Troubleshooting on Short-circuit Current of One 110kV Substation

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Abstract

It is extremely important for fault diagnosis of power systems where the normal production and living conditions are not affected, and the failure is reduced to a minimum degree. A short-circuit fault is a very common fault in power systems, at the same time, it has variety of types. Respectively, the specific type of fault can be distinguished via the size of the current because the different fault types have their own short-circuit currents. Taking one 110kV substation, for example, short-circuit currents are calculated under different fault types, and the short-circuit currents of different types of faults are taken as the basic elements, according to its own characteristics of wiring. The specific type of failure, in this article, can be effectively diagnosed in the event according to the magnitude of the short-circuit current.

Keywords: short-circuit fault, short-circuit currents, fault diagnosis, fault type

1. Introduction

A power system is related to all aspects of the national economy and people's living. Therefore, the safety, the economic efficiency and the reliability of the electric power system operation play significant roles in all these aspects. Common faults in the power system are divided into symmetrical short-circuit and asymmetrical short-circuit [1-5]. Symmetric short-circuit is the three phase short-circuit, while

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Asymmetric short-circuit is divided into single phase grounding short-circuit, two phase short-circuit, and two phase earth fault.

When fault occurs, the overall security of the power system is under a great deal of impac; and you must find out the faults and fault phases to reduce the loss of power systems to the minimum degree [6].The fault point’s voltage and current would have corresponding change when the fault occurs [7-10]. The specific type of fault and the fault point would be determined according to the magnitude of the measured short-circuit current with the characteristic of short-circuit currents. A 110kV substation’s input and output, in this paper, are used to determine the various short-circuit currents. The specific type of fault and the fault phase can be diagnosed finally by using the short-circuit current amplitude.

2. Analysis of Voltage Sag Source of Disturbance

The transformer model is SSPSL1-75000/110kVA, with three phases of forced oil circulating water cooled aluminum wires and three winding transformers. On the 35kV side of the transformer, three back to qualify. The loading capacity is $S_{35} = 70\% \times 30 \times (1+5\%)^8 = 31.02\text{MVA}$. In the 10kV side of the transformer, there are eight back into lines, and the loading capacity is $S_{10} = 41.36\text{MVA}$. On the 110kV side of the transformer, the loading capacity is $S_{110} = 72.39\text{MVA}$. The unitary resistance and reactance value of the transformer are $R_{T1*} = 0.00568$ $R_{T2*} = 0.00462$ $R_{T3*} = 0.00337$ $X_{T1*} = 0.15$ $X_{T2*} = 0.096$ $X_{T3*} = 0.0033$, respectively. The model from the substation to the 220kV side of 110kV 30km line wire is LGJ-185. The electric LGJ-185 dual split wire resistance is 0.315Ω/km when it is 20℃ [11-15].

3. Calculation of the Short-circuit Current

3.1 Unitary Calculation of Line Impedance

The total impedance of the 30km line to the 110kV side of the main transformer is $X_l = 0.315 \times 30 = 9.45\Omega$.

A per unit system [16-20] is adopted to complete the calculation for the convenience of operation. Based on this topic of transformer capacity and voltage grade, it is assumed that $S_B = 100\text{MVA}, U_B = U_{\text{av}}$. For the rated voltage of 220kV lines of 30km, the total per unit value is $X_{l*} = X_l \cdot \left(S_B / U_B{}^2\right) = 0.0179$ [22-24].

3.2 Calculation of Short-circuit Current of the Transformer When Short-circuit Occurs

1. Calculation of the short-circuit current on the 110kV side of the transformer when the short-circuit occurs

When the short-circuit accident happens on the 110kV side of the transformer, the short-circuit diagram is shown in Figure 1. According to the equivalent circuit diagram of Figure 1, we can draw it, as shown in Figure 2 [25-26].

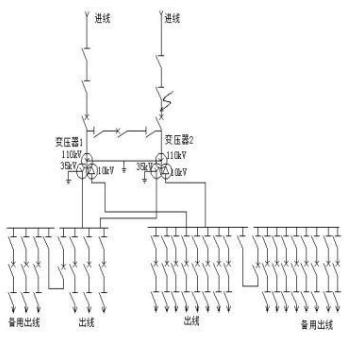

Figure 1: Schematic diagram of 110kV side short-circuit in Substation

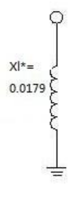

Figure 2: Equivalent circuit of 110kV side short-circuit in Substation

The short-circuit reactance can be calculated at this time according to the equivalent circuit of Figure 2, and the short-circuit reactance $X_{\Sigma 1*} = 0.0179$. Based on the calculation formula of short-circuit current (1), calculate the short-circuit current per unit value $I_{k1*} = 55.86$, on the 110kV side. According to the Formula (2), calculate the actual value of the short-circuit current $I_{k1} = 28.05\text{kA}$. According to the Formula (3), calculate the impulse current $i_{sh} = 71.53\text{kA}$, on the 110kV side. According to the Formula (4), calculate the effective value $I_t = 1015.53\text{kA}$ on the 110kV side. According to the Formula (5), calculate the maximum effective value $I_M = 42.64\text{kA}$, on the 110kV side.

$$I_{k*} = 1 / X_{\Sigma*} \quad (1)$$

$$I = I_{k*} \cdot \left[S_B / \left(\sqrt{3} U_B\right)\right] \quad (2)$$

$$i_{sh} = \sqrt{2} K_M I_{\text{k}} = 2.55 I_k \quad (3)$$

$$I_t = \sqrt{I_k{}^2 + i_{at}{}^2} \quad (4)$$

$$I_M = 1.52 I_k \quad (5)$$

2. Calculation of the short-circuit current on the 35kV side of the transformer when the short-circuit occurs

When the short-circuit accident happens on the 35kV side of the transformer, the short-circuit diagram is shown in Figure 3. According to the equivalent circuit diagram of Figure 1, we can draw it, as shown in figure 4.

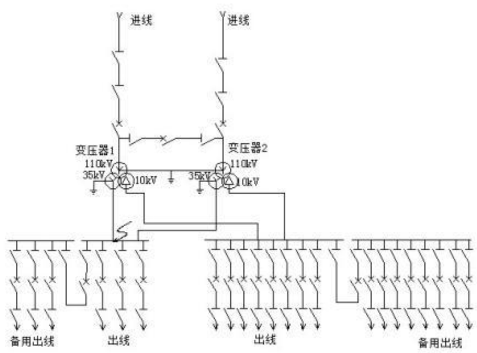

Figure 3: Schematic diagram of 35kV side short-circuit in Substation

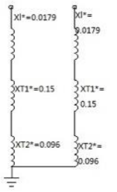

Figure 4: Equivalent circuit of 35kV side short-circuit in Substation

The short-circuit reactance can be calculated at this time, according to the equivalent circuit of Figure 4, and the short-circuit reactance is calculated as follows.

$$X_{\Sigma 2*} = \frac{1}{2}\left(X_{l*} + X_{T1*} + X_{T2*}\right) = 0.13195$$

Based on the Formula (1), calculate the short-circuit current per unit value $I_{k2*} = 7.579$, on the 35kV side. According to the Formulas (2), (3) and (4), calculate the maximum effective value $I_M = 17.976\text{kA}$, on the 110kV side. Because the 35kV side is the outlet side, and there are three outlet lines, the short-circuit current of each outlet line is $I_{35\text{k}} = I_{k2} / 3 = 3.942\text{kA}$.

At the same time, the impulse current of each outlet line is $i_{35sh} = i_{sh} / 3 = 10.052\text{kA}$.

3. Calculation of the short-circuit current on the 10kV side of the transformer when the short-circuit occurs

When the short-circuit accident happens on the 10kV side of the transformer, the short-circuit diagram is shown in Figure 5. According to the equivalent circuit diagram of Figure 1, we can draw it, as shown in Figure 6.

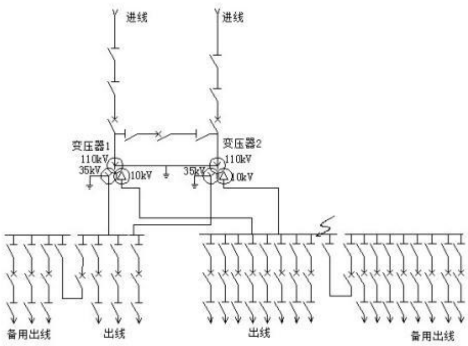

Figure 5: Schematic diagram of 10kV side short-circuit in Substation

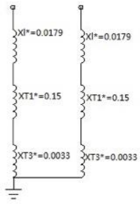

Figure 6: Equivalent circuit of 10kV side short-circuit in Substation

The short-circuit reactance can be calculated at this time according to the equivalent circuit of Figure 6, and the the short-circuit reactance is calculated as follows.

$$X_{\Sigma 3*} = \frac{1}{2}\left(X_{1*} + X_{T1*} + X_{T2*}\right) = 0.0856 .$$

According to the Formulas (1), (2), (3) and (4), calculate the maximum effective value $I_M = 97.636\text{kA}$, on the 10kV side. Because the 10kV side is the outlet side, and there are eight outlet lines, the short-circuit current of each outlet line is $I_{10\text{k}} = I_{k2} / 8 = 8.03\text{kA}$.

At the same time, the impulse current of each outlet line is $i_{35sh} = i_{sh} / 3 = 10.052\text{kA}$.

According to the calculation of the transformer above, the short-circuit value, the impulse current, the effective value and the maximum effective value can be drawn from each side, as shown in Table 1 for accessibility.

Table 1: The value of the short-circuit current of the transformer on each side

	110kV	35kV	10kV
Short-circuit current (per unit value)	55.86	7.579	11.682
Short-circuit current(kA)	28.05	11.826	64.234
The impulse value (kA)	71.53	30.156	163.798
The effective value (kA)	1015.14	180.738	5323.108
The maximum effective value (kA)	1015.53	17.976	97.636

At the same time, the value of the short-circuit current can be obtained under different voltage grades according to the above calculation, and the detailed parameters are shown in Table 2.

Table 2: Short-circuit current of each voltage grade line

	Line of 110kV	Line of 35kV	Line of 10kV
The value of the short-circuit current(kA)	28.05	3.94	8.03
The impulse value of the current(kA)	71.53	10.05	20.47

3.3 Asymmetrical Short-Circuit Current Calculation

3.3.1 Calculation of the Short-Circuit Current with Single Phase Grounded Short-Circuit

Calculation of short-circuit current in single phase to ground fault should be aware of the principle and boundary condition of single phase to ground fault. As shown in Figure7, the single phase grounding fault is supposed to take place at a phase.

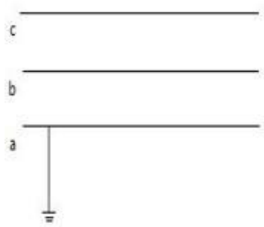

Figure 7: Schematic diagram of single phase grounding short-circuit

At this point, according to the boundary conditions of a phase when the single phase grounding

$$\begin{cases} \dot{U}_{f(1)} + \dot{U}_{f(2)} + \dot{U}_{f(0)} = 0 \\ \dot{I}_{f(1)} = \dot{I}_{f(2)} = \dot{I}_{f(0)} \end{cases} \quad (5)$$

And according to the general three sequence voltage balance equation [27-28]:

$$\begin{cases} \dot{U}_{f|0|} - \dot{U}_{f(1)} = \dot{I}_{f(1)} Z_{\Sigma(1)} \\ \dot{U}_{f(2)} = \dot{I}_{f(2)} Z_{\Sigma(2)} \\ 0 - \dot{U}_{f(0)} = \dot{I}_{f(0)} Z_{\Sigma(0)} \end{cases} \quad (6)$$

The three-sequence current can be obtained at the point of failure:

$$\dot{I}_{f(1)} = \dot{I}_{f(2)} = \dot{I}_{f(0)} = \frac{U_{f|0|}}{Z_{\Sigma(1)} + Z_{\Sigma(2)} + Z_{\Sigma(0)}} \quad (7)$$

$$\dot{I}_{f} = \dot{I}_{f(1)} + \dot{I}_{f(2)} + \dot{I}_{f(0)} = \frac{3U_{f|0|}}{Z_{\Sigma(1)} + Z_{\Sigma(2)} + Z_{\Sigma(0)}} \quad (8)$$

For asymmetric short-circuit, it is necessary to analyze the short-circuit current of its positive sequence, negative sequence and zero sequence equivalent circuit. Then $Z_{\Sigma(1)}$, $Z_{\Sigma(2)}$ and $Z_{\Sigma(0)}$ can be calculated, respectively, according to the sequence of the equivalent circuit. The short-circuit current can be calculated according to Formulas (7) and (8).

1) Short-circuit current calculation of single phase to grounding fault in 110kV side

When a single phase to ground fault occurs on the 110kV side, the diagram of the positive sequence and negative sequence's equivalent circuit is consistent, as shown in Figure 8.

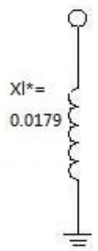

Figure 8: Positive and negative sequence equivalent circuit of transformer substation 110kV single phase grounding short-circuit

In asymmetric short-circuit, the value of the general line of zero sequence impedance is three times as much as that of the positive sequence impedance. Therefore, the zero sequence equivalent circuit can be measured, as shown in Figure 9, in the substation on the 110kV side.

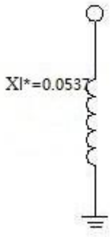

Figure 9: Zero sequence equivalent circuit of 110kV side single phase grounding short-circuit in substation

Each sequence impedance can be calculated when the single phase grounding short-circuit in the substation on the 110kV side

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.0179$; $X_{\Sigma(0)*} = 0.0537$.

According to the Formula (8), per unit value of the fault phase short-circuit current of the single phase grounding short-circuit can be calculated as $I_{f*} = 33.52$.

According to the Formula (2), the famous value of fault phase short-circuit current in single phase grounding short-circuit is calculated as $I_f = 16.83\text{kA}$.

2) Short-circuit current calculation of single phase to ground fault in 35kV side

Each sequence impedance can be calculated when the single phase grounding short-circuit in the substation on the 35kV side

$X_{\Sigma(1)*} = 0.13195$ $X_{\Sigma(0)*} = 0.15$

According to the Formula (8), per unit value of the fault phase short-circuit current of the single phase grounding short-circuit can be calculated as $I_{f*} = 7.25$

According to the Formula (2), the famous value of fault phase short-circuit current in single-phase grounding short-circuit is calculated as $I_f = 11.31\text{kA}$.

Therefore, the short-circuit current of each outlet line is $I_{35f} = I_f / 3 = 11.31/3 = 3.77\text{kA}$.

3) Short-circuit current calculation of single phase to ground fault in 10kV side

Each sequence impedance can be calculated when the single phase grounding short-circuit in the substation on the 10kV side

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.0856$ $X_{\Sigma(0)*} = 0.10$

According to the Formula (8), per unit value of the fault phase short-circuit current of the single phase grounding short-circuit can be calculated as $I_{f*} = 11.06$

According to the Formula (2), the famous value of fault phase short-circuit current in single-phase grounding short-circuit is calculated as $I_f = 60.82\text{kA}$. Therefore, the short-circuit current of each outlet line is $I_{10f} = I_f / 8 = 60.82/8 = 7.60\text{kA}$.

3.3.2 Calculation of Short-Circuit Current of Two Phase Short-Circuit

B and C phases are assumed to be the short-circuit faults, as shown in Figure 10.

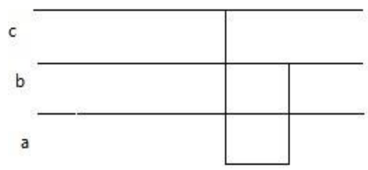

Figure 10: Schematic diagram of two phase short-circuit

Boundary conditions of B and C phases short-circuit are obtained:

$$\begin{cases} \dot{I}_{fa} = 0 \\ \dot{I}_{fb} = \dot{I}_{fc} \\ \dot{U}_{fb} = \dot{U}_{fc} \end{cases} \tag{9}$$

Three boundary conditions for two phase short-circuit are:

$$\begin{cases} \dot{I}_{f(0)} = 0 \\ \dot{I}_{f(1)} = -\dot{I}_{f(2)} \\ \dot{U}_{f(1)} = \dot{U}_{f(2)} \end{cases} \tag{10}$$

According to the Formula (6), the sequence current in the non fault is

$$I_{f(1)} = I_{f(2)} = \frac{U_{f|0|}}{Z_{\Sigma(1)} + Z_{\Sigma(2)}} \tag{11}$$

Short-circuit current of fault phase is:

$$\begin{cases} \dot{I}_{fb} = a^2 \dot{I}_{f(1)} + a \dot{I}_{f(2)} = -j\sqrt{3}\dfrac{U_{f|0|}}{Z_{\Sigma(1)} + Z_{\Sigma(2)}} \\ \dot{I}_{fc} = a \dot{I}_{f(1)} + a^2 \dot{I}_{f(2)} = j\sqrt{3}\dfrac{U_{f|0|}}{Z_{\Sigma(1)} + Z_{\Sigma(2)}} \\ I_{fb} = I_{fc} = \sqrt{3}\dfrac{U_{f|0|}}{Z_{\Sigma(1)} + Z_{\Sigma(2)}} \end{cases} \quad (12)$$

1) Short-circuit current calculation of 110kV side two phase short-circuit

When a two phase short-circuit fault occurs on the 110kV side, the positive sequence and negative sequence equivalent circuit diagram are the same. Each sequence impedance can be calculated when the two phase short-circuit in the substation on the 110kV side

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.0179$; $X_{\Sigma(0)*} = 0.0537$.

According to the Formula (12), per unit value of the fault phase short-circuit current of the two phase short-circuit can be calculated as

$I_{fb*} = I_{fc*} = 43.38$.

According to the Formula (2), short-circuit current of fault phase in two phase short-circuit is

$I_{fb} = 24.29\text{kA}$.

2) Short-circuit current calculation of 35kV side two phase short-circuit

Each sequence impedance can be calculated when the two phase short-circuit in the substation on the 35kV side

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.13195$; $X_{\Sigma(0)*} = 0.15$.

According to the Formula (12), per unit value of the fault phase short-circuit current of the two phase short-circuit can be calculated as $I_{fb*} = I_{fc*} = 6.566$.

According to the Formula (2), short-circuit current of fault phase in two phase short-circuit is

$I_{fb} = I_{fc} = 10.25\text{kA}$.

The short-circuit current of each outlet line is $I_{35\text{fb}} = I_{35\text{fc}} = I_{fb}/3 = I_{fc}/3 = 3.42\text{kA}$.

3) Short-circuit current calculation of 10kV side two phase short-circuit

Each sequence impedance can be calculated when the two phase short-circuit in the substation on the 10kV side

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.0856$; $X_{\Sigma(0)*} = 0.10$.

According to the Formula (12), per unit value of the fault phase short-circuit current of the two phase short-circuit can be calculated as

$I_{fb*} = I_{fc*} = 10.117$.

According to the Formula (2), short-circuit current of fault phase in two phase short-circuit is

$I_{fb} = I_{fc} = 55.63\text{kA}$.

The short-circuit current of each outlet line is $I_{10\text{fb}} = I_{10\text{fc}} = I_{fb}/8 = I_{fc}/8 = 6.95\text{kA}$.

3.3.3 Short-Circuit Current Calculation of Two Phase Earth Fault

B and C phases are assumed to be the two phase earth faults, as shown in Figure 11.

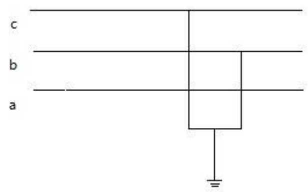

Figure 11: Schematic diagram of two phase earth fault

The B and C phase short-circuit grounding of the boundary conditions is

$$\begin{cases} \dot{I}_{fa} = 0 \\ \dot{U}_{fb} = \dot{U}_{fc} \end{cases} \quad (13)$$

Order boundary conditions for non fault phase

$$\begin{cases} \dot{U}_{f(1)} = \dot{U}_{f(2)} = \dot{U}_{f(0)} \\ \dot{I}_{f(1)} + \dot{I}_{f(2)} + \dot{I}_{f(0)} = 0 \end{cases} \quad (14)$$

According to the Formula (6), the non fault phase current of two phase earth fault is obtained as follows

$$\begin{cases} I_{f(1)*} = \dfrac{U_{f|0|*}}{Z_{\Sigma(1)*} + \dfrac{Z_{\Sigma(2)*} Z_{\Sigma(0)*}}{Z_{\Sigma(2)*} + Z_{\Sigma(0)*}}} \\ I_{f(2)*} = I_{f(1)*} \cdot \dfrac{Z_{\Sigma(0)*}}{Z_{\Sigma(2)*} + Z_{\Sigma(0)*}} \\ I_{f(0)*} = I_{f(1)*} \bullet \dfrac{Z_{\Sigma(2)*}}{Z_{\Sigma(2)*} + Z_{\Sigma(0)*}} \\ I_{fb*} = I_{fc*} = \sqrt{3}\sqrt{1 - \dfrac{Z_{\Sigma(2)*} Z_{\Sigma(0)*}}{Z_{\Sigma(2)*} + Z_{\Sigma(0)*}}} I_{f(1)*} \end{cases} \quad (15)$$

1) The calculation of short-circuit current two phase earth fault in the 110kV side

Each sequence impedance can be calculated when the two phase earth fault in the substation on the 110kV side is

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.0179$; $X_{\Sigma(0)*} = 0.0537$.

According to the Formula (15), per unit value of the fault phase short-circuit current of the two phase earth fault can be calculated as $I_{f(1)*} = 31.92$.

The per unit value of short-circuit current at fault is $I_{fb*} = I_{fc*} = 54.91$.

Short-circuit current of fault phase in two phase earth fault is $I_{fb} = I_{fc} = 27.57\text{kA}$.

2) The calculation of short-circuit current two phase earth fault in the 35kV side

Each sequence impedance can be calculated when the two phase earth fault in the substation on the 35kV side is $X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.13195$ $X_{\Sigma(0)*} = 0.15$.

According to the Formula (15), per unit value of the fault phase short-circuit current of the two phase earth fault can be calculated as $I_{f(1)*} = 4.95$.

Per-unit value of short-circuit current at fault is $I_{fb*} = I_{fc*} = 8.27$.

Short-circuit current of fault phase in two phase earth fault is $I_{fb} = I_{fc} = 12.90\text{kA}$.

The short-circuit current of each return outlet is $I_{35\text{fb}} = I_{35\text{fc}} = I_{fb}/3 = I_{fc}/3 = 4.30\text{kA}$.

3) The calculation of short-circuit current two phase earth fault in the 10kV side

Each sequence impedance can be calculated when the two phase earth fault in the substation on the 10kV side is

$X_{\Sigma(1)*} = X_{\Sigma(2)*} = 0.0856$; $X_{\Sigma(0)*} = 0.10$.

According to the Formula (15), per unit value of the fault phase short-circuit current of the two phase earth fault can be calculated as $I_{f(1)*} = 7.59$.

Per-unit value of short-circuit current at fault is $I_{fb*} = I_{fc*} = 12.84$.

Short-circuit current of fault phase in two phase earth fault is $I_{fb} = I_{fc} = 70.60\text{kA}$.

The short-circuit current of each outlet line is $I_{10\text{fb}} = I_{10\text{fc}} = I_{fb}/8 = I_{fc}/8 = 8.83\text{kA}$.

Based on the calculation of the above three kinds of asymmetric short-circuit currents, it can conclude the short-circuit current. The short-circuit current of the asymmetric short-circuit is shown in Table 3,

Table 3: Asymmetric short-circuit current

			110 kV	35kV	10kV
Single line to ground fault（kA）	Fault phase	a	16.83	11.31	60.82
	Non-fault-phase	b	0	0	0
		c	0	0	0
Line to line fault（kA）	Non-fault-phase	a	0	0	0
	Fault phase	b	24.29	10.25	55.63
		c	24.29	10.25	55.63
Phase-grounded fault（kA）	Non-fault-phase	a	0	0	0
	Fault phase	b	27.57	12.9	70.60
		c	27.57	12.9	70.60

At the same time, it can have a variety of asymmetric short-circuit current calculation, which can be obtained at each voltage level, and the short-circuit current is on each line; the detailed parameters are shown in Table 4.

Table 4: Asymmetric short-circuit current on each line under different voltage levels

			110kV	**35kV**	**10kV**
Single line to ground fault（kA）	Fault phase	a	28.05	3.77	7.6
	Non-fault-phase	b	0	0	0
		c	0	0	0
Line to line fault（kA）	Non-fault-phase	a	0	0	0
	Fault phase	b	24.29	3.42	6.95
		c	24.29	3.42	6.95
Phase-Grounded Fault（kA）	Non-fault-phase	a	0	0	0
	Fault phase	b	27.57	4.3	8.83
		c	27.57	4.3	8.83

According to Tables 1, 2, 3, and 4 conclusions, the fault phase short-circuit current and the fault phase short-circuit current are stored as basic elements. When a short-circuit fault occurs in the substation, the short-circuit current is used as the basic factor to determine the fault type and fault phase. It is both reliable and practical, and has made great contribution to the fault investigation.

4. Conclusions

Power system short-circuit fault type is the majority, but fault short-circuit current of each type of fault and the fault of short-circuit current amplitude are not the same. Therefore, it can take advantage of the short-circuit current as the basic standard of judge fault type. In this paper, the using of one 110kV substation is according to the specific circumstances of each side; the magnitude of the fault current is calculated, and the short-circuit current is a judge fault type of basic elements, making a reliable guarantee for the timely development of short-circuit fault type and fault phase.

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