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Research Review on Fault Detection and Protection Strategy for Flexible DC Distribution Network

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Abstract

In recent years, with the connection of distributed power sources, the structure and the operation mode of the network have been more diverse and complicated. As a result, the difficulty in identifying faults in the distribution network and the amount of power grid construction have also increased. At the same time, DC power distribution technology has broken through rapidly and has gradually become a key technology in the distribution network because of the continuous development of high-power power electronics technology. This paper has referred to the research, including the protection of flexible DC distribution network and fault identification, both at home and board, main contents of this article are as follows: firstly, this paper introduces the development status of Flexible DC distribution network both at home and abroad. Then, it analyzes the fault characteristics of AC side fault and DC side fault on flexible DC distribution network, as well as the impact of different system grounding methods on fault characteristics. After that, the principle of flexible DC distribution network protection strategy, the fault identification and fault location are summarized, and the advantages and disadvantages of each principle are simply analyzed. Finally, the challenges and difficulties faced in the development on flexible DC distribution network are presented in this paper.

Keywords

Flexible DC distribution network; Fault detection; Fault characteristics; Protection strategy.

1. Introduction

With the continuous development of science and technology, more and more distributed energy and DC loads are connected in the distribution network. At the same time, the modern electricity market also places higher requirements on the reliability of power supply and the economics of transmission and distribution. And the traditional AC power distribution networks have been unable to meet these

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requirements, so that flexible DC power distribution networks have once again received great attention from researchers due to their strong advantages.

Compared with the traditional AC power distribution network, the flexible DC power distribution network has a simple structure, good system stability, large transmission capacity, high power quality, high power supply reliability, and can save line investment. At the same time, it can also effectively coordinate the conflict between the large power grid and distributed power sources, and give full play to the value and benefits of distributed energy. It is very flexible for the control of active and reactive power and does not appear electromagnetic ring network phenomenon. The flexible DC power distribution network meets the needs of the intelligent power distribution network and the Energy Internet, and has the advantages of better controllability and flexibility. Therefore, the flexible DC power distribution network has the conditions to replace the traditional AC power distribution network as an important supporting link for future urban power distribution systems[1-2].

At present, domestic and foreign researches have been carried out on related aspects of flexible DC power distribution networks. As far as domestic flexible DC distribution network technology research is concerned, more research has been carried out in the high-voltage field, and related technologies are relatively more mature; in contrast, there are fewer studies on medium-voltage DC distribution networks. In July 2015, CIGRE established the SC6.31 working group to study and promote DC distribution network technology[3].

Based on the related research on flexible DC distribution networks by domestic and foreign scholars, this paper summarizes the research on fault identification and protection strategies of flexible DC distribution networks, summarizes their related research methods, and finally lists the flexible DC distribution systems so far Challenges and Difficulties Facing the Development of the Internet.

2. Fault characteristics of flexible distribution network

Analysis of fault characteristics is an important aspect of flexible DC distribution network research. Existing literature research divides DC distribution network faults into: AC side fault, AC unit fault, DC side fault and load fault[27]。

2.1 AC side failure

The faults on the AC side of the inverter are mainly divided into two types: transformer network faults and transformer valve faults. However, because the fault type of the valve-side fault of the connection transformer is closer to a permanent fault, this type of fault is more serious than the network-side fault. In DC power distribution networks, converter transformers and bridge arm reactors are mostly connected by cables, and they are generally arranged indoors or in a sampling box structure. The probability of failure is extremely low. Therefore, in general, the valve-side fault can be ignored, and only the network-side fault can be considered. Literature [1] analysis shows that under asymmetric faults, AC power and DC-side voltage and current will have double-frequency fluctuations, and the power transmission of the converter will be limited as a result. After the fault is cleared, the link type of the link transformer directly affects whether the capacitor voltage can be recovered. When a unipolar fault occurs on the DC side, a high ground resistance value can help fault ride through and system recovery. The main protection of this kind of fault adopts DC voltage unbalance protection to make the protection act on the alarm and the system can run with fault; and the fault Fault isolation can be achieved through the strategy of fault line selection and location[4]. However, during fault detection, the system also misjudges AC-side faults as DC-side faults due to misjudgments. Literature [5] pointed out that: when an AC short-circuit fault occurs on the AC side line of the converter, the fault current and fault voltage may pass through the MMC and enter the DC system, causing this type of fault to be misjudged as a DC fault. When a single-phase ground fault occurs on the AC bus of the converter station, the phase voltage at the fault point will drop to zero, and the phase voltage at the non-fault point will rise to $\sqrt{3}$ times the rated voltage.

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2.2 DC side fault

When a unipolar fault occurs on the DC side, the upper and lower bridge arm capacitors will be imbalanced due to the discharge of the inverter fault side capacitors to ground. The literature [4] analysis pointed out that: the DC positive pole fault will cause the DC zero point to shift, causing the DC voltage of the fault pole to drop to zero, and the voltage of the non-fault pole will rise to the inter-electrode voltage. Literature [5] analysis shows that the back-to-back system adopting the single-maximum loop operation mode when the DC side ground fault occurs, the fault current will flow in the AC and DC circuits, which makes the fault harm the DC side at the same time. Has a greater impact on the AC side. Literature [7] comprehensively analyzed the fault current characteristics of DC short-circuit faults in AC-DC hybrid distribution networks with different topologies. It is pointed out that when a branch short-circuit fault occurs in an AC-DC hybrid distribution network, the system can be regarded as an equivalent A simple system of DC capacitors, AC power supplies, and equivalent impedance. The fault process can be divided into a DC capacitor discharge phase and an AC-side current feeding phase. Reference [8] based on the VSC DC-side positive ground fault, studied and analyzed the transient process after the fault, and the results showed that the ground resistance at the fault point would have a huge impact on the inter-electrode voltage and the terminal voltage between the positive and negative terminals after the fault. It will seriously affect the safety of the equipment and the stable operation of the system. The analysis in [9] shows that the impedance value of the DC system is lower than the impedance value of the AC system, so when a short circuit fault occurs on the DC side, the MMC fault may rapidly spread. In flexible DC power distribution networks, in order to stabilize the DC side voltage, a large number of power electronic converters are often connected in parallel on the grid side. These converters have large-capacity capacitors. When a fault occurs, the fault current will rise rapidly due to the rapid discharge of the capacitor, which places higher requirements on the fastness of DC protection equipment and protection methods[11].

2.3 Pole-to-pole fault

The literature [14] divides the fault period of DC pole short circuit into: DC fault "detection phase" and DC fault "isolation phase". After the fault occurs, the DC bus capacitor will discharge to the fault point. In the "detection phase", the fault current is mainly composed of the capacitor discharge current; in the "isolation phase", the capacitor voltage will increase and the fault current will gradually decrease to zero. Literature [10] shows that: in the case of a DC system short-circuit fault, the fault current is mainly composed of the module capacitor current and the three-phase short-circuit current of the AC power supply, and the capacitor discharge current may reach the order of thousands of amperes after the fault occurs for 1ms Excessive current will seriously affect the switching devices of the converter valve, and even seriously endanger the safe operation of the system. In a back-to-back system, since one pole is grounded, when a single-pole ground fault occurs in the system, it is equivalent to an inter-pole short-circuit fault[6]. Literature [9] pointed out that due to the extremely low fault circuit impedance, the peak value of the fault current of an inter-pole short-circuit fault can usually reach tens of times the rated value. Excessive current will generate a lot of heat, which will cause irreversible damage to the semiconductor device.

3. Fault location and ranging

In the flexible DC power distribution network, the converter protection action is fast, the effective fault information is small, and the required fault information is very easy to be affected by distributed capacitance, noise and transition resistance. As far as related research is concerned: traveling wave method, fault analysis method and active injection method are the main existing positioning methods in flexible DC systems. It should be pointed out that different fault types have different effects on fault detection. When a metal ground fault occurs, if it is simply judged that the AC current and voltage changes on the AC valve side after the fault occurs, the protection of the non-fault end will malfunction, and the fault end cannot be identified [12]. In [13], after analyzing the advantages and disadvantages of the three main fault location methods of traveling wave method, fault analysis

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method and active injection method, an offline fault location method based on ± 10 kV DC distribution network with double-ended power supply was proposed. This method uses an injection LC device to fit the collected current data to obtain an ideal waveform to obtain the ideal waveform's oscillation frequency and attenuation coefficient. Finally, the relationship between the oscillation frequency, attenuation coefficient, and fault distance is used to accurately locate the fault location. This method does not need to rely on communication or synchronization equipment to achieve accurate fault location, and has certain ability to withstand transient resistance, distributed capacitance, noise, and line parameter errors. Reference [5] designed a fault location module to improve the single-pole ground fault location module by constructing a second-order underdamped discharge circuit that discharges the fault point by a capacitor to perform fault location. This method avoids the influence of uneven distribution of line inductance and different transition resistances at fault points on ranging accuracy by means of double-end asynchronous discharge. The literature [15] analyzed the relationship between the electrical quantities in the capacitor discharge stage in detail. Based on the DC reactance voltage at both ends of the line, a differential equation in the time domain was constructed, and the fault distance and the excessive resistance value were obtained by numerical methods. This method has the advantages of less electrical quantity and less influence by the transition resistance. [14] proposed a protection scheme based on the current waveform curvature algorithm. This method uses the current waveform curvature algorithm to judge and distinguish between high-resistance internal faults and external faults. This protection method does not rely on communication equipment when identifying faults; at the same time, it meets the protection's fastness, reliability, and resistance to noise interference.

4. Protection Strategy of Flexible DC Distribution Network

Research on the protection strategy of flexible DC distribution network is one of the key issues of flexible DC distribution network. Good and targeted protection strategy is of great significance to the safe and reliable operation of flexible DC distribution network. According to the different topological structures of flexible distribution network and the location of key equipment, the protection of flexible DC distribution network can be divided into different protection areas: AC protection area, converter protection area, DC bus and line protection area, DC / DC protection zone, feeder protection zone, load and distributed power protection zone six parts[10,27].

4.1 Protection strategy of dc side

Literature [17] proposed a method for pilot protection of flexible DC distribution network based on wavelet transform. This method uses wavelet transform and phase-mode transform to analyze and process the fault current, and has the advantages of rapid response and high reliability. Literature [2] proposed a DC fault isolation and recovery strategy based on full fault current for engineering applications based on multi-terminal flexible DC distribution network. This strategy uses the transient direction current differential protection to identify Fault location; use the steady-state current differential protection based on small resistance switching to judge the fault location when the transient component is not obvious; in the case of inter-pole faults, use the DC circuit breaker reclosure scheme of fault location information to implement the system after a fault Fast recovery. This strategy can achieve second-level isolation of inter-pole faults, second-level recovery, and no overvoltage or overcurrent occurs during the period. [18] proposed a fault start criterion for DC-side faults to distinguish between AC-side and DC-side faults. The branch line adopts a single-ended quantity protection method based on the S-transform phase angle to achieve rapid fault detection, and the detection process can be completed within 2ms; the main feeder uses the integrated method of longitudinal protection and positioning based on the S-transform phase angle to achieve Quickly locate the faulty section, so that the non-faulty section can operate normally. Reference [29] used a flexible DC distribution network dynamic simulation platform to perform control tests on the DC line side based on single and bipolar faults on the DC line side. The results show that under both faults,

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the protection devices can operate accurately and meet the rapid protection requirements and effectiveness requirements.

4.2 Protection strategy on the AC side

Literature [18] shows that in general, when an AC fault occurs, the traditional protection method is to use an independent fault management device to detect the fault and cut off the power electronic equipment from the power distribution network. Literature [20] pointed out that SOP (Soft Open Point) may improve the fault identification, fault location, fault isolation, and power recovery because of its ability to respond quickly and flexibly. Based on this analysis, the literature [22] shows that the complexity of the fault response will also increase with the use of the SOP. Therefore, a positive sequence component and a negative sequence component of the grid node voltage in the SOP are proposed for FI (Fault-Index) method for correcting AC fault detection. FI quantifies the imbalance in the network through the nominal voltage, and the consistency of the voltage sequence in the network makes it reliable and effective in fault detection. This has a very important impact on understanding existing protection settings and introducing SOPs into the network of feeder automation equipment. Reference [4] analyzed the asymmetric fault characteristics on the AC side, and proposed a protection strategy using the loop current differential protection as the main protection. The action of this strategy is delayed in the setting of the action time of AC undervoltage protection, DC system ground overcurrent protection and DC line protection. Such a protection configuration method has good adaptability in a flexible DC power distribution network, and can solve the problem of non-faulting protection maloperation when a single-end AC asymmetric fault occurs.

5. Difficulties in fault detection and protection

As far as the current research status of flexible DC power distribution network and its application in practical engineering are concerned, because there are many devices connected in flexible DC power distribution network, different grounding methods and different access points will also affect fault detection and failure. Positioning has some impact. For example, when an AC short-circuit fault occurs on the AC side line of the inverter, the fault current and fault voltage may pass through the MMC and enter the DC system, causing this type of fault to be misjudged as a DC fault. In terms of fault protection, existing researches have adopted some auxiliary measures to help isolate faults, such as configuring corresponding current limiting devices or adopting different converter topologies. In terms of fault detection: the short distribution of urban power distribution network leads to insignificant differences in fault characteristics between different faults; the impact of distributed power, different topologies and grounding methods on the accuracy of fault location; flexible DC power distribution network The medium fault information is more complicated, and the effective information is less, which is still the difficulty in the fault detection of flexible DC power distribution network. In terms of urban power distribution, the length of the lines used in urban power distribution is generally only a few kilometers, and the shorter line length reduces the difference between different fault feature quantities, which makes the difficulty of fault identification and accurate location greatly increased. . In flexible DC power distribution networks, the access of distributed power sources (mostly multi-terminal power systems) causes fault currents to flow into branches, which affects the accuracy of fault location. At the same time, due to the small overload capacity of the power electronic components used in the distribution network, the current-limiting link or the installation of a current-limiting device for the converter also makes the protection of the DC distribution network more complicated [24-26].

In terms of fault protection strategies, although there are many protection schemes for flexible DC systems, not all of them are applicable to flexible DC distribution networks. Flexible DC power distribution network puts forward higher requirements on speed and selectivity for its protection strategy. The single-ended electrical quantity protection scheme is limited in the measurement stage, resulting in incomplete information collection and unable to protect the full length of the line. Therefore, this method cannot be adopted as the main protection of the flexible DC distribution network. The double-ended electrical protection scheme is a common protection method for current differential protection and pilot protection, but the current differential protection is easily affected by the capacitor and affects the reliability of the protection. It is not suitable for flexible DC power distribution networks. Compared with the first two schemes, the pilot protection method is more suitable for flexible DC distribution networks, but it has many limitations and will also affect the reliability of the protection. Therefore, researching a new or improved protection scheme based on existing protection schemes is the biggest difficulty in the current protection of flexible distribution networks [27].

6. Conclusion

With the development of high-power power electronic devices, flexible DC power distribution networks have become a new trend in the development of power distribution networks in the future with their economic, reliability, stability, and flexibility advantages. However, the current flexible DC distribution network technology is still in the early stages of research, and there is still much research space for fault detection and protection of flexible DC distribution networks. Based on the research results of related papers, this paper reviews the different fault characteristics, fault location and ranging, and protection strategies of existing flexible DC distribution networks at home and abroad, and points out their respective advantages and disadvantages.

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