110 kV substation relay protection

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Abstract. In this paper, the main electric wiring mode of 110kV substation is selected, the structure of substation is determined, and then the main wiring diagram is drawn. According to the design and load of the primary electrical connection, select the maximum and minimum operating modes to calculate the short circuit separately. Then, according to the short-circuit current parameters, the relay protection of transmission lines, transformers, busbars, etc. is set, and the configured protections include current quick-break protection, gas protection, and longitudinal differential protection. Finally, a comprehensive evaluation of the selected protection devices is carried out. Adding relay protection device in substation can send out fault signal and cut off fault line in time to reduce the occurrence of substation fault, so as to ensure the reliable power supply of users and enterprises.

1. Introduction
The security of power system operation is the most important requirement [1]. In fact, due to the large number of components, different structures, complex operation conditions and vast territory covered by the power system, affected by natural conditions, equipment factors and human factors (such as lightning strike, tower turnover, internal over-voltage or mis-operation of operators), various faults and abnormal operation conditions will occur in the power system, and the power system will have overload, over-voltage, frequency reduction, system oscillation and other phenomena [2]. Power system fault mainly includes various types of short-circuit and break, such as: single-phase short-circuit, two-phase short-circuit, three-phase short-circuit.

2. Analysis of original data
There is a substation in the suburbs, the substation contains 110kV, 35kV, 10kV three voltage levels, the substation to 110kV down to 35kV and 10kV. When the substation can not work normally when serious fault occurs, it can be operated by neighboring substations instead. The 110kV voltage of the substation is sent to the substation by two single-circuit lines. 35kV is the medium voltage side bus, the outlet has 2 circuits, the output capacity of each circuit is 5MW, and the power factor is 0.85. 10kV is the low voltage side bus, the outlet has 2 circuits, the capacity of each circuit is 4MW, and the power factor is 0.85.

3. Selection of electrical main wiring scheme
For the 110kV line scheme, the inner bridge line is mainly used for long lines without frequent transformer replacement. On the contrary, the outer bridge line is mainly used for short circuit, which requires frequent switching of transformers. The double bus connection method is suitable for supplying power to some advanced loads and has a strong reliability. Due to the large number of
switches, complex interlock mechanism, complex switch and high cost, double bus is not recommended. Although single bus wiring is relatively simple, the use of less equipment, cost is lower, but the flexibility is poor, when a power supply side or bus failure, the whole line can not run. Considering the requirement of flexibility, the single bus sectionalized connection can remove the fault in time when one bus fault occurs, and the non-fault bus can continue to run. From the above, draw the 110 kV substation electrical main wiring diagram, as shown in Figure 1.

Figure 1. System diagram of 110kV substation.

4. Selection of operation mode
When selecting various electrical equipment in transformers and substations, it is necessary to calculate the value of the short-circuit current to check whether the selected electrical equipment parameters can work normally in different operation modes of substations. In order to meet the requirement of relay protection design of substation, the choice of operation mode should be analyzed. There are two extreme options for operating mode, maximum operating mode and minimum operating mode. In the maximum working mode, two or more transformer branches are selected for parallel calculation. The calculated impedance value is the minimum and the obtained short-circuit current value is the maximum. The minimum operation mode selects a branch path, the one with the highest impedance value, and the corresponding power supply capacity is the minimum. In the minimum operation mode, the short-circuit current is the minimum.

In the calculation of relay protection settings, the current speed protection is usually calculated using the short-circuit current in the maximum operating mode, so it will not exceed the end of the line. When the subordinate line fails, it will not enter the line. The two phase-short circuit-current [3] in the minimum operating mode is used to verify the sensitivity of the relay protection.

2
5. Short circuit current calculation
The designed substation is 110 kV, and the voltage is relatively high. In this case, the resistance of the electrical equipment is very small when calculating the reactance. For the convenience of calculation, only the impedance is calculated, and the resistance is not calculated.

We choose the standard unit value method to calculate the short-circuit current. The unit value method has an obvious advantage. The unit value has no unit, and the parameters of all electrical components can be reduced uniformly. Figure 2 shows the calculation process of the power system short circuit.

![Figure 2. Equivalent impedance diagram for short circuit calculation.](image)

5.1. Relevant parameters
The parameters of the known generator are as follows:
Generator G1: $P_N = 25 \text{MW}, \cos \varphi_N = 0.8, X_\varphi = 0.13$
Generator G2: $P_N = 50 \text{MW}, \cos \varphi_N = 0.8, X_\varphi'' = 0.14$
Transformer T1, T2: rated capacity 31.5MWA, capacity ratio 100/100/100, transformation ratio 110/35/10, $U_{K(1-2)} = 10.5, U_{K(1-3)} = 16, U_{K(2-3)} = 6.5$
Line L1, L2: length 70km, $X_r = 0.4 \Omega/km$
Line L3, L5, L4, L6: length 6km, $X_r = 0.4 \Omega/km$

5.2. Calculation of short-circuit current in maximum operating mode
The maximum operating mode [4] in this design is that two transformers operate at the same time. According to the impedance diagram in Figure 2, the three-phase short-circuit current at point d1 of 110kV bus can be calculated:

$$X_{\varphi*} = \frac{0.63 \times 0.43}{0.63 + 0.43} = 0.26$$

(1)

$$I_{d1}^{(3)} = \frac{I}{X_{\varphi*}} = \frac{0.502}{0.26} = 1.93$$

(2)

the three-phase short-circuit current at point d2 of 35kV bus can be calculated:

$$X_{\varphi*} = 0.26 + 0.17 = 0.43$$

(3)

$$I_{d2}^{(3)} = \frac{I}{X_{\varphi*}} = \frac{1.57}{0.43} = 3.65$$

(4)

the three-phase short-circuit current at point d3 of 10kV bus can be calculated:

$$X_{\varphi*} = 0.43 + 0.18 = 0.61$$

(5)

$$I_{d3}^{(3)} = \frac{I}{X_{\varphi*}} = \frac{1.57}{0.61} = 2.57$$

(6)
5.3. Calculation of short-circuit current in minimum operating mode

The minimum operation mode in this design means that there is only one transformer running, and the power supply is G1. The equivalent circuit impedance diagram is the upper part of Figure 2. According to the impedance diagram above, the two-phase short-circuit current when the 110KV bus is short-circuited, that is, the short-circuit at point d1:

\[ X_{\Sigma^*} = 0.63 \]  \hspace{2cm} (7)  

\[ L_{l}^{(2)} = \frac{\sqrt{3}}{2} \frac{I}{X_{\Sigma^*}} = \frac{\sqrt{3}}{2} \frac{0.502}{0.63} = 0.69 \]  \hspace{2cm} (8)  

Similarly, the 35KV bus is short-circuited, that is, the short-circuit at point d2:

\[ X_{\Sigma^*} = 0.63 + 0.34 = 0.97 \]  \hspace{2cm} (9)  

\[ L_{l}^{(2)} = \frac{\sqrt{3}}{2} \frac{I}{X_{\Sigma^*}} = \frac{\sqrt{3}}{2} \frac{1.56}{0.97} = 1.39 \]  \hspace{2cm} (10)  

The 10KV bus is short-circuited, that is, the short-circuit at point d3:

\[ X_{\Sigma^*} = 0.97 + 0.18 = 1.15 \]  \hspace{2cm} (11)  

\[ L_{l}^{(2)} = \frac{\sqrt{3}}{2} \frac{I}{X_{\Sigma^*}} = \frac{\sqrt{3}}{2} \frac{1.56}{1.15} = 1.17 \]  \hspace{2cm} (12)  

6. Backup protection for earthing short circuit

In this design, the high voltage side and medium voltage side of the transformer adopt the way of neutral point direct grounding. For the direct grounding of neutral point, we need to set up special relay protection, which is also the focus of this design.

Zero sequence current will be produced by earth fault. According to this point, the earth protection of zero sequence over current is designed as backup protection. The backup protection of zero sequence over current shall be installed on 110kV and 35kV sides of the transformer respectively, which can serve as the backup protection of adjacent components on each side and the backup protection of the transformer. The principle of zero sequence over current protection and compound voltage protection is basically the same, but the electrical quantity selected is different. One is negative sequence voltage and the other is zero sequence current. Their wiring is almost the same. Zero sequence current protection is also selective. Its relay has two time-limit controls. When the transformer is externally faulty, the short-time relay acts to cut off the circuit breaker on the fault side. When the transformer internally fails, the long-time circuit breaker acts to cut off all the transformer's circuit breakers.

![Figure 3. 110KV transformer protection configuration diagram.](image-url)
There are many protections for transformer, which need to cooperate with each other. We have designed a set of overall schemes of all transformer protections, as shown in Figure 3.

In Figure 3, protections 2 and 3 are longitudinal differential protections, protections 4, 5, and 6 are over current protections initiated by composite voltage, protections 7 and 8 are zero sequence current protections, and protections 9 and 10, 11 is overload protection.

7. Transmission line protection design
In case of short circuit fault of transmission line, the current of each phase between power supply and short circuit point will suddenly increase, and its current value may be more than ten times of rated current or normal working current. According to this characteristic, a component can be used to measure the current and compare it with the given current. When the measured current is greater than the given current, the corresponding control signal is output to control the opening and closing of the circuit breaker, so as to protect the safety of the line. This constitutes an over-current protection which acts when the reactive phase current increases [5]. This given current is called the setting value of the current protection, that is, the action current of the current protection. The over current protection of transmission line is divided into three parts: the first part is the non-time limit current quick break protection, which acts quickly as the main protection of the line; the second part is the time limit current quick break protection, which is also the main protection of the line, with a period of delay; the third part is the fixed time limit over current protection, which acts as the backup protection of the line. The above three protections constitute the three-section protection of the line. These three sections of protection cooperate with each other to jointly protect the line, as shown in Figure 4.

![Figure 4. Three-stage current protection diagram.](image)

8. Conclusions
In the process of relay protection design, it is very important for our design to choose what kind of protection. After the protection type is determined, we can check whether the selected protection is reasonable by short circuit calculation. After setting calculation and verification, determine whether the protection provided is reasonable. In this way, we can configure the protection.

In practical application, the setting value of relay protection can be set, but the protection type can not be changed. Therefore, in the design process, we should consider our protection type, and then
determine whether the protection is reasonable by setting calculation and verification. For example, if the sensitivity of the current quick break protection can not meet the requirements, we need to use the instantaneous current blocking voltage quick break protection.

References

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