Research on impact characteristics of a new graphite composite earthing device

Jianli Zhao 1, Yuanjie Li2*, Wang Le1 and Zhuohong Pan3

1 Inner Mongolia Power Research Institute, Hohhot, China
2 Department of Electrical Engineering, Wuhan University, Wuhan, China
3 School of Electrical Engineering, North China Electric Power University, Baoding, China

*Corresponding author. Email: 2098461259@qq.com

Abstract. For the new type of graphite composite earthing material, there is a lack of generally accepted rules and standards. In this paper, the impact properties of a new type of graphite composite earthing material are studied. The test results show that the new type of composite grounding device always has spark discharge effect. With the increase of impulse current amplitude, the value of impulse coefficient decreases, and the rate of decrease decreases. Increasing the amplitude of the shock current may only increase the electric field strength in the region, but not increase the spark discharge range in the soil, so the shock coefficient tends to be flat. The test results can provide guidance for the selection and application of new grounding materials.

Keywords. graphite, earthing device, spark effect, impact characteristic, impact coefficient.

1. Introduction

In the power system, in order to ensure the safe and stable operation of the system, and ensure personal safety, it is generally necessary to connect some parts of electrical equipment with the earth[1-3]. Through grounding, the ground potential gradient of power system can be limited[4-5]. No matter whether the system works normally or not, it can keep the current and voltage of the power system within a certain range to ensure the safety of personal equipment[6-7].

At present, the main materials of grounding devices in China are copper and steel, both of which have their own advantages and disadvantages[8-10]. Copper has strong conductivity and corrosion resistance, but its price is several to dozens of times that of steel. The economy of steel is better than that of copper, but the increase of grounding resistance caused by the corrosion of grounding materials should be considered[11-12]. In China, there have been many accidents caused by the corrosion of grounding grid and the failure of grounding resistance to meet the requirements, resulting in great economic losses[13]. The new type of flexible graphite grounding material has developed rapidly at the beginning of this century because it combines the advantages of copper and steel[14]. It is a new type of non-metallic conductive material. After high temperature expansion processing, it is braided. The material has stable properties, low resistivity, high and low temperature resistance, acid and alkali corrosion resistance, large impact current resistance, and the material properties do not change[15-17].
However, for the new grounding materials, China has not issued relevant national standards, and there are still disputes about the performance of the new grounding materials. It is necessary to carry out research and test on the new grounding materials, so as to provide guidance for the selection and use of the new grounding materials, and make the actual construction of the grounding system engineering of the power station more operable and normative. In view of this, this paper analyzes the grounding performance of graphite material under lightning current, and studies the change of impulse coefficient of graphite composite grounding grid under lightning current.

2. Experimental Techniques

2.1. Experimental principle

The impulse characteristics of grounding devices are generally measured by impulse grounding resistance \( R_i \) and impulse coefficient \( \alpha \). The state process of grounding device at each time can be expressed by five parameters, namely current \( i \)(A), soil resistivity \( \rho(\Omega \cdot m) \), characteristic size \( S(m) \) and soil critical breakdown field strength \( E_c(V \cdot m^{-1}) \). According to the similarity theory, if the two systems are similar, the criteria are equal and satisfy formula 2. From formula 1 and formula 2, it can be deduced that the proportion of impulse current in model test and true test meets formula 3. The similarity criterion can be obtained by multiplying Formula 1 and formula 3, as shown in formula 4. Formula 3 and formula 4 are the proportional relationship between the instantaneous value of current and voltage applied to the grounding device in the physical test and model test. Because the peak point of the waveform is the corresponding point of the time-varying function of the current and voltage, the peak value of the impulse current \( I_m \) and the peak value of the impulse voltage \( U_m \) in the physical and model tests must meet the formula 5 and 6. According to the definition of impulse grounding resistance, the proportional relationship of impulse grounding resistance \( R_i \) can meet formula 7. According to the definition of impulse coefficient \( \alpha \), the impulse coefficient of physical test and model test can meet formula 8.

Inductance effect is an important characteristic of impulse current flowing through grounding device, and the inductive reactance \( Z_L \) of grounding body meets formula 9. Where \( f \) is the equivalent frequency of the impulse current; \( L_0 \) is the inductance per unit length of the grounding body, because the length and diameter of the grounding body are reduced in proportion, the inductance per unit length remains unchanged; \( l \) is the length of the grounding body, the length of the grounding body is reduced by \( n \) times; in order to keep the inductive reactance between the true test and the simulated grounding body equal, the amplitude of the impulse current should be increased by \( n^2 \) times, that is, the impulse current The current time is shortened by \( N \) times. The amplitude and waveform of impulse current directly determine the impulse characteristics of grounding device. Compared with the actual impulse current, the wave head time of impulse current in model test should be reduced by \( n \) times, and the amplitude of impulse current should be reduced by \( n^2 \) times. The wave head time of the impulse current in the model test should also be \( 1/n \) of the actual test. In the simulation test, as long as the applied impulse current peak value \( I_m \) makes the electric field strength produced by the current density \( J \) scattered on the conductor surface of the grounding device in the soil exceed the critical breakdown electric field strength \( E_c \) of the soil breakdown, the simulation of the impulse characteristics, especially the spark effect in the soil, can be basically guaranteed.

\[
\prod_0 = \frac{\rho i}{S^2 E_c} \quad (1)
\]

\[
\prod_1 = \prod_2 \quad (2)
\]

\[
i_f = n^2 i_2 \quad (3)
\]

\[
\sqrt{i_0} = \sqrt{i_f} / (S E_c) = u / (S E_c) \quad (4)
\]

\[
I_m = n^2 I_m \quad (5)
\]
\[ U_{m1} = nU_{m2} \quad (6) \]
\[ R_i = R_{i2}/n \quad (7) \]
\[ a_1 = a_2 \quad (8) \]
\[ Z_L = 2\pi fL_0l \quad (9) \]

2.2. Experiment

The experiment is carried out in an UHV test base. The parameters of impulse current generator provided by the base are 55kV/12kA. By adjusting the resistance and inductance parameters in the circuit, the wave head and half peak time of the waveform can be adjusted. The impulse voltage waveform is collected by voltage divider, and the current waveform is collected by Pearson current coil. The impulse digital oscilloscope is used to record and display the current and voltage waves in real time and connect to the computer to save. In addition, there is a 100kA impulse current generator in the test base. The test circuit is shown in Figure 1. The impulse current generator first uses the power frequency current to charge the capacitor. After charging, it controls the impulse current test platform through the ball gap to discharge the flexible graphite grounding grid. The impulse current in the circuit is measured by coil.

![Figure 1. Schematic diagram of impulse current test for grounding model.](image)

![Figure 2. Schematic diagram of grounding electrode](image)

In the impulse characteristic test of graphite grounding grid, four connection points of square grounding grid are used as current injection points, as shown in Figure 2, which are gathered together through wires, and then connected to the impulse current generator. According to the requirements of lightning current parameters, the inductance and resistance in the circuit are adjusted. The standard lightning current waveform of 8/20μs is used in this test. If the heating condition of the experimental equipment is allowed, and the personal safety is guaranteed, it should be increased as much as possible, because the peak value of lightning current in nature can reach hundreds of kA. The higher the peak value of current in the simulation experiment, the closer the simulation of ground grid dispersion characteristics is to the real situation. Each current peak should be repeated to eliminate the interference of accidental factors. And ensure that the impulse current waveform between each time has good consistency.

3. Results

The representative experimental data of graphite grounding grid impulse characteristic test are shown in Figure 3. During the test, the charging voltage should be increased gradually from small to large, which can not only ensure the safety of the test, but also ensure the readability of the data. The impulse current output waveform under each charging voltage level is recorded in Table 1. According
to the knowledge of circuit science, the impedance is the ratio of voltage to current. In this test, the ratio of the peak value of two measured values is taken as the apparent impulse grounding impedance $Z_{ch}'$ of flexible graphite grounding grid. Considering the influence of the measurement error on the voltage during the test, the mutual impedance between the grounding device and the return loop is $Z_{12}=0.185\Omega$, and the power frequency grounding resistance is $R_{22}=1.705\Omega$. The correction value $Z_{ch}$ of impulse grounding impedance and the impulse grounding coefficient $\alpha$ are calculated as shown in Table 1.

**Table 1. Measurement and correction of impulse grounding resistance of graphite composite grounding device.**

| $I_{ch\_max}$ (kA) | $U_{ch\_max}$ (kV) | $Z_{ch}'$ (Ω) | $Z_{ch}$ (Ω) | $\alpha$ |
|-------------------|-------------------|----------------|-------------|---------|
| 25.105            | 35.79             | 1.435          | 1.670       | 0.950   |
| 30.951            | 43.75             | 1.444          | 1.699       | 0.938   |
| 37.254            | 50.4              | 1.370          | 1.588       | 0.918   |
| 43.044            | 58.59             | 1.368          | 1.575       | 0.924   |
| 50.745            | 67.93             | 1.358          | 1.553       | 0.926   |
| 55.149            | 76.26             | 1.382          | 1.566       | 0.909   |
| 61.741            | 83.48             | 1.389          | 1.534       | 0.961   |
| 68.157            | 95.28             | 1.326          | 1.583       | 0.947   |
| 74.559            | 113.57            | 1.388          | 1.553       | 0.962   |

**Figure 3.** Typical measurement data of lightning current impulse grounding test for four down conductors.

**Figure 4.** Variation Trend of impact coefficient of graphite composite grounding device.

4. Discussion

It can be seen from table 1 that the measured data show that the impact grounding resistance of graphite composite grounding device changes under different impact current amplitudes, and the impact coefficient under each impact current amplitude is less than 1, and the change trend is shown in Figure 4.

The phase of the measured current lags behind the measured voltage, which indicates that the graphite composite base device is an inductive impedance. With the increase of impulse current amplitude, the value of impulse coefficient $\alpha$ shows a decreasing trend, and the decreasing rate is slowing down, which indicates that there has been spark discharge effect in graphite composite grounding device. From the numerical point of view, the value of impact coefficient $\alpha$ is basically above 0.91. Therefore, it can be inferred that under the test conditions, due to the low soil resistivity, large area of grounding device and many stray branches, the spark discharge effect of grounding device is weak or the spark discharge range is small, and the spark discharge effect only appears near the four down conductors. Increasing the amplitude of impact current may only cause the spark discharge in this area. With the increase of electric field intensity in the field, the range of spark discharge in soil does not increase significantly, so the impact coefficient $\alpha$ tends to be flat.
This is mainly due to the skin effect of the grounding body under the action of high-frequency lightning current or short-circuit current. The current distribution inside the grounding body is uneven, which makes the distribution of the magnetic lines of force inside the grounding body also appear skin effect. The distribution of the magnetic lines of force inside the grounding body is sparse, which makes the internal inductance of the grounding body decrease and the total inductance slightly decrease. However, compared with the influence of the increase of current frequency on the inductive reactance value, the decrease of the inductive reactance value is almost negligible due to the decrease of the inductance value of the grounding body itself. Therefore, the graphite composite grounding material can effectively reduce the inductive reactance component of the impulse grounding impedance.

5. Conclusion
In this paper, the impact characteristics of a new type of graphite composite grounding material are studied and analyzed. The test results show that the new composite grounding device has spark discharge effect. With the increase of the amplitude of the impulse current, the value of the impulse coefficient α decreases, and the decreasing rate slows down. At the same time, increasing the amplitude of impulse current may only increase the electric field strength in the region, but not greatly improve the spark discharge range in the soil, so that the impact coefficient α tends to be flat. The test results can provide guidance for the selection and use of new grounding materials.

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