Research and application of active comprehensive protection in LVDC system

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ABSTRACT

During the operation of the LVDC distribution system in the building of Nanjing Golden Cooperate DC Power Distribution Technology. Co.,Ltd., we find that some faults may occur in the system, for example DC ground fault, DC short circuit fault, AC intrusion DC, DC insulation reduction and other faults. In order to solve the above problems, it's urgent to study DC fault protection to deal with the above typical faults, The causes of faults and their evolutionary process are analyzed in this paper, and a power electronic protection strategy based on power electronics technology, digital control technology and relay protection principle is proposed, which effectively integrates the DC protection with the power electronic transformer, and can realize the active isolation and intervention of the above faults. The strategy with the effective coordination between the protection action logic and control logic can realize the protection and failure active isolation based on the topology structure and the operation mechanism of the power electronic transformer. The principle, method and functional composition of the ACP(ACP, short for active comprehensive protection) are analyzed, the protection mechanism and criterion of ACP, as well as the research status of DC distribution protection are expounded in this paper . The results of the actual application in the LVDC system show that ACP can realize the rapid and accurate isolation of the faults in DC distribution system, the control and protection strategy is reliable in operation and quick in action, which ensures the steady and reliable operation of the system.

KEY WORDS

active comprehensive protection, LVDC of building, DC faults, evolutionary process, active isolation

INTRODUCTION

With the continuous development of new technology, such as renewable energy generation technology, energy storage system and electric vehicle technology and DC technology of civil and industrial electric loads, the LVDC technology is attracting wide attention in the industry. At present, the technical problems of effective integration of distributed generation, voltage conversion and control, optimal system configuration and reliability of power supply in LVDC system have been basically solved, but the DC protection technology in the LVDC system is still in the stage of theoretical research and experimental exploration at home and abroad[1-4].

The factors restricting the development of DC protection technology in LVDC system are as follows: DC current has no zero-crossing point and arc extinguishing is difficult, it needs more arc extinguishing space and complicated control[5-7]; DC distribution system is different from AC distribution network in terms of fault type, fault developing process, and fault consequences[7,8]; the LVDC system includes diversified distributed power supply, load and energy storage, as well as various operation states, and has many power electronic devices, which bring challenges to the development of DC protection[7,9]. So the research and application of DC protection must consider the relationship between different operation states, source-load sensitive characteristics and fault types.

In order to solve the problem of DC protection in LVDC system, we built a LVDC system of building, and the common DC fault types and causes, fault characteristics and transformation relations of LVDC system were studied. Furthermore, the ACP principle and control method is proposed, and the experimental environment is built and the experimental verification of DC active protection is carried out, finally, some ACP devices are deployed in the LVDC system of building for operation practice.

FAULT CAUSES AND EVOLUTION PROCESS ANALYSIS OF LVDC SYSTEM

Common DC faults types and causes analysis

Types of DC faults

As the LVDC network is close to the user terminal, the faults are complex and diverse. Through investigation and analysis of actual operation, the common DC faults in LVDC network include DC grounding and insulation reduction fault, DC short-circuit fault, AC intrusion DC fault, DC under-voltage fault and DC over-voltage fault.

Causes analysis of DC faults[10-11]

(1) DC grounding and insulation reduction faults

a. Due to the large number of DC distribution branches and the long cable of each branch, it is easy to cause

wiring errors.
b. branches terminals or cables grounding due to bad weather.
(2) DC short circuit fault
Both positive and negative poles are grounded or directly connected by metal, which will cause DC short circuit fault.
(3) AC intrusion DC fault
a. Due to the staff operation mistake, AC line is connected to DC circuit.
b. The field AC and DC cables are mostly in the same bridge frame, if the insulation of the cables is damaged, the AC and DC cables will be connected.
c. There is a large amount of conductive dust and rainwater in the outdoor power supply operation box, which result in the electrical connection between AC and DC terminal.
(4) DC under-voltage fault
Under-voltage of power supply, overload or short circuit of load will cause DC voltage drop, and direct start of heavy load will also cause DC voltage drop, which will eventually lead to DC under-voltage fault.
(5) DC over-voltage fault
Power supply over-voltage or regenerative over-voltage.

Analysis of evolution process between DC faults

Generally, there is , only the abnormal change of ground voltage without fault current in the insulation reduction fault. If the fault can not be controlled, then it will evolve into a ground fault.
When AC intrusion DC, there is no fault current, but it will cause DC single-point grounding fault.
In the DC distribution system with suspended positive and negative poles, there is no fault current in single pole grounding, only abnormal voltage to the ground. when the other pole is grounded, it will evolve into short-circuit fault, or when the positive and negative poles are directly connected, there will also be DC short-circuit fault.
When DC under-voltage occurs, the input current will increase dramatically, and the insulation of equipment or cable will be reduced by long time over-current operation, which will lead to insulation reduction.
When DC over-voltage occurs, it will result in the insulation reduction of the equipment or the breakdown and burnout of the device, resulting in DC short circuit or other faults.

RESEARCH ON ACTIVE COMPREHENSIVE PROTECTION

Principle research of ACP

Summary of DC protection in the LVDC system
In terms of most types of DC faults in LVDC systems, there are no mature protection technologies or equipment. At present, insulation monitoring devices are used for fault monitoring and fault alarm. In recent years, the protection function of power electronic converter has attracted the attention and research of scholars. The application of this protection technology in power electronic devices can achieve some relay protection functions to a certain extent. The above technology and equipment can be used for traditional power equipment or system with strong shock resistance ability and fault types with obvious fault voltage and current characteristics. However, for new power electronic devices and systems with weak current impulse withstanding ability and fault types without obvious fault voltage and current characteristics, the corresponding DC protection obviously needs further research and optimization[7].

The principle of ACP
This paper presents a new type of active comprehensive protection for LVDC system which is based on power electronics, digital control technology and relay protection principle. ACP, which is based on the structure and control principle of power electronic transformer, integrates DC fault detection principle into the hardware design of DC protection , and DC fault detection and protection control strategy are integrated into the protection and isolation control strategy of DC protection as well, and the protection action is integrated into the control logic of power electronic transformer. Accordingly, DC fault detection, protection, location and isolation in LVDC system can be realized. ACP is based on multiple protection modes and multiple control strategies, and it effectively uses isolation unit of power electronic transformer to realize active isolation of above faults and active blocking of DC short-circuit fault circuit in low-voltage DC distribution system, preventing minor faults from developing into serious faults and upward transmission of DC faults, and ensuring the normal operation of LVDC system to the maximum extent.
In addition, based on the self-protection function of power electronic transformer, ACP can also realize the functions of over-voltage protection, under-voltage protection and over-current protection.

Research on protection function and protection criterion of ACP

The functional block diagram of ACP is shown in fig.1.

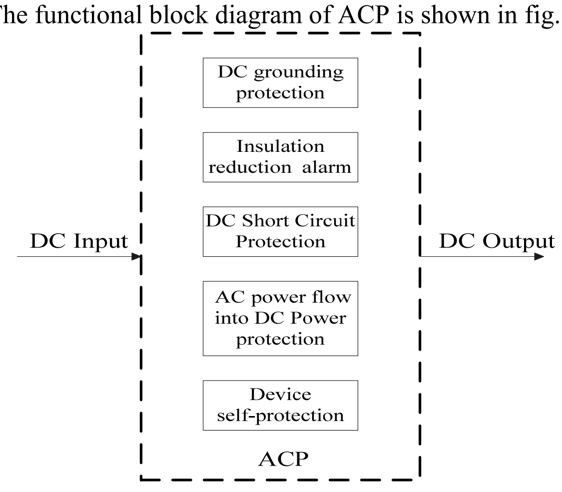

Fig. 1 the function block diagram of ACP

The protection criterion of ACP

(1)DC grounding and insulation reduction protection

ACP monitors the information of DC bus by grounding monitoring circuit, and using internal controller to calculate the ground resistance of DC positive and negative bus, and comparing calculated value and setting value, and according to the comparison results, the controller executes the corresponding control algorithm to turn off the control signal of power electronic transformer and stop power output, and realize fault protection and active isolation, at the same time, the fault alarm signal is sent out.

(2)DC short circuit protection

ACP monitors input current, output voltage and output current through short circuit monitoring circuit, if the output of ACP is short-circuited, the above data will be changed, when the input current is greater than the setting value, and the output voltage is less than the setting value or the output current is greater than the setting value, according to the comparison results, the controller implements the corresponding control algorithm to turn off the control signal of power electronic transformer and stop power output, and cut off short-circuit current and realize fault protection and active isolation, and the fault alarm signal is sent out.

(3)AC intrusion DC protection

ACP monitors AC data information of DC bus through AC monitoring circuit, using internal controller to calculate the value AC power, and comparing calculated value and setting value, and according to the comparison result, the controller executes the corresponding control algorithm to turn off the control signal of power electronic transformer and stop power output, and realize fault protection and active isolation, at the same time, the fault alarm signal is sent out.

Test environment construction of ACP

In order to verify the protection function of ACP, the relevant test principle and and the system parameters are shown in fig.2, an experimental prototype is designed and a test platform is constructed, the test environment is shown in fig.3.

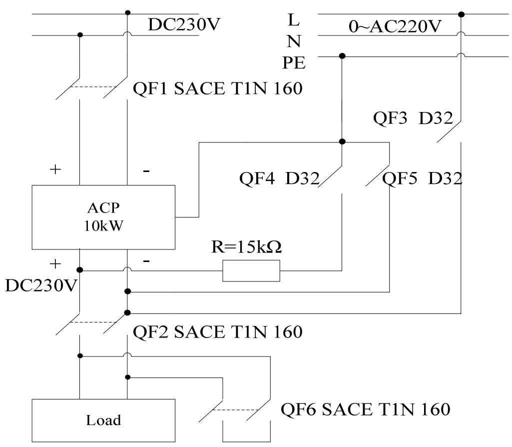

Fig. 2 the experimental principle of ACP system

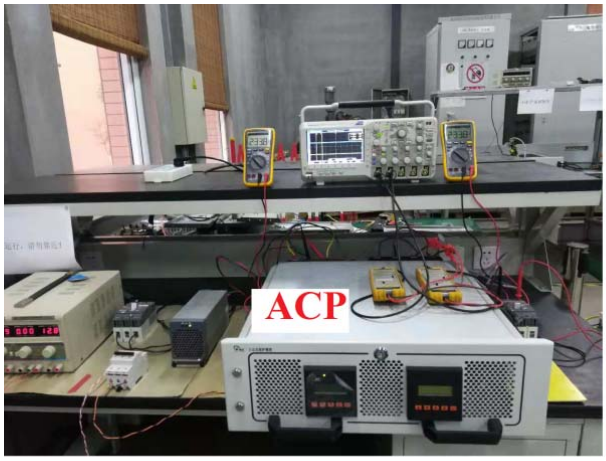

Fig. 3 the test environment of ACP

Function test and experiment verification of ACP

Before the experiment, all the circuit breakers in Figure 3 were in the open state. After the circuit breaker QF1 and QF2 are closed in turn, the ACP starts to work with load, and the system is in normal working condition, and the input and output voltage of ACP is DC230V. The waveform of DC positive bus voltage to ground and negative bus voltage to ground of ACP are shown in fig.4. Among them, CH1 represents negative bus voltage to ground, CH2 represents positive bus voltage to ground. According to the waveform, the positive and negative bus voltage to ground of ACP output is basically symmetrical and the voltage is normal.

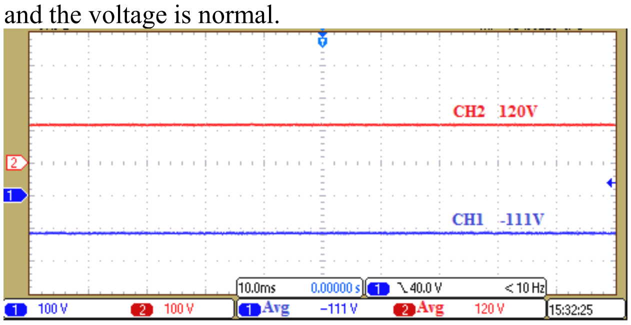

Fig. 4 the voltage of ACP positive and negative bus to ground under normal conditions

Experimental verification of DC grounding protection

After closing the circuit breaker QF5, DC grounding fault occurs in the negative bus of the load branch. The waveform of the voltage between the positive and negative bus voltage to the ground is shown in fig.5.

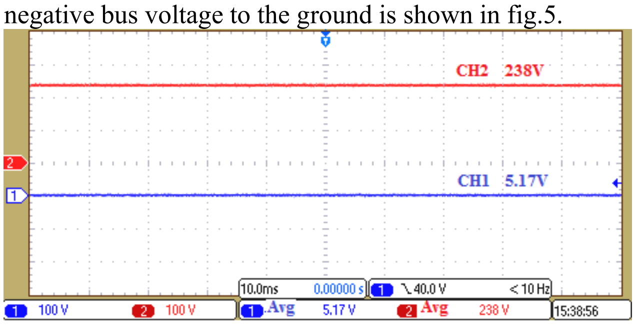

Fig. 5 the voltage of positive and negative bus to ground when the negative bus grounding of ACP

Fig.5 shows that when the output negative bus is grounded of the ACP, the negative bus voltage to the ground is about 0V, and the positive bus voltage to the ground increases to twice the original voltage. At the same time, ACP carries out grounding fault alarm and fault active isolation, while other DC branches and DC systems are not affected by grounding fault.

Experimental verification of insulation drop

After closing the circuit breaker QF4, connecting the analog resistance R between the ACP output bus and the ground causes the insulation reduction fault of the DC bus due to the small resistance value. The voltage waveform of the positive and negative bus to ground is shown in fig.6.

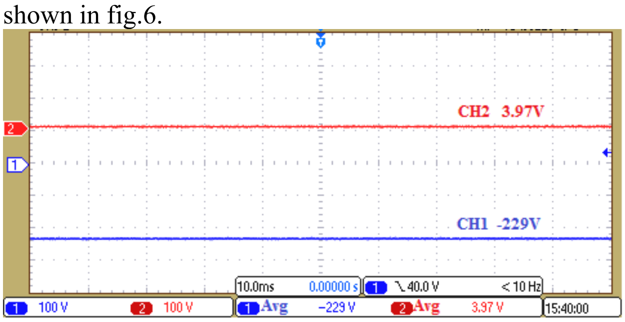

Fig. 6 the voltage of positive and negative bus to ground

From fig.6, it can be seen that when the insulation decreases of output positive bus, the voltage of positive bus to ground decreases, and the voltage of negative bus to ground rises. When the analog grounding resistance of positive bus is different, the value of positive bus to ground voltage is inconsistent. However the voltage difference between positive bus and negative bus of ACP output is basically the same, which ensures the continuous power supply of DC load.

Experimental verification of DC short-circuit fault protection

After closing the circuit breaker QF6, connecting the positive and negative buses of ACP directly results in short circuit fault of the positive and negative bus. The response waveform of the system is shown in fig.7.

CH1 represents the output current, CH2 represents the input voltage, and CH3 represents the output voltage.

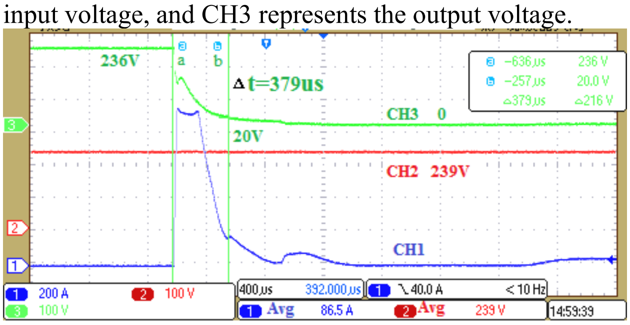

Fig. 7 the voltage and current waveform when the DC short-circuit of ACP

From fig.7, it can be seen that the output voltage of ACP drops rapidly from rated value to near 0V at short-circuit instant, and the output current rises for a very short time, then rapidly changes to a smaller constant value. ACP starts DC protection and closes output, thus turning off short-circuit current, and the short-circuit protection time is about 379 μs. When short-circuit occurs, because of the DC protection function of ACP, the waveform and value of DC input voltage remain unchanged, and will not affect the LVDC system, because ACP provides short-circuit fault alarm and fault active isolation.

Experimental verification of AC intrusion DC fault protection

After closing the circuit breaker QF3, connecting the negative bus of ACP directly with the L-line of ACcauses the fault of AC intrusion DC.The voltage waveform of the positive and negative bus to the ground is shown in fig.8. CH1 represents the input voltage of ACP, CH2 represents positive bus voltage to ground, CH3 represents negative bus voltage to ground.

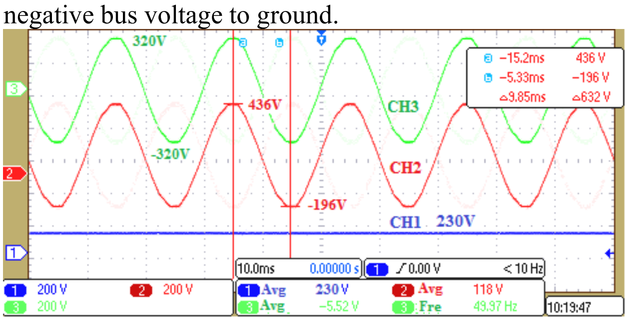

Fig. 8 the voltage of positive and negative bus to ground

From fig.8, it can be seen that the peak values of positive and negative bus voltage to ground represented by channels 2 and 3 are (436V, -196V), (320V, -320V), channel 1 represents the DC bus input voltage of ACP, and its value is about 230V, the frequency of AC is 50Hz. According to the waveform, the output waveform positive and negative bus voltage to ground of ACP are changed, while the input DC bus voltage is not affected by AC intrusion, and the waveform is normal.

APPLICATION OF ACP IN LVDC SYSTEM

Background and topology

The LVDC system of buildings have been built in the production and office buildings[12], the distribution cabinet as shown in fig.9.

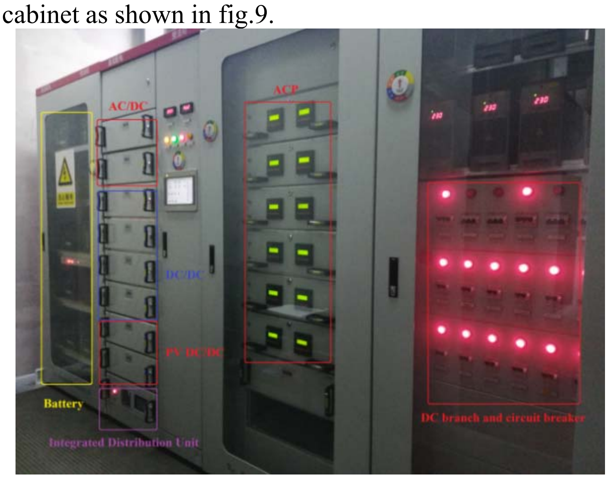

Fig. 9 the distribution cabinet of LVDC system

The system adopts radial topology structure, and some ACP have been set in the system. From fig.9, it can be seen that the LVDC system of building consist of power electronic converter, photovoltaic power generation, DC loads, energy storage unit, switch, integrated DC distribution unit and ACP.

Configuration of ACP in LVDC System

In the LVDC system of building, ACP is installed on DC 230V bus, each DC branch is equipped with one ACP, which is connected in series between the DC bus and each DC load branch, i.e. one branch corresponds to one or more active protection, which can reduce the impact of DC fault, improving the reliability of DC power supply. The configuration of the ACP is shown in fig.10.

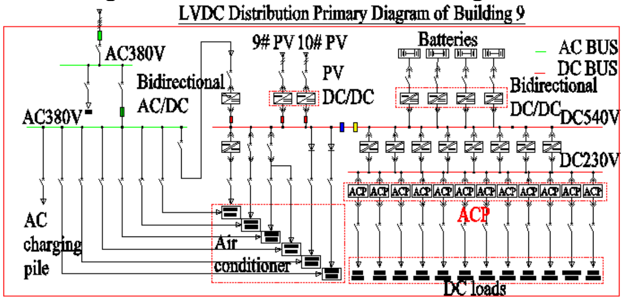

Fig. 10 configuration of ACP in LVDC system

Test of ACP in LVDC System

In more than one year's actual operation, the related performance of ACP has also been verified. In the process of operation, the ACP of a DC feeder branch sends out alarm records, according to the alarm information, the fault detection is carried out, the insulation reduction fault of the DC branch bus occurs. Due to the fault active isolation function of ACP, DC insulation reduction fault do not occur within other DC branches , therefore, ACP can reduce the scope of fault impact and achieve accurate fault location.

CONCLUSION

In this paper, the types and causes of DC faults and the characteristics of DC faults and their transformation relationship are analyzed and studied. An active protection technology based on power electronics and digital control technology is proposed. Then the active protection topology structure, function and implementation principle are deeply studied and analyzed, and the test environment is built to verify the relevant experiments.

The active protection proposed has been applied in LVDC system of buildings. After more than one year's operation practice, the theory and technology of ACP are proved to be feasible. ACP can realize fast protection for distributed DC generation, DC bus and DC load, and the action time of short circuit protection is very short. ACP can effectively isolate faults of DC system, and limit faults within fault branches, synchronously give fault alarm signals, and realize fast line selection of fault branches and optimal configuration of system topology. The realization of ACP reduces the influence scope of DC fault and reduces the dependence on DC circuit breaker, with the optimization of topology structure, it allows DC system to operate with fault in different scenarios, and improves the ability to integrate distributed power supply and the reliability of power supply for the LVDC system.

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