poor installation quality; cracks or small holes in the sheath layer during the cable manufacturing process; metal sheath layer is damaged by external force; cable protection Severe sheath corrosion causes cable damage and damp insulation.

4.3. *Overvoltage faults*
When the power cable is subjected to overvoltage, it breaks down at the weak point of the cable insulation and forms a fault.

4.4. *Cable insulation ageing*
There is an air gap inside the cable insulation medium. The air gap will be released under the action of an electric field, which will reduce the cable insulation. When the insulation medium is ionized, certain chemical products such as ozone and nitric acid will be generated in the air gap, which will corrode the cable insulation layer. Long-term high-load operation of the cable or poor cable ventilation will cause the cable to heat up, and the overheating of the cable will accelerate the speed of the cable insulation aging; the moisture in the cable insulation layer will hydrolyse the insulation fibre and cause the cable insulation to drop [6].

5. *Analysis of power cable fault diagnosis technology*
The diagnosis of power cable fault mainly includes three parts: fault diagnosis, distance measurement and location. Fault diagnosis is mainly to determine the type of fault and identify its severity, so as to help inspectors use appropriate ranging and positioning technology for further operations. Determine whether the fault resistance is a closed fault or a flashover fault, whether it is a single-phase fault or a two-phase or three-phase fault, a high-resistance fault or a low-resistance fault, a short-circuit fault or an open-circuit fault. The distance measurement of the cable fault location is mainly based on the distance detection performed by professional equipment at one end of the cable. Currently, traveling wave ranging technology is usually used. Low-resistance and short-circuit faults mainly use low-voltage pulse reflection, which is more intuitive and simpler than traditional bridge detection technology [7]. The cable fault location technology is based on the calculation results of the fault location, combined with the cable laying direction, so as to roughly determine the specific location of the fault, and control the fault point in a small interval, and use the discharge acoustic method and other methods to identify the fault the actual exact location of the point.

6. *Wavelet fault location for power cables*

6.1. *Framework of high-voltage cable fault location method based on wavelet transform*
Figure 3 is a schematic diagram of the framework of a high-voltage cable fault location method based on wavelet transform. As shown in Figure 3, the specific process is as follows:
6.2. Implementation of high-voltage cable fault location method based on wavelet transform

This article uses the time-frequency analysis method in the wavelet analysis method, and first introduces the continuous wavelet transform. The function $f(x)$ is subjected to continuous wavelet transform, the formula (1) is as follows:

$$W_f(a,b)=\left[ f, \psi_{a,b} \right] = \left| a \right|^{1/2} \int_{R} f(t) \psi_{a,b}(t) \frac{t-b}{a} dt$$  \hspace{1cm} (1)

From where $a$ is the wavelet scale, $b$ is the translation parameter; $\psi(t)$ is the wavelet basis (also called the wavelet kernel function). $\psi_{a,b}$ is the frequency, which is inversely proportional to $a$, that is, the lower the wavelet scale, the higher the corresponding frequency. After continuous wavelet transformation is performed on the traveling wave time domain signal, the decomposed time domain signal can be analysed, that is, the decomposed component of $a$ can be obtained according to $b$. Then we can find the extreme points of wavelet transform on $(a, b)$, as shown in formula (2).

$$\frac{\partial W_f(a, b)}{\partial t} \bigg|_{t_0} = 0$$  \hspace{1cm} (2)

Where $(a_0, b_0)$ is the extreme point of function $W_f(a, b)$ at $t_0$, formula (2) can be updated as:

$$\left| W_f(a_0, t_0) \right| \leq \left| W_f(a_0, t_0) \right|$$  \hspace{1cm} (3)

That is, the extreme point of $W_f(a, b)$ at time $t_0$. Then, after the input traveling wave signal undergoes wavelet transformation, the modulus maximum value can be calculated according to formulas (2) and (3), and finally the modulus maximum value of the input traveling wave signal is estimated by least squares according to the modulus maximum value. Find the extreme point and its corresponding time value $t_0$, so as to find the running time of the wavelet traveling wave head.

6.3. Simulation analysis

In order to verify the accuracy and feasibility of the theoretical derivation and design of the energy source, a hardware platform was built for verification. First, verify the operating characteristics of the second part of the energy-taking coil with an air gap [8]. Two pieces of material with a thickness of about 0.5mm are added to the two ends of the open-close current transformer. This article uses FLUKE199C to test the CT secondary side voltage output waveform. The primary current value ranges from 0A to 1200A. Figure 4 (a) is the secondary side output waveform without air gap, (b) is the output waveform of the CT with the air gap, and the energy coil with 200-ohm resistance load at 400A, 800A, 1000A, 1200A current. Figure (a) Distortion has occurred when the primary current is 100A. When the primary current increases to 200A, the distortion is very serious and CT is severely saturated; Figure (b) shows that the CT secondary voltage waveform is slightly distorted when $I1=1000A$ When $I1=1200A$, it has been severely distorted. It can be seen that adding an air gap significantly increases the linear region of CT operation.
Figure 4. CT secondary side output waveform before and after air gap

7. Conclusions
In recent years, the scale of my country's power grid system has become larger and larger, and the power cable line structure has become more and more complex, so more and more problems have arisen. Traditional power cable fault detection technology has been unable to cope with the current huge power system demand, so it is particularly important to quickly locate faults and respond in time based on more advanced fault diagnosis technologies. The partial discharge detection technology for cross-linked polyethylene cables under the damped oscillating wave voltage is mainly based on the damped oscillating wave broadband pulse current method for detection and positioning, using pulse separation technology and multi-mode separation detection methods to quickly and accurately identify cable faults. Through the detection and fault identification of the discharge sample library and intelligent comprehensive analysis and identification software, the efficiency of the power grid is greatly improved, the scope of the fault's impact on users is shortened, the efficiency of current line fault maintenance is improved, and the 200-ohm of the power grid system is further promoted development of.

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