Fault identification of medium and low voltage DC distribution system based on high frequency fault component

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Abstract. The protection technology of medium and low voltage DC distribution system is still in its infancy, and its accuracy is not high in the process of practical application. Therefore, a fault identification method of medium and low voltage DC distribution system based on high-frequency fault component is proposed, and the topology, grounding mode, protection equipment, fault type and fault transient characteristics are closely related to the design of protection scheme. Based on the high-frequency fault component, the fault identification algorithm of medium and low-voltage DC distribution system is optimized, and different fault categories of AC and medium and low-voltage DC distribution system are divided, so as to achieve the research goal of accurate positioning of different fault types. Finally, it is confirmed by experiments. The fault identification method of medium and low voltage DC distribution system based on high frequency fault component has high accuracy and fully meets the research requirements.

1. Introduction
The high-frequency fault component of low-voltage DC distribution system will produce high-frequency fault components from power frequency to high-frequency noise. These high-frequency fault components have various fault related information, including fault location, fault direction, fault type, fault degree, etc. The effective extraction and application of high-frequency fault component information is one of the starting points to improve the performance of existing relay protection. With the application of a large number of medium and low voltage DC equipment and the increasing access and utilization of various distributed energy sources, the application prospect of medium and low voltage DC distribution system is broad[1]. In the ideal networking mode of high-frequency fault component distributed power generation, regional power supply of urban power grid with high-frequency fault component power electronic load, medium and low voltage DC distribution system It is widely used in power supply system of large data center[2]. Medium and low voltage DC distribution system includes medium and low voltage DC distribution system and user side medium and low voltage DC distribution system. Compared with the traditional AC medium and low voltage DC distribution system, it has the advantages of high efficiency, excellent power quality and energy saving due to its low loss, no frequency and reactive power problems, and reducing the number of AC and DC conversion when using DC equipment. Compared with the traditional HVDC based on line commutation converter, the medium and low voltage DC distribution system based on high frequency fault component distributed power generation, regional power supply of urban power grid with high-frequency fault component power electronic load, medium and low voltage DC distribution system It is widely used in power supply system of large data center[2]. Medium and low voltage DC distribution system includes medium and low voltage DC distribution system and user side medium and low voltage DC distribution system. Compared with the traditional AC medium and low voltage DC distribution system, it has the advantages of high efficiency, excellent power quality and energy saving due to its low loss, no frequency and reactive power problems, and reducing the number of AC and DC conversion when using DC equipment. Compared with the traditional HVDC based on line commutation converter, the medium and low voltage DC distribution system based on high frequency fault component is not only suitable for accessing distributed generation and DC load with fast and independent active and reactive power control, but also has the ability of black start, multi terminal network structure expansion and rapid reduction of interference power quality[3]. Therefore, the medium and low voltage DC distribution system mainly uses two-level voltage source converter, and the inverter load is VSC load. Starting from the basic structure of medium and low voltage DC distribution system with high frequency fault...
component, this paper expounds its research status according to the fault location, fault zoning, protection device, fault detection and protection involved in DC protection, and finally prospects the research of low voltage medium and low voltage DC distribution system protection in the future.

2. Fault identification method of medium and low voltage DC distribution system

2.1 Topology of medium and low voltage DC distribution system with high frequency fault component

The faults of medium and low voltage DC distribution system will produce fault components from power frequency to high frequency. Effectively extracting and applying various information related to the topology and faults of medium and low voltage DC distribution system with high frequency fault components is one of the starting points to improve the performance of existing relay protection[4]. On the basis of effectively capturing the high-frequency components of fault components, the transient protection of medium and low-voltage DC distribution system further extracts the frequency domain information of high-frequency components through digital signal processing, and finally constitutes a new protection principle[5]. How to effectively and reliably obtain the transient high-frequency component of voltage is the primary problem faced by transient protection. In order to adapt to the development of distribution system, the topology of medium and low voltage DC distribution system needs to be able to accommodate distributed power generation and effectively provide power for DC load[6]. On the other hand, because the medium and low voltage DC distribution system does not have the same electromagnetic ring network problem as AC distribution system, multi power supply and ring network power supply can be adopted[7]. The common topology of medium and low voltage DC distribution system can be divided into radial topology, ring topology and power supply topology at both ends, as shown in the figure.

Fig.1 Topology of DC distribution system

Because the construction of medium and low voltage DC distribution system lags behind the power transmission network and has not received considerable attention, the medium and low voltage DC distribution system has not been well developed, resulting in the inherent backwardness of technology and equipment[8]. In addition, with the large-scale increase of distributed power sources and controllable loads connected to the medium and low voltage DC distribution system network, the traditional medium and low voltage DC distribution system network began to change from a slowly changing radiation network to a more dynamic multi-source network, and the power flow of the distribution system slowly began to change from the original one-way to two-way[9]. That is, the medium and low voltage DC distribution system began to be gradually transformed into active medium and low voltage DC distribution system. In this case, the active medium and low voltage DC distribution system puts forward new and higher requirements for fault location devices and technology. The traditional relay protection devices such as overcurrent relays have gradually been unable to meet the requirements of active medium and low voltage DC distribution system[10]. The comparison of characteristics between
traditional medium and low voltage DC distribution system and active medium and low voltage DC distribution system is shown in the table 1.

Table 1 Comparison of characteristics between traditional distribution network and active distribution network

| Characteristic          | Traditional distribution network | Active distribution network |
|-------------------------|----------------------------------|-----------------------------|
| Power Supply            | Self passive                     | Self active                 |
| control model           | passive                          | active                      |
| Network layout          | Radial                           | reticular                   |
| Tidal current form      | one-way                          | two-way                     |
| Operation form          | single                           | various                     |
| Fault handling load     | later                            | In advance or in process    |
| load                    | Non adjustable                   | Adjustable                  |

Starting from the overview of topology, converter equipment, grounding mode and fault characteristics of medium and low voltage DC distribution system, this paper analyzes and summarizes the research status of protection principle and scheme, realization idea of control protection integration and engineering application of medium and low voltage DC distribution system at home and abroad\[11\]. The key research directions of protection technology for medium and low voltage DC distribution system are prospected. Because the medium and low voltage DC distribution system does not have the problem of electromagnetic ring network, it has a more flexible networking form than AC distribution system. Its typical topology includes radial topology, "hand-in-hand" double terminal topology and ring topology. Under the premise of reliability requirements, the power supply mode of double terminal or multi terminal topology is usually considered, but the realization of its control and protection is more difficult\[12\]. The topology of double ended DC distribution network has engineering application prospects under the condition of comprehensively considering the system reliability, economy and the realization of protection control\[13\]. The wiring form of medium and low voltage DC distribution system mainly refers to the general wiring form of the system through the converter. Referring to the DC transmission system, it can be divided into single pole wiring and double pole wiring, in which the single pole wiring can be divided into asymmetric single pole wiring and symmetrical single pole wiring. The specific structure is shown in the figure 2.

Fig. 2 Single pole wiring and symmetrical single pole wiring structure

The mode transformation of voltage is used to reflect the frequency of high-frequency fault components of fault phase and non fault phase\[14\]. The analysis of these characteristics can realize fault phase selection. When the line fails, the voltage transient high-frequency signal is captured by the tuning coupling circuit, and then transformed into a digital signal through high-speed A / D conversion, entering the digital signal processing link. Medium and low voltage DC distribution system grounding mainly involves AC side converter transformer grounding and DC side grounding\[15\]. The AC side grounding
mode is mainly divided into non-grounding, direct grounding of valve side winding, resistance grounding of valve side winding and resistance grounding of neutral point of valve side reactor.

2.2 Fault feature recognition algorithm for medium and low voltage DC distribution system

The fault identification and location technology in this paper is mainly aimed at DC line fault. DC line faults can usually be divided into single pole grounding fault, double pole short-circuit fault and double pole grounding fault through crossover resistance [16]. These faults may produce serious short-circuit current, which requires the protection device to detect and isolate the area as soon as possible. Fault identification includes two aspects: rapid detection of faults to ensure quick action. Locate the specific fault line to ensure selectivity. When the fault identification is completed and the fault area is determined, the fault area is removed through DC circuit breaker and other fault protection equipment. Fault identification technology is the most critical part to realize protection selectivity in the whole DC protection scheme [17]. On the contrary, the protection equipment with different performance also has different requirements for fault identification time. Overcurrent protection is the simplest and oldest fault protection method. Three-stage overcurrent protection is widely used in AC system. However, in the case of mesh DC power grid and connected to a large number of distributed generators, overcurrent protection may lack the selectivity of protection. At the same time, the overcurrent of DC system is rapid, and the delay in a certain period of time cannot be accepted, which is difficult to meet the requirements of rapidity. It is difficult to use this method to design the protection scheme of medium and low voltage DC distribution system. It can be combined with other methods to comprehensively design the protection scheme or provide backup protection [18]. The current rate of change protection method can speed up the speed and sensitivity of fault detection, and the selectivity of protection can be improved by using the polarity of current rate of change. By analyzing the second-order RLC fault loop equation in the capacitor discharge stage after DC line fault, it is deduced that:

\[ \Delta i = \frac{v_C(0)}{L} \Delta t \]  

(1)

Where, \( \Delta i \) is the current variation; \( v_C(0) \) is the initial voltage of the capacitor; \( L \) is fault loop inductance; \( \Delta t \) is the sampling interval. Therefore, the protection scheme can be designed by detecting the current change rate, and the selectivity and reliability of the protection scheme can be enhanced by using the current direction information. Different from AC system, the transient signal of DC system contains various frequency components. Since there is no fundamental frequency signal, it is not easy to calculate the loop impedance parameters at the fault through the voltage and current information measured at the measuring point, so as to determine the distance from the fault point to the measuring point [19]. Moreover, the symmetrical component method cannot be used to eliminate the interference of transition resistance, and the fault location technology has great challenges in medium and low voltage DC distribution system. In addition, different from DC transmission network, due to the short length of lines and mostly cable lines, the traditional traveling wave location method is difficult to apply in medium and low voltage DC distribution system [20]. It is necessary to explore new fault location technology. The fault component current expressions of fault lines and sound lines obtained by using high-frequency equivalent model are as follows:

\[ u = L \Delta i \frac{di}{dt} + (R + R_f) i \]  

(2)

Where, \( R \) and \( i \) are respectively the voltage and current measured at the protection installation at a certain time after the fault; \( d, L \) is the equivalent line resistance and line reactance from the protection installation point to the fault point; \( R_f \) is the transition resistance. By taking the measured values at two different times when the DC line is short circuited, two independent equations can be obtained and solved together to obtain the unknowns \( A \) and \( B \). By further using the least square method, the following formula can be obtained:
$$\begin{bmatrix}
L \\
R + R_t
\end{bmatrix} = \left( A^T A \right)^{-1} A^T B - u$$

(3)

Where:

$$A = \begin{bmatrix}
\frac{d i(0)}{d r} & i(0) \\
\vdots & \vdots \\
\frac{d i(N)}{d r} & i(N)
\end{bmatrix}, \quad B = \begin{bmatrix}
u(0) \\
\vdots \\
u(N)
\end{bmatrix}$$

(4)

Where \(r\) is the ordinal number of sampling points after fault. When the bipolar short-circuit fault parameter is \(d\) and the transition resistance \(V(n) > 0\) in case of metal grounding fault, the fault distance is:

$$x = \frac{V(n)}{V(n) - V(r)} dL - U_{dc}$$

(5)

Where, \(V(n)\) and \(V(r)\) are the voltage measured at \(n\) and \(r\) respectively; \(d\) is the distance from \(n\) to \(r\). The measured voltage and current are used to calculate the transition resistance and fault distance. At the beginning of the fault, the DC voltage \(U_{dc}\) is greater than the AC side line voltage. At this time, the DC line fault current will mainly discharge the DC capacitor to the short-circuit point. The dynamic process at this stage can be expressed as a differential equation. Since the equivalent resistance of DC line is very small and its damping generally meets \(RC < 2\), the characteristic root in the formula is a pair of conjugate complex numbers, as shown in the formula

$$LC \frac{d^2 u_{dc}}{dt^2} + RC \frac{du_{dc}}{dt} + u_{dc} = 0$$

$$\lambda_{1,2} = \frac{-R}{2L} \pm \sqrt{\left( \frac{R}{2L} \right)^2 - \frac{1}{LC}} = -\sigma \pm j \omega$$

(6)

Where:

$$\sigma = R / (2L)$$
$$\omega = \sqrt{\frac{1}{LC} - \left[ \frac{R}{2L} \right]^2}$$

(7)

Assuming that the values of DC voltage and DC line current at the moment of fault are \(L\) and \(R\), the solutions of DC voltage \(u_{dc}\) and DC line current \(i\) can be obtained according to initial condition a

$$u_{dc} = A e^{-\sigma} \sin(\omega t + \sigma)$$

$$i_t = A \sqrt{\frac{C}{L}} \lambda_{1,2}^{-\sigma} \sin(\omega t + \sigma - 1)$$

(8)

Where:
\[
A = \sqrt{U_0^2 + \left( \frac{U_0 \sigma}{\omega} - \frac{I_0}{\omega C} \right)^2}
\]

\[
\theta = \arctan \left( \frac{U_0}{\frac{U_0 \sigma}{\omega} - \frac{I_0}{\omega C}} \right)
\]

\[
\beta = \arctan \left( \frac{\omega'}{\sigma} \right)
\]

From the formula, the DC capacitor discharge is a second-order underdamped oscillation process, and the capacitor voltage will attenuate and oscillate across zero. At the same time, since the short-circuit current supplied by the AC side in this stage is only the continuous current of the AC reactor, there is no overcurrent at the AC side and inside the converter. On the DC line, overcurrent occurs due to the discharge of large capacitance. Because the unit resistance \( U_0 \) and unit reactance \( I_0 \) of the line in the cable line are very small, the measured fault distance error may be large, while the error of transition resistance \( V(n) \) is small. Using the one-time iterative method, the calculated RF is used to modify the positioning equation, and the fault distance is obtained as follows:

\[
\hat{x} = \frac{V(n) - R_i i(n)}{u_{dc} - \beta \theta} - d
\]

The positioning error \( R_f \) is further reduced so that most of the errors are within 2%. This method does not need to know the parameter information of DC line and has high reliability, but it also needs to measure the voltage at two different positions, which may increase the cost. Further extract the initial amplitude \( C \) and attenuation time constant of voltage attenuation \( \alpha \) and oscillation frequency \( \omega \). When the transition resistance is zero (metal short circuit), the fault distance \( x \) is:

\[
y = \frac{1}{s_1 s_2 L_p C - (R_2 - L_2)(R_1 - L_1)}
\]

\[
\begin{cases}
  s_1 = y \alpha_1 + j \omega_1 \\
  s_2 = y \alpha_2 + j \omega_2
\end{cases}
\]

Where \( L_n \) is the inductance per unit length of the line, that is, the method needs to know the line parameter information, and \( j \) is the parallel capacitance on the DC side. If \( \alpha \) indicates the distance from the protection installation to the fault point, \( R_1, L_1 \) equivalent resistance and reactance of this section of line, \( \omega_1 \) and \( \omega_2 \) are the longest and shortest values of the line respectively, \( R_2, L_2 \) are the equivalent resistance and reactance of the line at the other end. After the DC circuit breakers \( S_1 \) and \( S_2 \) cut off the fault line, the SP in the PPU acts to input the capacitor \( C_P \) with initial voltage, so that the fault circuit forms the RLC second-order oscillation circuit, and the inductance \( L_p \) is used to ensure that the oscillation circuit meets the under damping condition. The second-order oscillation differential equation is:

\[
\frac{d^2 i_p(t)}{dt^2} + \frac{1}{L_p} \frac{di_p(t)}{dt} + \frac{i_p(t)}{C_p} = 0
\]

Where, \( i_p \) is the current of the oscillation circuit; \( d, S_p, t \) are the total equivalent resistance, reactance and capacitance of the oscillation circuit. Increasing the resistance \( R' \) of the DC fault circuit has more prominent advantages for limiting the fault current and isolating the fault: as a lossy element, increasing the resistance of the fault circuit can increase the energy consumption speed in the fault
circuit and reduce the fault overcurrent level of the DC line. Increasing \( a \) can change the damping of the fault circuit. If the increased fault circuit resistance is represented by \( u \) and meets \( RLC' > 2 \), that is, the fault circuit changes from underdamping to overdamping. At this time, the characteristic roots shown in the formula will be two unequal real roots, and the corresponding solutions of \( u_{dc} \) and \( i_l \) are

\[
\begin{align*}
    u_{dc} &= A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t} \\
    i_l &= -2C \left( A_1 \lambda_1 e^{\lambda_1 t} + A_2 \lambda_2 e^{\lambda_2 t} \right)
\end{align*}
\]

(14)

By extracting the information of oscillation current, it can be obtained that the fault distance is:

\[
x = \frac{1 - 4\pi^2 f^2 L_p C_p}{4\pi^2 f^2 L_u C_p}
\]

(15)

Where, \( f \) is the frequency of current attenuation oscillation. Assuming that the RLC attenuated oscillation frequency is equal to the natural oscillation frequency, it is extracted by fast Fourier transform algorithm. Assuming that there is a certain error, it is proposed to calculate the attenuation coefficient through the peak points of a series of oscillation attenuation signals \( \alpha \). The fault distance with higher accuracy is obtained by calculating the attenuation oscillation frequency:

\[
x = \frac{1 - \left( \alpha_d^2 + \alpha^2 \right) L_p C_p}{\left( \alpha_d^2 + \alpha^2 \right) L_u C_p}
\]

(16)

Where, \( \omega_d \) is the natural oscillation angular frequency. The fault distance is obtained by calculating the total reactance of the fault circuit and comparing it with the line parameters.

2.3 Realization of fault identification in medium and low voltage DC distribution system

Once the medium and low voltage DC distribution system fails, it will directly affect the national economy and people's daily life. The fault diagnosis of medium and low voltage DC distribution system takes a certain voltage level power grid or a regional power grid as the research object. The current diagnosis research of medium and low voltage DC distribution system often tends to analyze and judge after the accident. It uses some diagnosis mechanism to determine the fault cause and fault section based on the comprehensive fault information and knowledge base. For the fault diagnosis of distribution lines, the current methods mainly focus on single-phase grounding and phase-to-phase short circuit. For high resistance faults and intermittent faults, it is relatively difficult to extract fault features because of their small fault current, low voltage and unclear three-phase imbalance characteristics. Fault signals in power system are often non-stationary and nonlinear signals. For this kind of signals, time-frequency analysis is usually an effective method. Fault identification methods based on event information include longitudinal directional protection in traditional protection methods. It only needs to transmit fault event information rather than fault data, which can greatly reduce the requirements for communication system capacity, communication speed and data synchronization. Artificial inductors are connected in series on the line, the detected current change rate is used to judge the fault type and generate corresponding event information, and the fault event is transmitted by communication to determine the fault area and selectively remove the fault. Among them, communication events include bus fault, interconnection line fault, adjacent feeder fault or adjacent bus fault, as shown in the figure 3.
The high frequency fault classification is proposed to identify and detect the current amplitude and voltage amplitude detection faults, judge the fault line by transmitting the current direction information, and combined with the protection method of solid-state DC circuit breaker. It is proposed that both ends of the line transmit information based on goose standard, including whether fault occurs and fault current direction. The current direction at both ends of the line is used to judge whether the line has fault. The following table summarizes and compares various fault detection methods in DC and AC distribution systems, and records them, as shown in the following table 2:

| test method                  | DC distribution system                                                                 | AC distribution system                                      |
|------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------|
| Current differential protection | Just compare the magnitude and direction of fault current                                | The phase angle and other information of three-phase AC current need to be compared, which is not widely used |
| Overcurrent protection       | Simple, fast and general protection                                                     | Simple, reliable, universal and limited                      |
| Overcurrent protection       | There is no fundamental frequency component, excessive resistance cannot be eliminated, and the error is large | Estimate the fault distance and eliminate the interference of excessive resistance |
| distance protection          |                                                                                        |                                                             |
| Current direction pilot protection | It is required to quickly detect the direction, which is easier                        | The direction of detecting current is through voltage and current, which is cumbersome |
| Boundary based protection    | A special method designed to meet the stringent requirements of protection              | In AC distribution, it may not be necessary                |

When realizing rapid fault recovery in medium and low voltage DC distribution system, it is necessary to consider the control role of DC transformer, converter and other power electronic equipment in the process of fault, and form the protection of power electronic equipment with weak ability to withstand impulse current. Therefore, considering the synergistic effect of the integration of control and protection of distribution system, the system has a certain fault ride through and fault clearing ability. Based on the different topologies and converter valve types of medium and low voltage DC distribution system, considering the controllable power electronic equipment and protection strategy in the system, the system fault current and voltage control can be realized, which can improve the fault ride through and fault clearing ability in the process of system fault. At present, the research on the
integration of control and protection is mainly based on the control strategy of converter valve. For two-level VSC or half bridge sub module, it does not have the ability to deal with inter pole DC fault. It is considered to realize the fault clearing function by cooperating with DC circuit breaker; For high-frequency fault component topologies with DC fault clearing capability, such as full bridge sub module, clamp twin module and hybrid bridge high-frequency fault component, the sub module structure is optimized and effectively controlled to realize fault clearing and fault ride through functions. The results of fault identification also provide basis for fault control process. It can be seen that the mutual cooperation of protection and control of DC system can effectively strengthen the reliable operation of medium and low voltage DC distribution system, especially improve the fault identification and fault recovery ability under system fault state. The figure below shows the relationship between the integration of control and protection.

Fig. 4 Relationship between control and protection integration of DC distribution system

The high-frequency fault component converter composed of medium voltage side parallel two-level converter and side parallel high-frequency fault components realizes the fault tolerance of the system, effectively suppresses the overcurrent and overvoltage in case of system fault, and reduces the interruption of power transmission of the system. The basic principle and working procedure of on-line diagnosis technology are shown in the figure. It includes the establishment of state information base and fault archive, as well as four working procedures: signal detection, feature extraction, state recognition and prediction decision-making. See the following figure 5 for details:

Fig. 5 Optimization of on-line fault diagnosis and identification steps of equipment

In the research of fault line location, the zero sequence voltage and zero sequence current signals are used as input signals to calculate the zero sequence instantaneous power. In a typical zero sequence component of distribution line, the characteristics of power direction are as follows: capacitive branch releases reactive power; Inductive branch absorbs reactive power; Resistive branches absorb active power. In this paper, the zero sequence instantaneous power theory is applied to the fault line location
of distribution line. The zero sequence instantaneous power is calculated by using the zero sequence voltage and zero sequence current at each monitoring point of distribution line. The line at the monitoring point opposite to the zero sequence instantaneous power direction of normal line is the line through which the fault flows, and then the actual fault line is judged according to the topology of distribution system.

3. Analysis of experimental results
In order to verify the practical application effect of fault identification of medium and low voltage DC distribution system based on high-frequency fault component, an experimental detection is carried out. A four terminal flexible medium and low voltage DC distribution system is built in Matlab / Simulink environment. In order to ensure that the experiment is really effective. Unified specification of relevant system parameters, as shown in the table 3 below.

| Parameter          | Numerical Value | Parameter          | Numerical Value |
|--------------------|-----------------|--------------------|-----------------|
| Rated capacity/MVA | 10              | AC reactor/H       | 0.02            |
| Current voltage/kV | 10              | Lo/(mH/km)         | 0.156           |
| DC line/(Ω/km)    | 0.0216          | DC capacitance/F   | 0.03            |
| DC load/M2        | 2               |                    |                 |

Based on the information in the above table, after the occurrence of medium and low voltage DC fault and low resistance fault in the distribution line, the fault identification effect of the traditional distributed distribution system is compared and analyzed, and the zero sequence voltage waveform identification data measured at the monitoring points are obtained. It is assumed that the basic frequency of the medium and low voltage DC distribution system is 50z. The voltage and current signals are sampled simultaneously at a fixed sampling frequency to obtain the voltage sampling sequence and current sampling sequence. The sampling frequency is 2000Hz, that is, 40 times in a cycle. According to the fault frequency range analyzed earlier, the set sampling frequency fully meets the requirements of subsequent analysis, as shown in the figure 6.

![Fig. 6 Zero sequence current fault identification effect of DC distribution system](image-url)
It can be seen from the figure that during normal operation of the line, due to the influence of some factors such as unbalanced line parameters, the zero sequence voltage under the guidance of this method is very small, but relatively stable, and there is no non fundamental frequency transient signal; The amplitude of signal recognition under the guidance of traditional methods is higher than that under normal operation. This situation is the same for the neutral ungrounded system and the neutral grounded system through arc suppression coil, so the characteristic of zero sequence voltage is often used as the condition to judge the fault in the research, because the zero sequence voltage signal is obvious and stable; The zero sequence current signal is too small and the environmental interference is large, and the useful signal is often submerged in the noise; The uncertainty of the influence of random factors is easy to cause the instability of zero sequence fault current. According to the comparison diagram, the zero sequence voltage waveform has more high-frequency transient components, which is more conducive to fault detection. Therefore, a scheme of using zero sequence voltage to detect distribution line fault is proposed, which has high sensitivity and is less affected by the operating conditions of distribution line. According to the research on the transient process of three port resonant converter and VSC rectifier in case of inter pole fault, the working mode and parameters of the converter will affect the fault characteristics of the transient process of the converter. Using the control variable method, the effects of three port resonant converter working mode, DC side parallel capacitor, fault resistance and fault distance on the transient characteristics of inter pole fault are studied. When the three port LLC resonant converter is in different working modes, the short-circuit fault peak occurs in the capacitor discharge stage. The initial values of current $I$ and voltage $u$ before the fault will affect the fault response process and the current borne by each distribution system in the subsequent stages. The peak value and generation time of fault current and the peak value of current entering the distribution system are closely related to the formulation of protection scheme. Therefore, under the condition that the fault location, fault resistance and system parameters are the same, explore and record the impact of different working modes on the fault peak and the current borne by the distribution system. The detection results are shown in the figure below.

![Fig. 7 Influence of different working modes on fault current](image)

As shown in the figure, in the initial working mode, the distribution system first enters the freewheeling stage, and the distribution system will also bear relatively large current. In contrast, the fault current generated by operating mode B is the smallest, because VSC mainly provides power to the load before the fault occurs, the initial value is small, and the fault current borne by the distribution system is relatively minimum when it enters the freewheeling stage of the distribution system at the latest. The fault condition of working mode 3 (photovoltaic port and energy storage port work at the same time) is between the other two modes. In this case, 7 lines are selected to compare and analyze the fault location accuracy of the two systems, and the results are shown in the table.
| line | traditional method Recognition accuracy | Time (s) | Paper method Recognition accuracy | Time (s) |
|------|----------------------------------------|----------|----------------------------------|----------|
| 1    | 69.85                                  | 30       | 92.46                            | 15       |
| 2    | 64.46                                  | 35       | 94.75                            | 20       |
| 3    | 68.48                                  | 40       | 93.65                            | 25       |
| 4    | 68.75                                  | 45       | 95.80                            | 30       |
| 5    | 69.60                                  | 50       | 94.80                            | 35       |

It can be seen from the table that the fault identification method of medium and low voltage DC distribution system with high-frequency fault components proposed in this paper has higher fault location accuracy than the traditional system, and the fault identification process takes significantly less time, which can more quickly achieve the research goal of accurate fault identification in complex power grid environment.

4. Conclusions
Medium and low voltage DC distribution system provides a new solution for renewable energy, DC load access and urban high-density distribution, which is a research hotspot in recent years. Fault protection technology is an urgent problem to be solved in the development of medium and low voltage DC distribution system. This paper comprehensively classifies and summarizes the two key technical problems in protection: fault identification and fault location, and analyzes the principles, advantages and disadvantages of each method. The fault identification and fault location technology of medium and low voltage DC distribution system mainly stays at the theoretical research level, Lack of practical engineering verification, most schemes are difficult to be effectively popularized, and further extensive research is still needed.

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