Research on protection configuration of AC/DC hybrid distribution network in industrial park

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Abstract. Under the rapid development of power electronics technology, AC/DC hybrid power supply can be used to comprehensively solve the demand for source and supply. The article takes the first comprehensive demonstration project of the dual-stage AC-DC hybrid system based on multi-function power electronic transformer cluster in China as the research object. A distributed renewable energy system simulation platform with AC/DC hybrid is established in the hardware RTDS to simulate and analyze the fault characteristics under different conditions. Based on the fault characteristics and the principle of protection division, in order to ensure that the ranges between the protection zones overlap each other and cover the entire AC-DC distribution network, this paper studies the specific protection zones and configurations for the industrial park system, and has developed a comprehensive protection configuration plan.

1. Background introduction

The traditional AC distribution network has been unable to meet the demand for efficient access load of AC and DC power supplies [1, 2]. The problem of high AC/DC energy conversion loss, poor flexibility of power distribution, and low matching between power distribution and power consumption is becoming increasingly serious. Driven by the rapid development of power electronics technology, AC/DC hybrid power supply can comprehensively solve the source and load requirements. The use of AC/DC power technology can reduce the intermediate link of AC and DC conversion in the process of power supply, and improve the economy, reliability and flexibility of the power distribution. It is an important development direction in the field of international power distribution research [3, 4, 5, 6, 7, 8]. However, the distributed renewable energy system with AC/DC hybrid has a series of new complex problems such as decentralization, complicated power flow direction, unstable renewable energy intermittent, and AC/DC network cooperative operation [9, 10, 11, 12].

In order to solve these problems, it is necessary to consider the energy usage requirements of different scenarios, such as data centers, office and living parks, and industrial parks. Design and analysis of AC/DC distribution network structure under typical energy scenarios, multi-source optimization configuration in the system, selection and integration design of system primary and secondary equipment, data communication system architecture design, and finally form AC/DC hybrid distributed Renewable energy system demonstration program. The protection of AC/DC distribution network is still not mature in China. At present, the main protection is based on high-voltage AC-DC protection, and the characteristics of low-voltage AC-DC are not considered. The article takes industrial park as the research object, and establishes a distributed...
renewable energy system simulation platform based on AC/DC hybrid distributed renewable energy system demonstration scheme. Complete the feasibility verification of the demonstration program. The article discusses the fault characteristics, protection zones and the protection configuration scheme of the industrial park system. It has pointed out the direction for the development of AC and DC hybrid distribution network protection.

2. Introduction of industrial park scene
As the first comprehensive demonstration project of dual-stage AC/DC hybrid system based on multi-function power electronic transformer cluster in China, this project covers three typical energy use scenarios: data center, office and living park and industrial park. Among the three, the industrial park mode uses two transformers to connect back and forth through the voltage level busbars to form a cluster system, which realizes the free bidirectional flow of power between the ports of different voltage grade busbars. It contains four ports, including 10kV AC, 380V AC, 10kV DC and ±375V DC, as shown in Fig 1.

3. Fault test and protection analysis
Models including power electronic transformers, fault current controllers, photovoltaic systems, energy storage systems, etc. are built in RTDS real-time digital simulation software. The RTDS simulation platform is used to connect the tested devices and all the control and protection system devices involved in the test into a complete Simulation test system. Based on the topology of the industrial park, the RTDS test was used to simulate the failure test of two power electronic transformers under the full load of DC. The simulation is carried out according to the different voltage levels and AC/DC characteristics of the four ports, including the outlet side, the bus side and the load side of the two power electronic transformers, and the fault categories are comprehensive.

3.1. Analysis of fault characteristics in 10kV DC region
The 10kV DC system uses a monopole line operation, the zero pole is grounded through a high resistance (1000 Ω). The positive output voltage is $U_{dc}$ and the zero-pole output voltage is zero. Figure 2 shows the 10kV DC positive pole grounded through $R_g$.

When a ground fault occurs in which the positive pole generates a resistance, the positive current is as shown in Fig. 3. Due to the presence of the zero-grounding resistance, the positive voltage drops to near zero and the pole voltage remains almost unchanged.
At this time, the positive current is the superposition of the rated current and the grounding short-circuit current. Since the rated current is much larger than the amplitude of the grounding current, the peak value of the fault current is only 1.1 times the load current (from 0.1A to 0.11A). The short-time discharge of the DC capacitor installed at the corresponding port of the power electronic transformer causes a voltage drop, as shown in Fig. 4.

![Fault Model of 10kV DC single-pole grounding](image)

Figure 2. Fault Model of 10kV DC single-pole grounding

As can be seen from the above two figures, the amount of change in current does not have sufficient sensitivity, so overcurrent protection is not applicable to DC positive faults. The positive voltage will drop and the zero voltage will become a negative voltage, so the low voltage protection can operate correctly.

![Positive current of 10kV port positive ground fault](image)

Figure 3. Positive current of 10kV port positive ground fault.

![Positive and negative voltages of 10kV port in case of positive ground fault](image)

Figure 4. Positive and negative voltages of 10kV port in case of positive ground fault.

When a pole fault occurs in the 10kV DC region, the DC capacitor installed at the corresponding port of the power electronic transformer will discharge to the external circuit. During this process, the short circuit current increases sharply and decays to zero within tens of milliseconds. Figure 5 reflects the positive and negative current waveforms of the 10kV port in the event of an inter-pole short circuit fault. In the above process, overcurrent protection can effectively protect the faults between the poles.

![Positive and negative current of 10kV port short circuit between poles](image)

Figure 5. Positive and negative current of 10kV port short circuit between poles.

![Positive and negative voltages of 10kV port DC open circuit fault](image)

Figure 6. Positive and negative voltages of 10kV port DC open circuit fault.
Figure 6 reflects the positive and negative poles and the inter-electrode voltage waveform of the 10kV port when the DC-line occurs open-circuit fault. The positive and inter-electrode voltages rise. It can be seen that the overvoltage protection can operate correctly.

3.2. Analysis of fault characteristics in ±375V DC region

The ±375V DC system is operated in bipolar mode with the midpoint grounded through a 10 ohm resistor. When a unipolar ground fault occurs in the zone, the unbalanced current of the two poles will flow from the midpoint grounding resistance to the ground. Fig.7 reflects the ground current of the ±375V port positive ground fault. Since the value is much smaller than the load current, the overcurrent protection is not applicable to the DC ground fault. When the system is in normal operation, the positive and negative poles operate symmetrically in the low-voltage DC distribution network system. When a unipolar ground fault occurs in the network, it can be considered that a transient fault power supply is superimposed at the fault location. At this time, the positive and negative lines will no longer operate symmetrically, and an unbalanced voltage will appear between the two poles. There are two reasons for the existence of the unbalanced voltage between the poles: the voltage drop caused by the capacitor discharge of the fault pole; and the offset of the reference potential caused by the ground fault voltage drop. As shown in Figure 8, the unbalanced voltage that occurs after the positive ground fault is negative. The phenomenon is similar when the negative pole is grounded. Therefore, unbalanced voltage protection can be used to protect single pole ground faults.

![Figure 7](image1.png) **Figure 7.** Ground short-circuit current of ±375V DC port positive ground fault.

![Figure 8](image2.png) **Figure 8.** Bus voltage of ±375V DC port positive ground fault.

![Figure 9](image3.png) **Figure 9.** Branch current of ±375V DC port interpole short circuit fault.

![Figure 10](image4.png) **Figure 10.** Bus voltage of ±375V DC port interpole short circuit fault.

When an inter-pole short circuit fault occurs, the short-circuit current in the DC line rises rapidly. The short-circuit current mainly flows through the load branch which the fault is located, while the non-fault line current is close to zero. Figure 9 shows the ±375V port load branch current waveform for a short-circuit fault between poles. When the fault occurs, the current of the fault branch rapidly
increases, and the non-faulty branch current decreases to zero. So fault isolation can be achieved by overcurrent protection.

Figure 10 shows the voltage waveform of the ±375V port between the inter-pole short-circuit faults. When the fault occurs, the short-time discharge of the DC capacitor, the voltage between the poles drops significantly in a short time. Low voltage protection works correctly.

3.3. Analysis of fault characteristics in 10kV AC region
The 10kV AC bus adopts an ungrounded connection. The fault is the same as the conventional 10kV side action. In the case of single-phase or phase-to-phase faults, large short-circuit currents are generated, so overcurrent protection can be used for fault identification and isolation. So there is nothing special about the protection configuration. No further analysis is done here.

3.4. Analysis of fault characteristics in 380V AC region
In the AC/DC hybrid power grid of this demonstration project, due to the special characteristics of the power electronic transformer, the 380V port is the output of the inverter, and the characteristics of the fault current are different from the short-circuit current of the traditional power grid, mainly in the amplitude and duration. Analysis takes the most severe three-phase short circuit as an example.

Figure 11 and 12 shows the short-circuit current waveforms of the inverter bridge arm and the 380V AC port in the 380V AC area. The inverter bridge arm current is over current. In order to protect the converter device and limit the over current peak, the 3ms inverter is blocked. After 5ms, the AC breaker in the fault area moves, and the fault is removed and isolated.

It can be seen that increasing the response speed of the inverter to the fault, the fast blocking inverter can significantly suppress the fault current flowing on the bridge arm.

Under various fault types, the 380V port current fault phase current suddenly increases, while the non-fault phase current does not change much. The above is in accordance with the operating conditions of conventional overcurrent protection.

![Figure 11](image1.png)

Figure 11. Inverter bridge arm current of three-phase ground fault.

![Figure 12](image2.png)

Figure 12. 380V port current of three-phase ground fault.

4. Industrial Park Protection Configuration
The power electronic transformer and fault current controller developed by this project have been configured with self-protection, which can quickly isolate (cut) the abnormal working conditions that affect the safety of the main equipment. The protection configured by the system discussed in this paper is considered as its backup.

In order to ensure that the protection scopes of the protection zones overlap each other and cover the entire AC-DC distribution network, the industrial park system is mainly divided into several protection zones: 10kV AC protection zone, 10kV DC protection zone, low-voltage AC protection zone, low-voltage DC protection zone and power electronic transformer protection zone, as shown in Figure 13.

1. 10kV DC protection zone: The protection range is DC bus and DC outlet switch, and it can also be used as backup for the protection of the equipment connected to the outlet. The main protection functions are DC bus differential protection, overcurrent protection, overvoltage/undervoltage protection.

2. ±375V DC protection zone: The protection range is the part between all DC measurement points, and can be used as a backup for the protection of the equipment connected to the DC outlet. The main protection functions are bus differential protection, overcurrent protection, overvoltage/undervoltage protection, and unbalanced voltage protection.

3. 10kV AC protection zone: The main protection functions include quick-break protection, overcurrent protection, and zero-sequence protection. The upper level protection of the power inlet switch is used as backup protection for this switch.

4. 380V AC protection zone: It realizes the protection of 380V station power outlet and 380V AC load outlet. The main protection functions are overcurrent protection and overload protection.

5. Power electronic transformer protection zone: The protection range is the four voltage level switches of the power electronic transformer. The protection devices in this zone are arranged according to the transformer, and each transformer is equipped with a transformer protection.

Figure 13. Protection configuration.

5. Summary
In the RTDS real-time digital simulation software, the tested device and all the control and protection system devices involved in the test are connected into a complete simulation test system. Based on the system, a real-time simulation test project is carried out to verify the fault protection test. For the fault characteristics analysis of 10kV AC, 380V AC, 10kV DC, ±375V DC region, this paper proposes a protection configuration scheme for AC/DC hybrid system, which can quickly and reliably remove all
kinds of typical faults and ensure the safe and stable operation of the system. This paper provides a reference for the protection scheme of AC/DC hybrid systems with high proportion of distributed renewable energy in China. It has strong reproducibility and scalability.

6. References

[1] Guerrero J M, Loh P C, Lee T L, et al, Advanced Control Architectures for Intelligent Microgrids—Part II: Power Quality, Energy Storage, and AC/DC Microgrids[J]. IEEE Transactions on Industrial Electronics, 2013, 60(4): 1263-70.

[2] Kojima, Y, Koshio, M, Nakamura, S, Maejima, H, Fujioka, Y, Goda, T., A Demonstration Project in Hachinohe: Microgrid with Private Distribution Line[P]. System of Systems Engineering, 2007, SoSE'07. IEEE International Conference on, 2007.

[3] Navigant Research. More Than 400 Microgrid Projects are Under Development Worldwide [EB/OL]. http://www.navigantresearch.com/newsroom/more-than-400-microgrid-projects-are-under-development-worldwide, 2013-4-2.

[4] Kazuyuki Takada. The 2011 Earthquake & Tsunami and Microgrid Research[C]. Evora 2012 Symposium on Microgrid, 2012.

[5] Majumder R. Control of Parallel Converters for Load Sharing with Seamless Transfer between Grid Connected and Islanded Modes[C]// IEEE PES General Meeting, 2008.

[6] Zhao B, Zhang X, Chen J. Integrated Microgrid Laboratory System[J]. IEEE Transactions on Power Systems, 2012, 27(4): 2175-2185.

[7] Zheng Zeng, Rongxiang Zhao, Huan Yang, et al. Policies and demonstrations of micro-grids in China: A review[J]. Renewable and Sustainable Energy Reviews, 2014, 29: 701-718.

[8] Guillermo Jimenez Estevez. Survey of Microgrid R&D in Latin America[C]. Tianjin 2014 Symposium on Microgrid, 2014.

[9] Anderson, G. W. J., Watson, N. R., Arnold, N. P., Arrillaga, J. A new hybrid algorithm for analysis of HVDC and FACTS systems[P]. Energy Management and Power Delivery, 1995. Proceedings of EMPD '95, 1995 International Conference on, 1995.

[10] Turner K S, Heffernan M D, Arnold C P. Computation of AC-DC System Disturbances. Part II - Derivation of Power Frequency Variables from Convertor Transient Response[J]. IEEE Power Engineering Review, 1981, PER-1(11): 16-16.

[11] Xuegong Wang, Wilson P, Woodford D. Interfacing transient stability program to EMTDC program[P]. Power System Technology, 2002. Proceedings. PowerCon 2002. International Conference on, 2002.

[12] Hongtian Su, Ka Wing Chan, Snider, L. A., TakShing Chung. A parallel implementation of electromagnetic electromechanical hybrid simulation protocol[P]. Electric Utility Deregulation, Restructuring and Power Technologies, 2004, (DRPT 2004). Proceedings of the 2004 IEEE International Conference on, 2004.

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