Modelling on Bus-Transfer Current and Enclosure Current of GIS

Feng Xue[1,] *, Yida Sheng[2], Haitao Li[1], Chaoming Wang[2], Siwei Wan[1], Chunsheng Ma[2]

[1]*Dongguan Power Supply Bureau*, *Guangdong Power Grid Corporation*, *Dongguan 523000*, *China*
[2]*Nanjing Softcore Company*, *Nanjing 210019*, *China*

Abstract. As the continuous development of social economy, a large number of gas insulated switchgear (GIS) has been put into use for its advantages. In order to prevent disconnector faults during the process of substation switching operation, it's important to measure the bus-transfer current to monitor the running status of disconnectors. By analyzing the structure of GIS, this paper proposes a method to figure out the relationship between the enclosure current and the bulk current of GIS. The work of theoretical study in this paper is helpful in measuring the bus-transfer current to discover the potential risks of substation switching operation in advance. It not only greatly improves the operation and motion reliability of gas insulated switchgear devices, but also brings high power supply reliability and huge economic benefit to our society.

1 Introduction

As the continuous development of social economy, the demand of power distribution reliability is growing. At the same time, the continuously pushing process of industrialization and urbanization causes many problems such as land tension. As a result, the cost of installing power transmission and distribution devices around cities is rapidly increasing. In this context, people are expecting a new high-voltage electrical apparatus with advantages of small land occupancy, compact structure, no pollution, easy maintenance and high reliability. The successful inception of gas insulated switchgear (GIS) is a dream come true. In recent years, more and more GIS devices have been put into practical operation. However, kinds of faults follow. In the southern part of China, there was an accident due to disconnector faults during the process of substation switching operation. To mitigate potential losses, it's important to measure the bus-transfer current to monitor the running status of disconnectors. This paper analyses the bus-transfer current and the enclosure current of GIS for further research.

2 Modelling on bus-transfer current

The duplicate-busbar loop wiring diagram is shown in Figure 1. The disconnector DS21 is in the open state, while the disconnector DS11, DS12, DS22 and the bus connection switch S are in the closed state. The load current i is divided into two parts at node a, the current component i_1 flows through DS11 and the other current component i_2 flows through DS12. The connected node between DS11 and the bus I is marked as node e. The connected node between DS12 and the bus II is marked as node b. The connected node between S and the bus I is marked as node d. The connected node between S and the bus II is marked as node c. The connected node between DS22 and the bus II is marked as node f. As a result, the current component i_1 flows through the branch a→e→d→c→f while the other component i_2 flows through the branch a→b→f. Due to the open state of DS21, all of the load current has to flow through the DS22.If the disconnector DS11 is disconnected to cut off the current i_1 at this moment, all of the load current has to flow through the branch i_2 .The current i_1 is called the bus-transfer current [1-4].

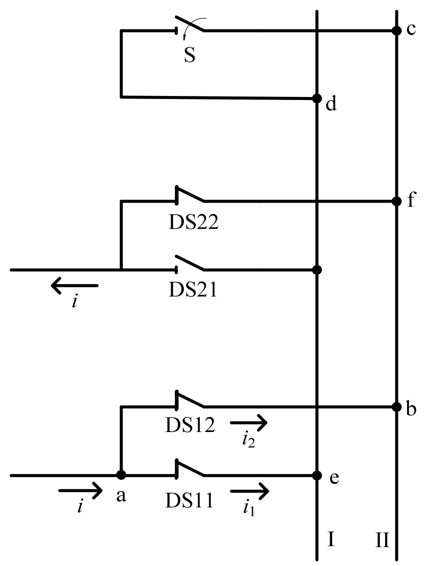

Figure 1. Double bus loop wiring diagram

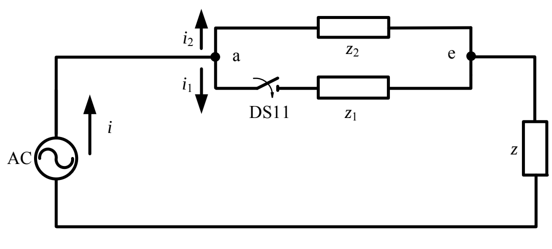

Figure 2. The equivalent circuit diagram

According to the principle above and the equivalent circuit diagram shown as Figure 2, formulas are derived as below:

$$\begin{cases} u = u_1 = u_2 \\ i = i_1 + i_2 \\ u_1 = i_1 \cdot z_1 \\ u_2 = i_2 \cdot z_2 \end{cases} \quad (1)$$

Where

i_1 is the current through the disconnector of DS11 (A);

i_2 is the current through the disconnector of DS12 (A);

u_1 is the voltage drop on the branch a→e (V);

u_2 is the voltage drop on the branch a→b→c→d→e (V);

z_1 is the line impedance of the branch a→e (Ω);

z_2 is the line impedance of the branch a→b→c→d→e (Ω);

z is the equivalent resistance.

According to the formula (1), it can be solved as below:

$$\frac{i_1}{i} = \frac{i_1}{i_1 + i_2} = \frac{\frac{u}{z_1}}{\frac{u}{z_1} + \frac{u}{z_2}} = \frac{z_2}{z_2 + z_1} = \frac{l_2}{l_2 + l_1} \quad (2)$$

When $l_2 >> l_1$,

$$\frac{i_1}{i} = \frac{l_2}{l_2 + l_1} \approx 1$$

and so the limiting value of i_1 turns out to be the whole load current i.

Under the circumstance of the disconnector DS11 being normally contacted, the proportion of bus-transfer current i_1 in the whole load current i is only associated with the line length (l_1, l_2) of two branches. The longer the branch a→b→c→d→e is, the higher proportion of bus-transfer current i_1 will be taken in the whole load current i. On condition that l_2 is much bigger than l_1, the limiting value of i_1 turns out to be the whole load current i.

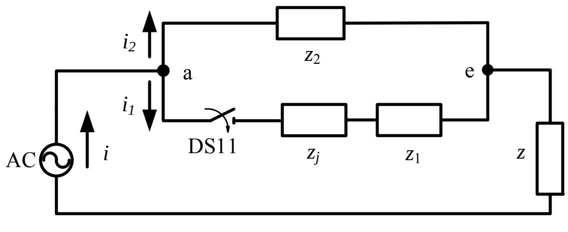

Figure 3. The equivalent circuit diagram

If the disconnector DS11 is contacted in bad condition, there will be a large contact resistance in the circuit. The line impedance of the branch a→e will greatly change due to the contact resistance, therefore, the bus-transfer current is also going to change.

According to the principle above and the equivalent circuit diagram shown as Figure 3, formulas are derived as below:

$$\begin{cases} u = u_1 = u_2 \\ i = i_1 + i_2 \\ u_1 = i_1 * (z_1 + z_j) \\ u_2 = i_2 \cdot z_2 \end{cases} \quad (3)$$

Where

z_j is the contact resistance due to the disconnector DS11's being contacted in bad condition(Ω).

According to the formula (3), it can be solved as below:

$$\frac{i_1}{i} = \frac{i_1}{i_1 + i_2} = \frac{\frac{u}{z_1 + z_j}}{\frac{u}{z_1 + z_j} + \frac{u}{z_2}} = \frac{z_2}{z_2 + z_1 + z_j} < \frac{z_2}{z_2 + z_1} \quad (4)$$

Generally, the line impedance is much smaller than the contact resistance.

When $z_j >> z_1$ and $z_j >> z_2$,

$$\frac{i_1}{i} = \frac{z_2}{z_2 + z_1 + z_j} \approx 0 \quad (5)$$

$$\frac{i_2}{i} = \frac{z_1 + z_j}{z_2 + z_1 + z_j} \approx 1 \quad (6)$$

It turns out that the disconnector's being contacted in bad condition will result in unreasonable current distribution between the two branches, which weakens the current flow ability. It may even cause power system faults in a larger range.

As it shows in Figure 4, a new variable z_3 is introduced to simplify the equivalent circuit diagram. If the disconnector is closed under normal circumstances, z_3 should be set as 0. If the disconnector is contacted in bad condition, z_3 should be set as z_j. If the disconnector is closed unsuccessfully, z_3 should be set as $+\infty$.

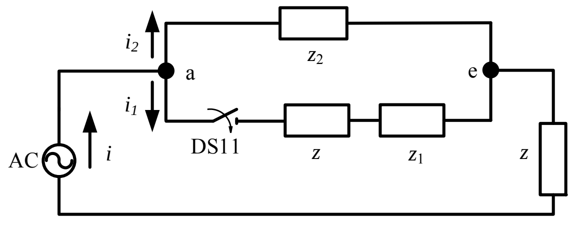

Figure 4. The simplified equivalent circuit diagram

Case 1: The load current i=400A, the line length of branch a→e l_1=3m, the line length of branch a→b→c→d→e l_2=10m, line impedance per unit length z_0=140μΩ. The contact resistance z_j=2mΩ [5].

According to the formulas above, the proportion of bus-transfer current i_1 in the whole load current i can be calculated as below:

When the disconnector is closed under normal circumstances,

$$\frac{i_1}{i} = 76.9\% \ .$$

When the disconnector is contacted in bad condition,

$$\frac{i_1}{i} = 36.6\% \ .$$

Case 2: Setting the line length of branch a→b→c→d→e l_2 as 30m, with other things equal, the proportion can be calculated as below:

When the disconnector is closed under normal circumstances:

$$\frac{i_1}{i} = 90.9\% \ .$$

When the disconnector is contacted in bad condition:

$$\frac{i_1}{i} = 63.4\% \ .$$

Comparing the two conditions above, it turns out that the proportion of bus-transfer current in the whole load current is associated with the contact condition of the disconnector. While the disconnector is contacted in bad condition, there will be a notable decrease in the proportion of branch current in the whole load current.

Comparing Case 1 with Case 2, it turns out that the proportion of bus-transfer current in the whole load current is also associated with the length of branch line. While the length of branch line where the disconnector locates is given, the longer the other branch is, the higher proportion of bus-transfer current will be taken in the whole load current.

3 Modelling on enclosure current of GIS

As the space between the enclosure and inner conductor of GIS is small, there is a strong electromagnetic coupling between them. The enclosure and inner conductor of GIS can be considered as a coreless transformer. As show in Figure 5, the inner conductor is the primary side and the enclosure is the secondary side.

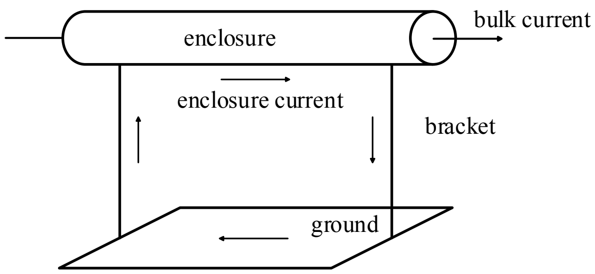

Figure 5. The enclosure current of GIS

When GIS is in normal operation, three-phase current is ideally considered to be balanced, which means the vector sum of induction current is 0.Therefore, the bulk current is hardly interfered by external environment. However, in practical application, even the GIS has the structure that three phases are in one tank, the enclosure can't completely shield the electromagnetic effects. As a result, there is unbalanced induced current in the enclosure of GIS. When the power system has an open-phase fault, this phenomenon of unbalanced induced current gets more obvious.

Nowadays, the structure that three phases are in one tank are widely applied in GIS of 550kV voltage level. When GIS is in operation, there will be circulating current in the loop consisted of the enclosure, the bracket and the ground.

As mentioned above, the inner conductor of GIS can be considered as the primary circuit with only one turn while the loop consisted of the enclosure, the bracket and the ground can be regarded as the secondary circuit with one turn. In that way, the primary circuit is the current in the inner conductor, also called as the bulk current. And the secondary circuit is the current flowing through the loop consisted of the enclosure, the bracket and the ground, also called as the enclosure current [6].

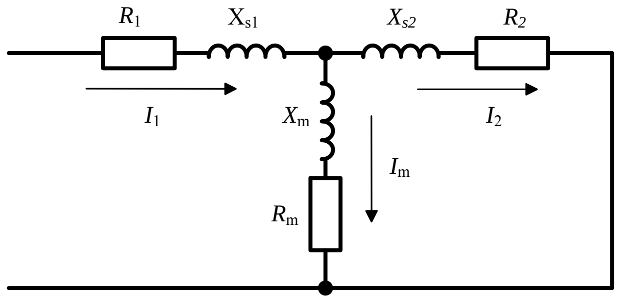

Figure 6. The equivalent circuit diagram of electromagnetic current transformer

Figure 6 shows the equivalent circuit diagram of electromagnetic current transformer.

Where

R_1 and X_{s1} are the leakage impedance of the primary side;

R_2 and X_{s2} are the leakage impedance of the secondary side;

R_m and X_m are the excitation impedance;

I_1 is primary current;

I_2 is secondary current;

I_m is the excitation current.

When it comes to the current transformer mentioned above, as its primary side and secondary side both have only 1 turn, its excitation inductance is the mutual inductance of the inner conductor and the external loop. So there only exists an excitation reactance without an excitation resistance for the transformer is coreless. Because the primary side has only 1 turn and there is no iron cores in the magnetic circuit of main magnetic flux, the magnetic flux coupling between the primary side and the secondary side is quite bad. The excitation impedance is approximate the leakage impedance so that the deviation is a large negative value. To conclude, the enclosure current is less than the bulk current although they are at the same order of magnitude.

The inductance, the mutual inductance and the leakage inductance are defined as below:

$$L_2 = \psi_2 / I_2 \tag{7}$$

$$M_{12} = \psi_2 / I_1 \tag{8}$$

$$L_{2s} = L_2 - M_{12} \tag{9}$$

Where

ψ_2 is the flux of secondary side;

L_2 is the inductance of secondary coil;

M_{12} is the mutual inductance of primary coil and secondary coil;

L_{2s} is the leakage inductance of secondary coil.

Formulas are derived as below:

$$B = \frac{\mu_0 I}{2\pi x} \quad (10)$$

$$d\psi_2 = BdS = \frac{\mu_0 I_1 l}{2\pi x} dx \quad (11)$$

$$\psi_2 = \int_r^{H-r} d\psi_2 = \frac{\mu_0 I_1 l}{2\pi} \ln \frac{H-r}{r} \quad (12)$$

$$M_{12} = \frac{\psi}{I_1} = \frac{\mu_0 l}{2\pi} \ln \frac{H-r}{r} \quad (13)$$

$$L_2 = \psi_2 / I_2 \quad (14)$$

$$d\psi_2 = \frac{\mu_0 I_2 l}{2\pi x} dx + \frac{\mu_0 I_2 l}{2\pi (H-x)} dx \quad (15)$$

$$\begin{aligned} \psi_2 &= \int d\psi_2 \\ &= \int_r^{H-r} \frac{\mu_0 I_2 l}{2\pi x} dx + \int_r^{H-r} \frac{\mu_0 I_2 l}{2\pi (H-x)} dx \quad (16) \\ &= \frac{\mu_0 I_2 l}{\pi} \ln \frac{H-r}{r} \end{aligned}$$

$$L_2 = \frac{\psi_2}{I_2} = \frac{\mu_0 l}{\pi} \ln \frac{H-r}{r} \quad (17)$$

Where

r is the radius of the enclosure;

h is the enclosure's height from the ground;

$H=h+2r$.

By taking formula (13), (17) into formula (18), (19), it's easy to find out the connection between X_{s2} and X_m as formula (20), (21).

$$X_m = \omega M_{12} \quad (18)$$

$$X_2 = \omega L_2 \quad (19)$$

$$X_2 = 2X_m \quad (20)$$

$$X_{2s} = X_2 - X_m = X_m \quad (21)$$

As the resistances are small enough to be ignored, from Figure 6 it can be found out that I_2 is just half of I_1.

$$I_2 = I_1 / 2 \quad (22)$$

Formula (22) gives the relationship between the enclosure current and the bulk current, which is a key point of monitoring the running status of disconnectors.

4 Conclusion

The paper proposes a modeling of bus-transfer current so that the running status of disconnectors can be easily monitored. During the process of measuring the disconnector's bulk current, the influence of the enclosure current should be excluded. For this purpose, the paper also analyses the relationship between the bulk current and the enclosure current of GIS.

The work of theoretical study in this paper is beneficial in monitoring the running status of disconnectors during the process of substation switching operation. It can discover the potential risks of substation switching operation and greatly improves the operation and motion reliability of gas insulated switchgear devices.

Acknowledgements

This work was supported by the Science and Technology Project: Research on the status monitoring and faults diagnosis for GIS switchgear based on multi-source parameters (GDKJ00000033).

References

[1] G. Li. *Analysis of Bus-transfer Current Switching by Disconnectors in GIS*. High Voltage Apparatus, 1, 57-59 (2002)

[2] C. Li. *Common faults and its solution during the process of the disconnector's switching operation*. Guangdong Science & Technology, 16, 247(2009)

[3] W. Liu. *Analysis on Causes of the Disconnector's Closing not in Place in the Substation Switching Operation*. Management and Technology of Small-medium Companies, 1, 318-319(2013)

[4] L. Wang. *Analysis on the Disconnector's Closing not in Place of Bus Side in the Bus-transfer Operation*. China Science and Technology Information, 21, 130-131(2013)

[5] Y. Zhang, X. Zheng. *Analysis of the Influence on Power System Operation due to Contact Resistance of Disconnectors*. Electric Engineering, 3, 34-35 (2013)

[6] G. Xu, Y. Guan. *Simplified Analysis and Calculation on Circulating Current and Power Loss in Enclosure of GIS and GIL*. High Voltage Engineering, 2, 247-249 (2009)