Study on Difference Between Two-Terminal LCC-HVDC and Three-Terminal LCC-HVDC Control and Protection System

L Feng¹,²
¹Maintenance & Test Centre, CSG EHV Power Transmission Company, Guangzhou, Guangdong Province, 510663, China

E-mail: 492794715@qq.com

Abstract. The paper studies the difference between two-terminal Line Commutate Converter Based High Voltage Direct Current (LCC-HVDC) and three-terminal LCC-HVDC control and protection system relying on the Yun-gui Interconnection Project of China Southern Grid (CSG). Contrapositing the difference of topology between two-terminal LCC-HVDC and three-terminal LCC-HVDC, the paper introduces several special topology structures of three-terminal LCC-HVDC. Then the paper conducts comparative analysis on control strategy, protection strategy and communication strategy between the two-terminal LCC-HVDC and the three-terminal LCC-HVDC. Finally, the paper illustrates the unique key problems of three-terminal LCC-HVDC and solving ideas, which has guiding significance on three-terminal LCC-HVDC engineering application.

1. Introduction

With the increasing demand of power load in eastern China and more power supply going into operation in western China, it is urgent to construct High Voltage Direct Current (HVDC) power transmission project to meet the demand of large-capacity long-distance power transmission. The two-terminal Direct Current (DC) transmission scheme need more DC lines to be built and the cost is high [1]. The multi-terminal DC system developed from the two-terminal DC system, which can make full use of the line corridor [2], is gradually attracting people's attention.

At present, the academic research on multi-terminal DC transmission technology mainly focuses on multi-terminal flexible DC system and multi-terminal hybrid DC system. In terms of control strategy, literatures [3-5] study and propose DC power flow controller topology and control strategy for multi-terminal flexible DC transmission system. Literature [6] proposes a nonlinear droop control strategy considering the current margin of each converter station for the multi-terminal hybrid DC system power coordination problem. Literature [7] proposes a coordinated control scheme for start/stop of the system and on-line input/exit of the third terminal for multi-terminal hybrid DC transmission system.

In terms of protection strategy, literature [8] proposes a permissive longitudinal protection based on refraction/reflection ratio of traveling wave at protection installation site for multi-terminal flexible DC system. Literatures [9, 10] study and propose multi-terminal flexible DC system line fault location scheme. Literature [11] proposes a sequential coordination method for current limiting device including fault current limiter and DC circuit breaker in multi-terminal flexible DC system.

At present, reports on multi-terminal LCC-HVDC are relatively few. Literature [2] studies the engineering application architecture of three-terminal LCC-HVDC, and proposes a constant voltage control strategy suitable for the three-terminal system. Literature [12] analyzes the operation mode of
three-terminal LCC-HVDC, and proposes an electrical connection scheme of the three-terminal system and the input/exit strategy of voltage control station. Literature [13] conducts a comparative analysis of AC fault characteristics of conventional and mixed dc at three terminals. The control strategy and fault characteristics for the three-terminal LCC-HVDC and hybrid DC system. The literatures above have made some progress in the control strategy and fault characteristics, but the specific technical problems of the three-terminal LCC-HVDC have not been studied deeply.

Based on the Yun-gui Interconnection Project of CSG, the paper systematically studies the difference between the two-terminal LCC-HVDC and three-terminal LCC-HVDC control and protection system. Firstly, the paper introduces the special connection topology of the three-terminal LCC-HVDC relative to the two-terminal LCC-HVDC, and then analyses the difference of the control strategy, protection strategy and communication strategy comparatively of the two-terminal LCC-HVDC and three-terminal LCC-HVDC. Finally, the paper proposes the unique key technical problems of three-terminal LCC-HVDC and solving ideas, which has certain guiding significance for the engineering application of three-terminal LCC-HVDC.

2. Special topology of three-terminal LCC-HVDC
A typical primary circuit of three-terminal LCC-HVDC is shown as the figure 1.

![Figure 1. Three-terminal LCC-HVDC typical primary circuit](image)

As can be seen from the figure, the three-terminal LCC-HVDC system consists of three stations: station A, station B and station C. Line AB and line BC are connected at station B. In typical engineering application, station A is the power source integrated with large-scale renewable energy. Station B is connected to a certain scale thermal power plant and local load, which can be either power source or load terminal, and station C is load terminal. Compared with the two-terminal LCC-HVDC, the topology connection of the three-terminal LCC-HVDC is more complicated. Station B has two connection modes: normal polarity and reverse polarity, which correspond to the rectifier mode and the inverter mode respectively, and connect different disconnectors and switches in the ground return and the metal return. Take pole 1 as an example to introduce the special connection topology of three-terminal LCC-HVDC.

(1) Pole 1 is configured as ground return and station B is in normal polarity mode. In this case station B runs in rectifier mode. The system connection topology is shown as the figure 2.

![Figure 2. Topology of Pole 1 configured as ground return and station B in normal polarity mode](image)

(2) Pole 1 is configured as ground return and station B is in reverse polarity mode. In this case station B runs in inverter mode. The system connection topology is shown as the figure 3.
Figure 3. Topology of Pole 1 configured as ground return and station B in reverse polarity mode

(3) Pole 1 is configured as metal return and station B is in normal polarity mode. In this case station B runs in rectifier mode. The system connection topology is shown as the figure 4.

Figure 4. Topology of Pole 1 configured as metal return and station B in normal polarity mode

(4) Pole 1 is configured as metal return and station B is in reverse polarity mode. In this case station B runs in inverter mode. The system connection topology is shown as the figure 5.

Figure 5. Topology of Pole 1 configured as metal return and station B in reverse polarity mode

3. Difference analysis of control strategy between three-terminal LCC-HVDC and two-terminal LCC-HVDC

3.1. The third terminal input/exit control strategy
The third terminal input/exit is a new control operation of the three-terminal LCC-HVDC relative to the two-terminal system. It refers to the input or exit of the third terminal while maintaining the operation of the other two terminals. The key of this strategy is to close/open HSS switch at the right time to ensure the safety of HSS switch equipment and not causing a big impact on the system. The specific input/exit strategy of the third terminal is shown as the figure 6 and the figure 7.

Figure 6. The third terminal input strategy
As can be seen from the figure, in order to ensure the safety of HSS switch and reduce system impact, force retard by the other two terminals is required to reduce the system voltage/current, and the HSS switch shall not be operated until the system voltage/current meets certain conditions.

3.2. Coordinated control and power distribution strategies

Different from the two-terminal LCC-HVDC, the three-terminal LCC-HVDC has the problems of three-terminal coordinated control and power distribution.

(1) Coordinated control

In normal operation, the rectifier side of the two-terminal LCC-HVDC controls dc current and the inverter side controls dc voltage. In the three-terminal system, there is only one constant-voltage control station, so the voltage margin and current margin of station B need to be adjusted accordingly when station B is used for inverter operation, so that station B can adopt constant-current control. In addition, since there is a minimum operating current limit at each terminal, control parameters such as VDCL at each terminal need to cooperate with each other according to the current distribution relationship.

(2) Power distribution

There is no power distribution problem for the two-terminal LCC-HVDC due to the uniqueness of the sending terminal and receiving terminal. The three-terminal LCC-HVDC has power distribution problem in the case of power modulation, pole blocking/exiting, current limiting, etc. In typical engineering application, station A is connected to large-scale renewable energy, and station C is the important load terminal. In order to improve the utilization rate of renewable energy and the reliability of important load power supply, and avoid system instability in the power distribution process, the power distribution strategy of the three-terminal LCC-HVDC is determined as follows:

1) Power transfer between stations is prohibited when blocking, exit or current limiting occurs at one station to avoid system instability in the power distribution process.

2) When station B is in the inverter mode, the strategy shall first satisfy the power input of station C. When station B is in the rectifier mode, the strategy shall first satisfy the power delivery of station A.

3) The power level of the converter station after power coordination shall not exceed the original bipolar power level.

4) When inter-station communication failure occurs, power transfer is prohibited.

4. Difference analysis of protection strategy between three-terminal LCC-HVDC and two-terminal LCC-HVDC

4.1. Converter station protection strategy

Compared with the two-terminal LCC-HVDC, station B has added new equipment such as polarity conversion bus, confluence bus, HSS switch, etc. Thus, corresponding protection function is added to station B:

1) Polarity transfer bus differential protection, which is protected from grounding fault in the polarity transfer bus area, and the action result is blocking of the terminals in operation.
(2) Confluence bus differential protection, which is protected from grounding fault in confluence bus area, and the action result is blocking of the terminals in operation.

(3) HSS switch protection. If the current flowing through the HSS switch is larger than a certain value, the HSS switch will be reclosed. After the reclosing command issues, if the switch closed signal is not received, the terminals in operation will be blocked.

4.2. Line protection strategy
There is only one DC line in the two-terminal LCC-HVDC, and if the line fails to restart after fault, the system will be blocked directly. In the three-terminal LCC-HVDC, there are two dc lines: line AB and line BC. In the case of line failure to restart, according to the protection selectivity requirement, it is necessary to be able to block the terminal related to the fault line, so as to ensure the normal operation of the remaining two terminals. Therefore, the line protection of the three-terminal LCC-HVDC should have the function of fault line identification.

A typical fault line identification strategy of the three-terminal LCC-HVDC is to configure protection for line AB and line BC respectively at station B, and identify the fault line by the changing direction of current in confluence bus area, and send the judgement result to the other two terminals.

5. Difference analysis of communication strategy between three-terminal LCC-HVDC and two-terminal LCC-HVDC

5.1. Communication structure configuration
In the two-terminal LCC-HVDC, the inter-station communication only sends the own station’s information. In the three-terminal LCC-HVDC, the inter-station communication sends the own station’s information and the third station’s information at the same time, and each station receives the same information of the other two stations through inter-station communication in two directions, as shown in the figure 8.

![Figure 8. Inter-station communication structure](image)

5.2. Inter-station communication channel switching
In the two-terminal LCC-HVDC, pole 1 of the two stations must be connected and it is the same for pole 2, so there is no problem of switching communication channel. In the three-terminal LCC-HVDC, station B has two connection modes: normal polarity and reverse polarity, which correspond to connection to different pole at station B respectively. For example, when station B is in normal polarity mode, pole 1 of station A, station B, and station C are connected to each other. When the station B is in reverse polarity mode, pole 1 of station A and station C, and pole 2 of station B are connected to each other. Therefore, when the connection mode of station B is switched, the inter-station communication channel also needs to be switched synchronously.

6. Special technical problems of the three-terminal LCC-HVDC

6.1. System oscillation during power distribution
In order to realize power distribution of the three-terminal LCC-HVDC, the control system of each terminal is coupled with each other. For example, when station B is in rectifier mode, the reference value of current at station B is set as the maximum value of current at station C minus the actual value of current at station A in order to give priority to the power delivery at station A when the current at station C falls. The decrease of the maximum value of the current at station C will cause the decrease of the reference value and actual value of the current at station B. Due to the electrical coupling between station A and station B, the decrease of the current at station B may cause the disturbance of the actual value of current at station A, and further cause the change of the reference value and actual value of the current at station B, which may finally induce the system oscillation shown as the figure 9, figure 10 and figure 11.

![The maximum value of current at station C decreases](image9)

**Figure 9. The maximum value of current at station C**

![The reference value and actual value of the current at station B decreases due to the decrease of the maximum value of the current at station C](image10)

**Figure 10. The reference value, actual value and maximum value of current at station B**

![A disturbance of the actual value of current at station A is caused by the change of the current at station B](image11)

**Figure 11. The actual value of current at station A**

In order to avoid system oscillation, the coupling of the three control systems should be weakened. When the control system of own terminal adopts the electric quantity of the control system of the other two terminals, certain filtering processing can be adopted to avoid the reaction of own terminal control system to the electric quantity change of the other two terminals being too sensitive.

6.2. Line protection coverage matching
Since the fault line identification function is realized by the line protection of station B, the protection coverage of the two line protections of station B shall cover the whole length of line AB and line BC respectively. When determining the line protection coverage at stations A and C, it is necessary to consider avoiding the misoperation of the line protection at station A and C under some special commutation failure conditions of the three-terminal LCC-HVDC. For example, station B in inverter
operation, the grounding fault occurs at the station B end of line BC of pole 1, and then the current of line AB of pole 1 increases rapidly. Due to the electromagnetic coupling of the lines of pole 1 and pole 2, the current of line AB of pole 2 will increase rapidly, which could lead to commutation failure of pole 1 at station B and quick drop of DC line voltage of pole 2. If the line protections of pole 2 at station A and station C are configured too sensitive, misoperation may occur. The relevant waveforms of the process mentioned above are shown as the figure 12, figure 13, figure 14 and figure 15.

![Figure 12. The grounding fault occurs at the station B end of line BC of pole 1](image1)

Commutation failure occurs at pole 1 of station B due to the electromagnetic coupling of the lines of pole 1 and pole 2, and leads to quick drop of DC line voltage of pole 2.

![Figure 13. Commutation failure of pole 1 at station B and quick drop of DC line voltage of pole 2](image2)
Misoperation of the line protection of pole 2 at station A

Figure 14. Misoperation of the line protection of pole 2 at station A

Misoperation of the line protection of pole 2 at station C

Figure 15. Misoperation of the line protection of pole 2 at station C

7. Conclusion
Relying on the Yun-gui Interconnection Project of CSG, the paper introduces special connection topology of the three-terminal LCC-HVDC relative to the two-terminal system, and analyses the difference of control strategy, protection strategy and communication strategy of the three-terminal system and two-terminal system. Finally, the paper puts forward the key technical problems and solving ideas of the three-terminal LCC-HVDC, which has certain guiding significance for the engineering application of the three-terminal system.

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