

The implementation of self-healing system and the optimization of PT setting schemes for 110kV substations in the 110kV chain structure

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Abstract. At present, developed cities such as Shanghai and Beijing, chain structure is mostly used in 110kV grids. There is a controversy for the implementation of the self-healing system and the PT layout scheme. By analyzing the role of self-healing system and its action logic, this paper gives the role of voltage value in the self-healing system. By comparing the reliability, floor area and investment of various PT arrangements, this paper proposes a PT setting recommendation plan, and analyzes the feasibility of the plan.

1 Background

1.1 110kV substations in a chain structure and protection configuration

The 110kV power grids in developed cities in China, such as Shanghai and Beijing, mostly adopt chain structure. This wiring method can ensure the reliability of power supply to the greatest extent. As shown in Figure 1 below, the chain structure is that 110kV substations A, B and C each have eight 110kV lines connected to the four 110kV chain structure channels between two 220kV substations, which form a loop network of two 220kV substations at both ends supplying power to three 110kV substations.

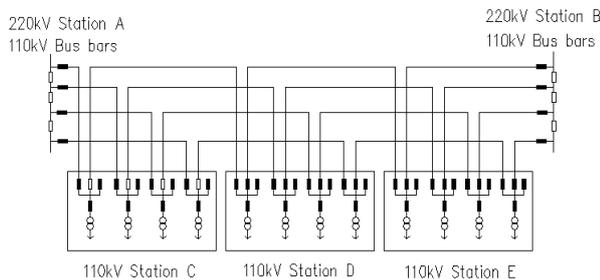


Figure 1. Diagram of 110kV substations in a chain structure

For the convenience of description, this article will simplify the structure of the above figure, including delete the user's interval, and keep two chain structures for discussion, as shown in Figure 2 below. 220kV stations A and B are on sides, and three 110kV substations C, D, E are in the middle. There are two chain loops in normal operation, namely A1-C1-C2-D1-D2-E1-E2-B1 and A2-C4-C5-D4-D5-E4-E5-B2. In both chain loops, one switch is opened as the open loop point,

and the other switches are closed. In terms of protection configuration, the 110kV sides of 220kV stations A and B are equipped with bus bar protection devices and power automatic switching devices; and the 110kV bus bars of 110kV stations C, D, E are equipped with bus bar protection devices, the lines are equipped with optical fiber differential protection devices, and the 10kV side is equipped with power automatic switching devices.

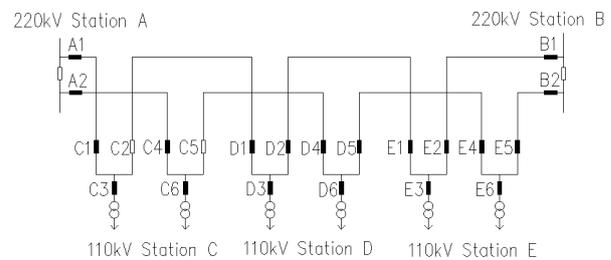


Figure 2. Typical diagram of 110kV substations in a chain structure

1.2 The role and action logic of the self-healing system

1.2.1 The role of self-healing system

In the chain structure as shown in Figure 2, the 110kV substation is only equipped with a 110kV power automatic switching device. When a fault occurs between A1-C1, the line protection first opens the A1 and C1 breakers to isolate the fault. Then, the power automatic switching device of 110kV C station closes the C2 switch to restore the power supply for the No.1 transformer of 110kV station C by judging that C1 and C2 are both in the opened state. However, when a fault occurs between D2-E1, the line protection opened the D2 and E1 breakers to isolate the fault, causing the No.1

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transformer of 110kV station D lose power. Then, the power automatic switching device of the 110kV station C could not operate, resulting can not restore the power supply to the No.1 transformer of 110kV station D, by judging that C1 is closed and C2 is opened. Therefore, the power automatic switching devices can only realize the function of backup power automatic switching when the substation where it is located is the open loop point of the chain structure. However, it cannot realize the function when the substation where it is located is not the open loop point of the chain structure.

In view of the shortcomings of the power automatic switching device, in order to improve the reliability of power supply, a self-healing system can be configured in the 110kV chain structure. Simply, the system is a wide-area power automatic switching device. When a fault occurs in the structure, the system quickly closes the backup power switch to restore power by receiving area information in real time, making comprehensive logical judgments, determining fault locations, and executing fault isolation decisions.

1.2.2 Action logic of self-healing system

In various grid operation modes, that is, any switch can be used as the open loop point of the chain structure, the self-healing system should all be able to operate correctly through a comprehensive analysis of the action of line protection and bus protection under various fault conditions to get the correct action logic. Take the chain structure A1-C1-C2-D1-D2-E1-E2-B1 as an example, the C2 breaker is the open loop point, 220kV station A supplies power to 110kV station C, and 220kV station B supplies power to 110kV stations D and E. When a fault occurs in A1-C1, the line optical differential protection opens A1, C1, and the self-healing system closes C2. When a fault occurs in C1-C2, the bus bar differential protection opens C1, and self-healing system does not act. When a fault occurs in C2-D1, the line optical differential protection opens D1 and the self-healing system does not operate. when a fault occurs in D1-D2, the bus bar differential protection opens D1 and D2, and the self-healing system does not operate. When a fault occurs in D2-E1, the line optical differential protection action opens D2 and E1, and the self-healing system closes C2. When a fault occurs in E1-E2, the bus bar differential protection opens E1 and E2, the self-healing system closes C2, and the station E restore power by 10kV section switch. When a fault occurs in E2-B1, the line optical differential protection opens E2 and B1, and the self-healing system closes C2. When a fault occurs on the 110kV bus of substation A, the self-healing system opens C1 and closes C2; When a fault occurs on the 110kV bus of substation B, the self-healing system opens E2 and closes C2.

In summary, the self-healing system is a wide-area power automatic switching device with input and communication function. The system opens the breaker of the lost power station next to the fault point, and close the breaker at the open loop point on the chain structure

to restore the power supply for the substation that has lost power from the other side.

2 The realization of self-healing system and the PT setting scheme of 110kV substation

2.1 Realization of self-healing system

Based on the action logic of the self-healing system mentioned above, the system needs to collect bus voltage signals and line current signals, as well as the protection action information etc. The self-healing system uses these information as a criterion to realize the operation of opening and closing the breaker and complete the self-healing function. The input and output information required by 220kV station A, B and 110kV station C, D and E are shown in the table below.

Table 1. The input and output information for self-healing system

Substation	Analog information	Digital input information	Digital output information
220kV substation A/B	three-phase voltage of 110kV bus three-phase current of A1/B1	TWJ, HWJ, KKJ of A1/B1 optical differential protection action of A1/B1	status of A1/B1
110kV substation C/D/E	three-phase voltage and current of C1/D1/E1 three-phase voltage and current of C2/D2/E2	TWJ, HWJ, KKJ of C1/D1/E1 optical differential protection action of C1/D1/E1 TWJ, HWJ, KKJ of C2/D2/E2 optical differential protection action of C2/D2/E2	status of C1/D1/E1 status of C2/D2/E2

When the 110kV bus bars of 220kV station A and B are under voltage, the bus bars of 110kV station C, D, and E are under voltage, and a switch in the chain structure is opened, and the others are closed, the self-healing system can be activated.

If a fault occurs somewhere in the chain structure, such as between D2-E1, the self-healing system first judges the open loop point (C2) in the normal operation mode. The optical differential protection of the line will open D2 and E1, and the self-healing system will receive information of the protection signal TWJ, the switch D2 and E1 are opened, and the 110kV D station bus bar lost voltage and others. When the action logic is satisfied, the self-healing system will close the open loop point switch C2 and restore the power supply of 110kV D station.

That is, under the current normal operating mode, If a fault occurs somewhere in the chain structure, the self-healing system first identifies the location of the fault, then open the switch of the station which lost power. After confirming that the switch is opened without current, the bus bar of the power station has no voltage, the self-healing system closes the open-loop point switch of the chain structure to restore the power supply to all substations.

In summary, the 110kV bus voltage of each station is need for the self-healing system. The voltage level provides a criterion for the self-healing system. The system judges the fault location and opens or closes the breaker according to the changes of the voltage in each substation.

2.2 Current layout plan of PT

At present, the self-healing system has been applied in Shanghai, Beijing and other regions, and there are differences in the PT setting schemes in various regions, as shown in Figure 3 and Figure 4 below.

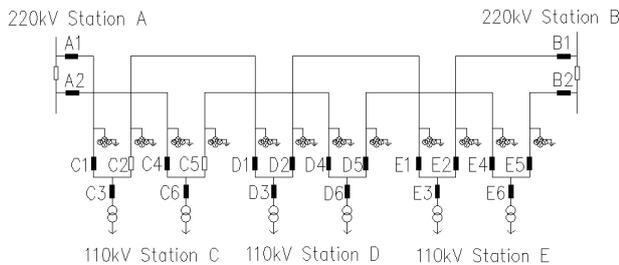


Figure 3. layout plan of PT in Shanghai

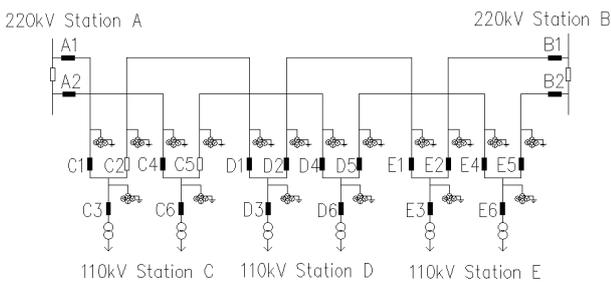


Figure 4. layout plan of PT in Beijing

As shown in the figure, there is no PT on 110kV bus in Shanghai, and a set of three-phase PT is arranged outside each circuit. In Beijing, a group of three-phase PT are also arranged on the outside of each circuit, and a group of three-phase PT are arranged on the high-voltage side of the main transformer.

In the two arrangements, the 110kV bus voltage required by the self-healing system is obtained by voltage switching device switches the voltage of the two 110kV lines. The implementation , advantages and disadvantages of the voltage switching device will be described later. The PT on the high-voltage side of the transformer set up in Beijing which can obtain the voltage directly through PT is considered that

transformer protection is more important for system stability.

2.3 Reliability of voltage switching circuit

As mentioned above, when the self-healing system opens or closes the switch, in order to obtain the correct voltage for the device, a voltage switching circuit is required to complete the switching function. The correct action of the voltage switching circuit will play an important role in the correct action of the self-healing system.

At present, the voltage switching device named CZX-12R of NARI is widely used. The basic principles of voltage switching device are illustrated below with Figure 5 and Figure 6. There are two breakers C1 and C2 on the bus, one voltage transformer 1PT installed on line 1, one voltage transformer 2PT installed on line 2. Through the opened and closed state of C1 and C2, the high voltage side of the transformer will be connected to line 1 or line 2 respectively. By using the voltage switching circuit, when the high-voltage side of the transformer is running on line 1, the device will obtain voltage from 1PT; when it is running on line 2, the device will obtain voltage from 2PT.

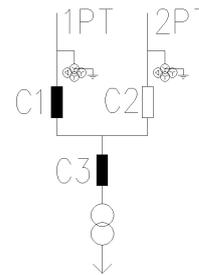


Figure 5. Schematic diagram of voltage switching circuit

Figure 6 is a schematic diagram of the voltage switching circuit. 1YQJF and 2YQJF are ordinary relays, 1YQJ1, 1YQJ2, 1YQJ3 and 2YQJ1, 2YQJ2, 2YQJ3 are dual position relays which has a self-holding function while the ordinary relay will reset. When C1 is closed and the high-voltage side of the transformer is connected to line 1, the auxiliary normally opened contact C11 of C1 is closed, so that the relay 1YQJF is excited and the dual-position relay is excited and self-holding, resulting that the normally opened contact 1YQJ1 is closed, and the voltage of 1PT is connected to the device. When the self-healing system need to close C2 and open C1, and the high-voltage side of the transformer runs on line 2, the auxiliary normally opened contact C21 of C2 turn to closed firstly. At this time, the relay 2YQJF is excited, and the dual position relays 2YQJ1, 2YQJ2, 2YQJ3 are excited and self-retaining, and their corresponding normally opened contacts are closed. Then the system opens C1, the corresponding auxiliary normally closed contact C12 turn to closed, the dual position relays 1YQJ1, 1YQJ2, 1YQJ3 are reset, and the corresponding normally opened contacts are opened. So that the voltage of 2PT is put into the device. When C1、C2、1YQJ1 and 2YQJ1 are all closed, we call it that the PT is in a second parallel state.

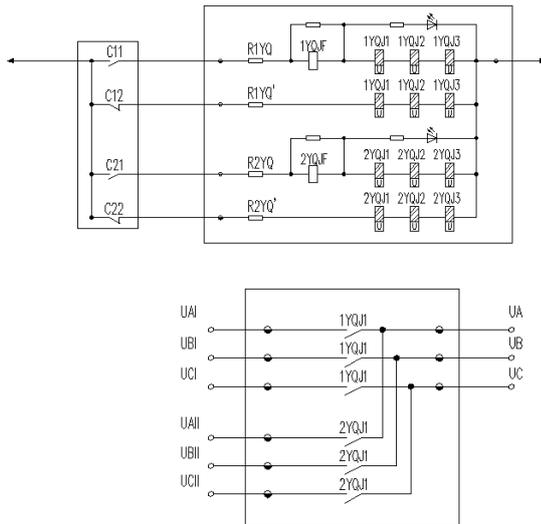


Figure 6. Schematic diagram of voltage switching circuit

This voltage switching circuit has a big hidden danger. If the reset coil of the dual position relay can not operate correctly, it will cause the PT take a second parallel state(that is, 1YQJ1 and 2YQJ1 are both closed). If the two lines are not running in parallel at this time, the shutdown line will be charged by the running line. The principle of charging is shown in Figure 9. When PT take a second parallel state, the secondary voltage of the line 1 is connected to the secondary winding of PT for line 2 through 1YQJ1, 2YQJ1, the PT interface screen, and the PT terminal box. Then, the secondary voltage of the line 1 reaches line 2 passes through the isolation switch of the PT, that is, the line 2 is charged by line 1. At this time, since the breaker C2 is opened and the primary side of the line2 and line1 have a difference on voltage value, a large current is generated in the charging circuit, so that the PT will trip. If it is unable to trip, the switching device will burned, causing the protection device can not work.

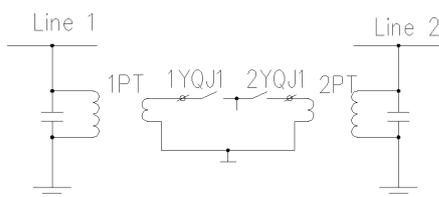


Figure 7. Schematic of PT anti-charging

As mentioned above, the self-healing system needs to close C2 and open C1. When the C1 is opened, the corresponding auxiliary normally closed contact should be closed and return the switching relay. However, if the auxiliary normally closed contact C12 cannot be closed due to poor contact, the dual position relay cannot return, which cause PT take a second parallel state. At this time, if you do not pay attention to the information of relay act simultaneously, line 2 will be charged by line 1. In addition, when the auxiliary normally closed contact is poorly contacted or the auxiliary contact cannot be closed immediately after the breaker is opened, it will also cause the relay fail to reset, and the PT will take a second parallel state.

In summary, the voltage switching device adopts a self-holding dual position relay, When the auxiliary contacts of the breaker are in poor contact or the reset coil of the relay does not operate correctly, it will cause that the PT take a second parallel state, and the maintenance line will be charged, the voltage switching device will be burned, and even the protection device of the whole station can not work. In recent years, affected by factors such as equipment quality, operating life and environment, the auxiliary contact is often not in place during operation, which affects the voltage switching circuit. Therefore, there is less reliable and more risky using voltage switching devices to obtain the correct voltage.

2.4 Recommended plan of PT layout

Taking into account the risk of PT secondary parallelism in the voltage switching circuit, this article recommends a PT arrangement, as shown in Figure 8 below. Set up a set of PT directly on the 110kV bus for self-healing system, transformer protection and bus differential protection, etc., and arrange a set of single-phase PT on the line side to check the same period and no voltage signal when the ring grid structure is formed. With this PT arrangement scheme, the self-healing system directly adopts the voltage on the bus, without obtaining through a voltage switching device, which greatly improves the reliability of the self-healing system.

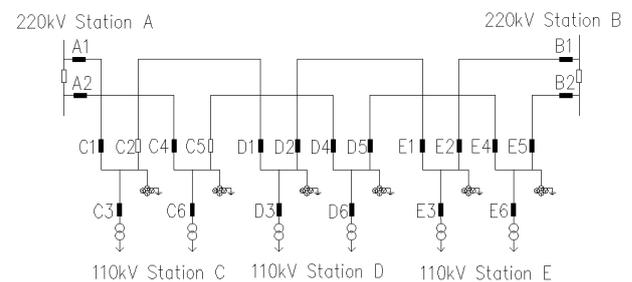


Figure 8. Recommended plan of PT layout

3 The feasibility of the recommended solution

3.1 The influence of PT layout scheme on area

According to Figure 9 below, when the PT is set on the line side or the high-voltage side of the transformer, only the height of the GIS device needs to be increased without affecting the interval width. Setting a group of PT on the bus will increase an interval on the bus, and accordingly, the overall width of the GIS equipment will increase.

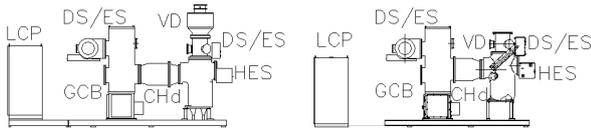


Figure 9. Cross-sectional view of a typical 110kV power distribution device

According to GB50060, channels for installation, maintenance and inspection should be provided on both sides of the GIS equipment in the house. The main channel should be close to the side of the breaker and the width should be 2000mm; the width of the inspection channel should not be less than 1000mm. As shown in Figure 10 below, the southern part of the 110kV GIS equipment room is the main channel, and the northern, eastern, and western parts are the inspection channels. The 110kV GIS equipment has an interval width of 1000mm. Calculated in this way, when the PT is installed on the bus, PT becomes a separate interval, the width of the 110kV power distribution room needs to be at least $4 \times 5 \times 1000 + 1000 + 1000 = 22000\text{mm}$, which is 22m. The length needs to be at least $6300 + 2000 + 1000 = 9300\text{mm}$, which is 9.3m. When the PT is set on the line side or the high-voltage side of the transformer, only the height of the GIS device needs to be increased without affecting the interval width. Therefore, when the PT is installed on the line side or the high voltage side of the main transformer, the width of the 110kV power distribution room needs to be at least $4 \times 4 \times 1000 + 1000 + 1000 = 18000\text{mm}$, which is 18m. The length is consistent with the above scheme, at least 9.3m is required.

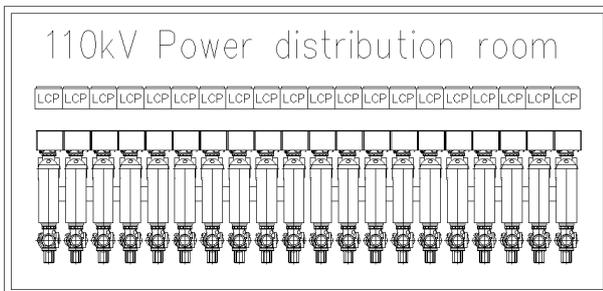


Figure 10. Diagram of 110kV power distribution equipment room

In combination with the general layout of most current substations, such as Rongxi and Xiongdong, the 110kV power distribution equipment rooms are mostly $25\text{m} \times 10\text{m}$ or more. Both the width and the area can meet the requirement of locating the PT on the side of the bus bar, and the recommended scheme in this article is feasible.

3.2 The impact of PT layout plan on investment

Through communication with multiple GIS equipment manufacturers, installing a set of three-phase PT on the bus bar, including isolation switches, will increase the equipment price by approximately RMB 300,000. Adding a set of three-phase PT in the line or transformer interval, including isolation switches or detachable

conductors, will increase the equipment price by approximately RMB 150,000. Adding a set of single-phase PT in the line or transformer interval, including isolation switches or detachable conductors, will increase the equipment price by approximately RMB 80,000. The price of a voltage switching device is approximately RMB 10,000.

Therefore, the cost involved in the first option is RMB $1,860,000(12 \times 150,000 + 6 \times 10,000)$; the cost involved in the second option is RMB $2,400,000(18 \times 150,000 + 6 \times 10,000)$; the cost involved in the recommended program in this article is RMB $2,760,000(6 \times 300,000 + 12 \times 80,000)$. In summary, the investment of the proposed scheme in this article is acceptable and feasible.

3.3 Other advantages of the recommended plan

Voltage information also plays a vital role in transformer protection and bus bar differential protection of 110kV substation. Generally, voltage information is added to the transformer over current protection, that is, the blocking conditions of low voltage and negative sequence voltage are stringed into the current criterion. Combined with the change of voltage, the protection can only be activated when the current and voltage criteria meet at the same time. This can reduce the current setting value, improve the sensitivity of the protection device, and prevent the protection device from malfunctioning, causing the transformer to be disconnected from the system. The function of the bus bar protection is to quickly detect the bus bar fault and selectively isolate the fault. The wrong action of the bus bar differential protection will have a huge impact on the system. In order to prevent erroneous operation of bus bar protection, composite voltage information is usually also used. That is, the bus bar differential protection cannot operate when the bus bar voltage is normal; when the bus bar voltage abnormally reaches a fixed value, the bus bar differential protection can operate.

Setting PT on the 110kV bus can avoid the use of voltage switching devices in the transformer protection and bus differential protection, resulting in PT take a secondary parallel state. Therefore, the recommended scheme is conducive to the correct action of the transformer protection and bus differential protection, and ensures the safe operation of the system.

4 Conclusion

Voltage information plays a very important role in the self-healing system of the 110kV substation in a chain structure. The use of voltage switching device will cause greater risks such as PT take a secondary parallel state. This article recommends a scheme for setting PT on the bus bar. Through the analysis of the layout of most current substations, this scheme meets the requirements of the station layout and the investment is within an acceptable range. Therefore, it is recommended to install PT on the bus of the 110kV substation in a chain structure.

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