

High current field test of impulse transient characteristics of substation grounding grid

eISSN 2051-3305

Received on 29th August 2018

Accepted on 19th September 2018

E-First on 10th January 2019

doi: 10.1049/joe.2018.8826

www.ietdl.org

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Abstract: It is significant to research the impulse characteristics of substation grounding grid for its optimal design and safe and stable operation. In order to obtain the impulse transient characteristics of substation grounding grid under lightning impulse current more accurately, the impulse current field test was done on a real substation grid. By monitoring the impulse grounding impedance, impulse coefficient, longitudinal current, and node potential under different test conditions, impulse characteristics curves and the effect of some influence factors are gotten, then the main zones of current dispersion and voltage drop are proposed, as well as the effective areas under different conditions are proposed combined with simulation analysis. The results show that: the impulse grounding impedance and impulse coefficient are smaller when the current is injected from the central of the grid. The main current dispersion region of the large-scale grounding grid is about 40 m around the injection point. The potential drops about 30% within 20 m around the injection point, and the change of the potential is small in the far distance. The effective area of substation grounding grid is affected by soil resistivity, and its side length is usually only tens of meters.

1 Introduction

The grounding grid of the substation has the functions of working grounding, protective grounding, and lightning protection grounding. When accidents such as lightning strike occur in or near the substation, the high-frequency large current may be injected into the grounding grid to make the grounding grid complicated transient characteristics, which may endanger the personal safety and equipment safety in the station and even cause secondary equipment failure through the cable. The performance of the grounding grid under lightning shock determines the level of protection provided by the grounding grid. Therefore, the good impact characteristics of the substation grounding grid are an important prerequisite for ensuring the safe and stable operation of the power system and the reliability of the power supply.

The equivalent frequency of impulse current is much higher than the power frequency, making the inductance effect of the grounding grid very significant. Grounding conductor criss-crossing arrangement, combined with the shielding effect, the result is that the current distribution in the conductor segment is extremely uneven, and the potential of different points are very different. Under the impulse current, the soil near the conductors has the spark discharge effect. The impulse grounding impedance of grounding grid presents non-linear transient characteristics, which is related to the grounding grid shape, size, conductor spacing, lightning current injection point position, waveform, amplitude, and soil characteristics, and many other factors.

There are two kinds of method for obtaining performance of grounding grids: numerical calculation and test. The research on transient characteristics of substation grounding grid is mostly based on simulation calculation. In the simulation calculation, the soil spark discharge area is usually not considered or simplified, and related hypothesis is usually lack of experimental basis. The accuracy and applicability of the analysis results need to be further improved [1–7]. At present, the impact characteristics tests at home and abroad are generally conducted on the simple and small size grounding bodies such as single horizontal grounding body, the vertical grounding body, and the tower grounding body. The impact characteristics test data of criss-crossing, larger-sized grounding grids are very scarce [8–12]. Paper [13–14] measured the impact characteristics of the actual large-scale grounding grid. However, it was tested under low current, and the test current amplitude was

only tens of amperes. It is hard to produce the spark discharge effect under the small current. Correspondingly, impact characteristics measured results were obviously different from the actual lightning impulse results.

There are two kinds of test methods to get impact characteristics: field test and simulation test. The field test is usually carried out after the construction of the grounding grid, and the equipment and site requirements are high. The simulation test can easily change the conditions such as the topology structure of grounding bodies and the soil environment, which is an effective method to study the influent factors of the impact characteristics. However, due to the large size and small buried depth of the substation grounding grid, considering the feasibility of the simulation test, the experimental model cannot be buried too small, so the geometric scale and the size of the grid to be simulated are very limited. At the same time, due to the limited output of test equipment, the amplitude of the test impulse current is usually too large after conversion, even after reaching hundreds of kA. Under the condition of small ground grid size and large impulse current amplitude, significant spark discharge effect occurs in the entire grounding grid, which makes it difficult to reflect the current and potential difference of different conductor segments.

In order to obtain the impact characteristics of the substation grounding grid more accurately and comprehensively, the impact characteristics field test on a real grounding grid is carried out. Aiming at the 110 kV grounding grid, under the lightning impulse current, the impact grounding impedance and impact coefficient characteristics, current dispersion characteristics and transient potential distribution characteristics are tested and analysed, to guide the optimisation design of substation grounding grid.

2 Test scheme

2.1 Test object

The size of the tested true ground grid is about 50 m × 52.5 m, and the side length of each mesh is about 5.5 m–6.5 m, which is the grounding grid of a 110 kV substation. The soil resistivity is about 99.6 Ω·m in the surface and 300 Ω·m in deeper.

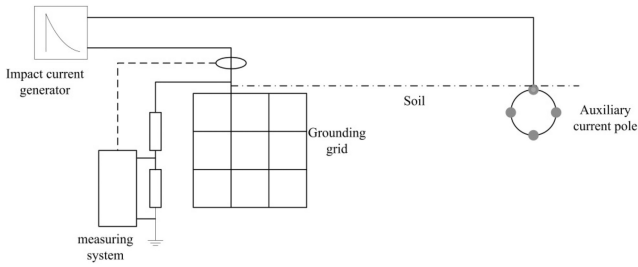


Fig. 1 Layout map of impulse current test

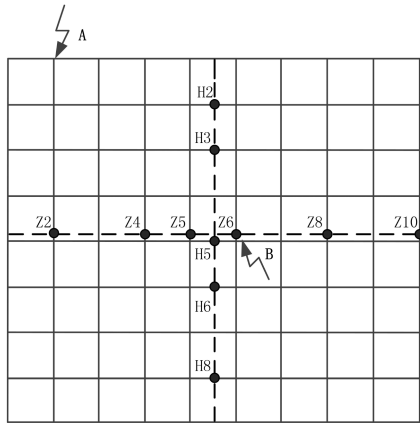


Fig. 2 Observation positions map

2.2 Test circuit and wiring

The three-pole circuit shown in Fig. 1 was used to test the impact characteristics of the grounding grid. In order to reduce the leads length of impulse current loop and the interference between the leads, the angle method is adopted, and the voltage lead and the current lead are arranged at 90° .

Due to the existence of auxiliary current pole, the distribution of the current field has a little distortion compared with the injection of lightning current from the grounding grid only. Accordingly, it will affect the potential rise of the grounding grid. If the zero potential point is selected as the potential reference point, the measurement results will be smaller than the actual value. To obtain the transient potential rise more accurately, the potential reference pole can be moved to the direction of the auxiliary current electrode to compensate for the decrease of the ground potential rise, just like the 0.618 way to measure the grounding resistance of power frequency. However, it is difficult to find the position of compensation point because of the complexity and dispersivity of the test under the impulse current.

In order to balance the feasibility of leads and the error of measurement results within acceptable limits, the measurement error of the auxiliary current pole at different positions is calculated by CDEGS software, which is a professional grounding calculation software developed by the Canadian SES company. Taking the grounding grids type W-60-10 (the grid side length is 60 m and the mesh side length is 10 m) and type W-100-10 (the grid side length is 100 m and the mesh side length is 10 m) as examples, the calculation results of the measurement error of the auxiliary current pole at different positions are shown in Table 1.

It can be seen that from Table 1: (1) the measurement error decreases with the increase of the distance between the auxiliary current pole and the grounding grid. (2) When the position of the auxiliary current pole is the same, the measurement error increases with the increase of soil resistivity. (3) When the relative position of the auxiliary current pole is the same, the measurement error increases with the size of the grounding grid. (4) Under the same auxiliary current pole position and soil resistivity, the measurement error increases with the increase of the wave front time.

Since the CDEGS software cannot take into account the soil spark effect, the calculation results of Table 1 are the results of no spark discharge. When the spark discharge is considered, the influence degree of the area near the current injection point is

Table 1 Measurement errors in different cases

Grounding grid type	Distance between the auxiliary pole and the grid edge, m	Soil resistivity, $\Omega \cdot m$	Current waveform, $\mu s/\mu s$	Measurement errors
W-60-10	20	100	2.6/50	-1.28%
W-60-10	30	100	2.6/50	-0.75%
W-60-10	60	100	2.6/50	-0.20%
W-60-10	30	200	2.6/50	-1.61%
W-60-10	30	100	8/22	-9.03%
W-100-10	50	100	2.6/50	-1.34%

increased, and the influence of the auxiliary current pole will be reduced. It can be seen that the measurement error can be controlled within 10% and within the acceptable range of the project when the auxiliary current pole is arranged at least $1/2L$ away from the edge of the grounding grid (L is the side length of the grounding grid).

In the test, combined with the surrounding topography and geomorphology, the auxiliary current pole is arranged on the grassland about 60 m away from the edge of the grounding grid, and the potential reference point is about 110 m away from the edge of the grounding grid where is nearly the zero potential point.

2.3 Observation point layout

A number of observation wells are provided on the transverse and longitudinal centre lines of the grounding grid. Voltage dividers and current sensors are connected in the observation wells to measure the conductor potential and longitudinal current respectively, as shown in Fig. 2. Current injection points were selected as the middle point and the edge point, respectively, and the wave front time of the impulse current is about 8 μs .

3 Test results and analysis

3.1 Characteristics of impact grounding impedance and impact coefficient

The impulse current of 8/20 μs is injected into different points of the true grounding grid, and the change curves of impact grounding impedance and impact coefficient with the current amplitude are shown in Fig. 3. It can be seen that:

- With the increase of the impulse current amplitude, the impact grounding impedance and impact coefficient of the grounding grid show a downward trend. The results show that the spark discharge effect exists in the grounding grid under the impact current. With the increase of the current amplitude, the spark discharge of the grounding conductor is gradually strengthened, and the equivalent size of the conductor increases gradually. The impact coefficient is >1 under the impact current of several kA, indicating that the grounding effect is dominated by the inductance effect, whose influence exceeds the spark effect.
- The impulse grounding impedance and impact coefficient are larger when the current is injected from the edge of the grid than that from the middle of the grid. The main reason is that the current path is longer and the inductance effect is stronger when the current is injected from the edge point, while the current flow channel is more and the inductance effect is weaker when the current is injected from the middle of the grid.

3.2 Current dispersion characteristics

Measuring conductor longitudinal current of multiple observation points simultaneously, the longitudinal current distribution of the grounding grid is obtained as shown in Fig. 4, taking the injection current as reference. It can be seen that:

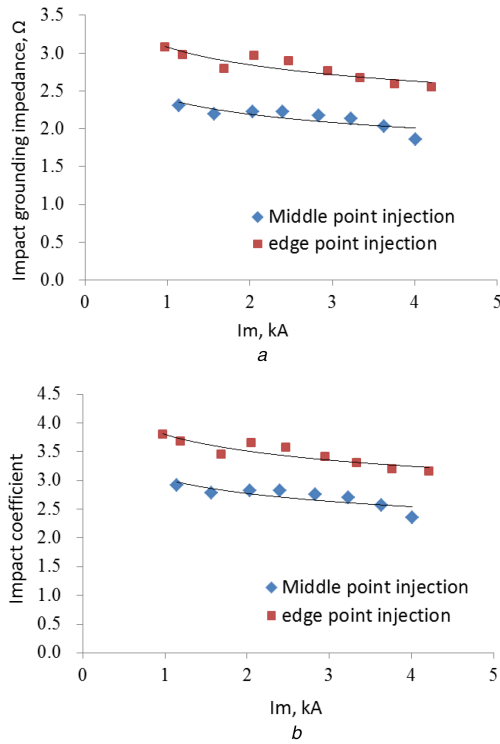


Fig. 3 Impulse characteristics of the grounding grid
(a) Curve of impact grounding impedance, (b) Curve of impact coefficient

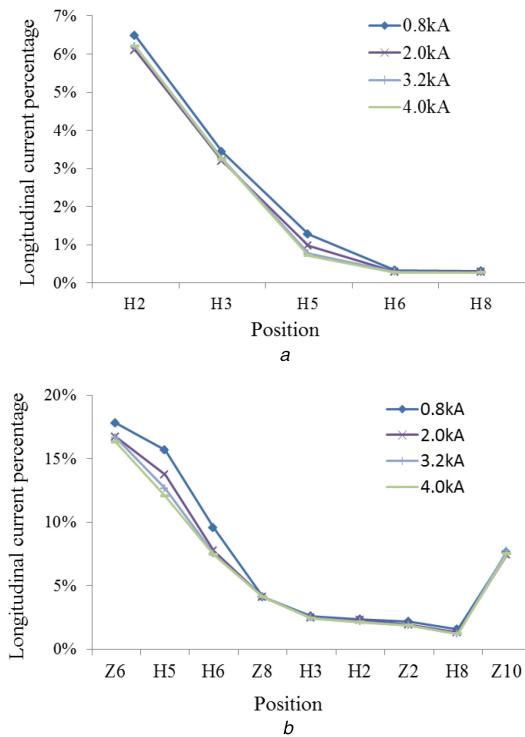


Fig. 4 Longitudinal current distribution at different positions
(a) Edge point injection, (b) Middle point injection

(i) When the current amplitude is very small, the percentage of the longitudinal current in the near area of the current injection point is relatively slightly larger. When the current is slightly larger, the percentage of the longitudinal current of each conductor varies very little with the increase of the injection current amplitude, which indicates that the variation of the current dispersion of each conductor is smaller. It shows that when the current is just beginning to increase, the spark effect appears in the conductor near the current injection point. The current dispersion rate of the conductor increases, and the longitudinal current ratio decreases. When the current amplitude continues to increase the current

amplitude, the current dispersion rate of each conductor changes less.

(ii) The longitudinal current of the conductors in the vicinity of the injection point vary greatly, and the longitudinal current of the conductors far away from the injection point change little, reflecting the current dispersion relatively large in the near area and current dispersion relatively small in the far area. When the current is injected from the edge point, the longitudinal current decreases by only 0.02% from the conductor H6 to the conductor H8, indicating that the 0.02% of the current is scattered from the conductor H6 to H8. The main current dispersion zone is within the H6 position near the injection point.

(iii) The current dispersion is mainly on the conductors around 40 m in the vicinity of the current injection point by comparing position and distance. When the current is injected from the middle point, the longitudinal current and the scattered current of the edge conductor increase again compared with the adjacent middle conductors. This is because the current flow path is short, and the edge conductor is very close to the injection point, but the shield effect of the edge conductor is smaller than that of the middle conductor.

3.3 Transient potential distribution characteristics

Simultaneously measuring the conductor potential of multiple observation points, the potential distribution of the grounding grid is obtained as shown in Fig. 5, taking the potential of the current injection point as reference. It can be seen that:

(i) The potential decreases gradually with the increase of the distance to the injection point, and the descent rate in the near zone is faster, and the descent speed tends to be saturated in the far distance. The higher the current amplitude is, the faster the potential falls.

(ii) The potential drop mainly appears within 20 m near the current injection point. When the distance from the injection point is within 20 m, the potential is about 70% and above of the injection point. The potential varies small in the farther distance, and the potential maintain at about 60% of the injection point.

4 Effective area of the grounding grid

From the test results, it can be seen that the inductance effect plays a major role in the impact characteristics of the substation grounding grid. When the current is injected into the grounding grid, the inductance effect makes the current disperses within a certain range. There is an effective area of the substation grounding grid under impulse current. The current dispersion of conductors outside the effective area is very small. Here, based on CDEGS simulation software, the grounding grid model is established, the impact grounding impedance of grounding grid of different sizes is calculated, and the effective area of grounding grid is studied.

Under different soil resistivity, the calculation results of the grounding grid grounding impedance variation with the side length of the grounding grid are shown in Fig. 6. It can be seen that with the increase of the size of the grounding grid, the impulse grounding impedance of the grounding grid decreases gradually, but with obvious saturation tendency. The higher the soil resistivity is, the harder it is for current to flow into the soil, resulting in more current flowing through the conductor farther from the point of injection, and the effective area of the grounding grid will be larger.

The formula for calculating the change rate of impulse grounding impedance of grounding grid (δ) is defined as follows:

$$\delta = \left| \frac{R_l - R_{l+10}}{R_{l+10}} \right| \times 100\%$$

where the R_l and R_{l+10} are the impulse grounding impedance of the grounding grids whose side length is l m and $(l+10)$ m, respectively.

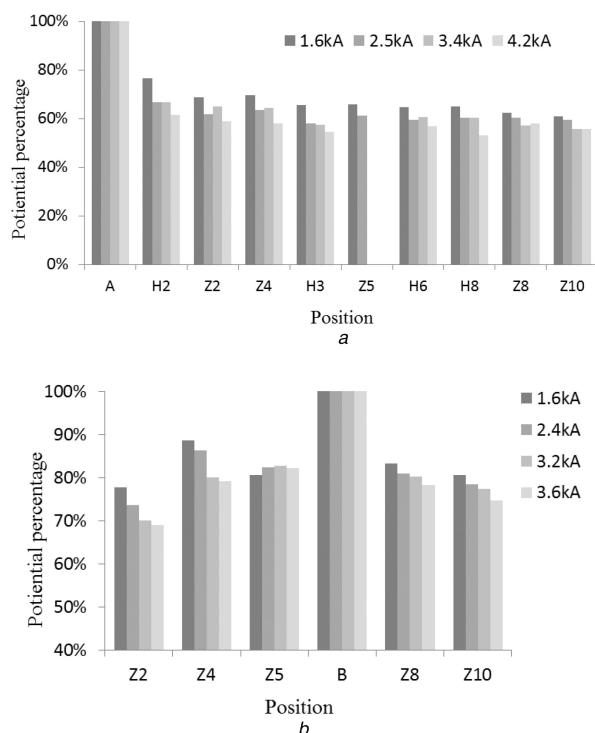


Fig. 5 Conductor potential distribution at different positions
(a) Edge point injection, (b) Middle point injection

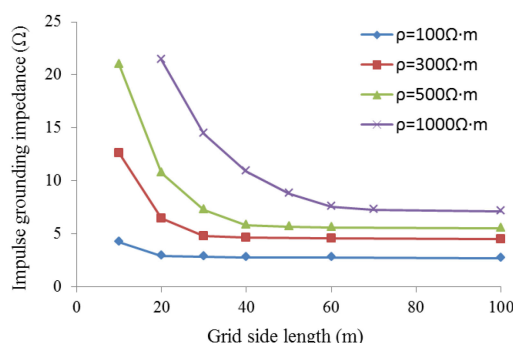


Fig. 6 Impact grounding impedance of grounding grids of different sizes under different soil resistivity

When the change rate of impact grounding impedance is $<5\%$, it is considered that the impulse grounding resistance of substation grounding grid will no longer change with the size of the grounding grid. The corresponding side length of the grounding grid is the effective area of the substation grounding grid.

According to the above definition, when the soil resistivity is $100\ \Omega\cdot\text{m}$, $300\ \Omega\cdot\text{m}$, $500\ \Omega\cdot\text{m}$, $1000\ \Omega\cdot\text{m}$, the corresponding effective area of the grounding grid is about $20 \times 20\ \text{m}^2$, $30 \times 30\ \text{m}^2$, $40 \times 40\ \text{m}^2$, $60 \times 60\ \text{m}^2$, respectively. The calculated results are similar to the measured results and have a certain reference.

The grounding grids of substations are generally built in places where soil resistivity is $<500\ \Omega\cdot\text{m}$. At this moment, the effective area of the grounding grid actually participating in the current dispersion is about $40 \times 40\ \text{m}^2$ under the lightning impact current. The grid conductor outside the effective area can reduce the power frequency grounding resistance, but it cannot reduce the impact impedance. Therefore, it is ineffective to reduce the grounding

impedance and potential rise only by increasing the area of the ground grid in lightning protection.

5 Conclusion

(i) When using the three-pole method to measure the lightning impact characteristics of substation grounding grids, the return electrode should be arranged at least $1/2L$ away from the edge of the grounding grid, then the measurement error can be controlled within 10% .

(ii) The impact characteristics of substation grounding grids are affected by the injection point position. The impulse grounding impedance and impact coefficient are smaller when the current is injected from the central point of the grounding grid.

(iii) With the increase of the distance from the injection point, the dispersion current of conductor segments gradually decreases, but dispersion current of edge conductors will increase if the distance between the edge conductors and the injection point is relatively close. The main current dispersion region of the large-scale grounding grid is about $40\ \text{m}$ around the injection point under impulse current.

(iv) The potential drop occurs mainly within $20\ \text{m}$ from the current injection point, and the decrease is about 30% . In the area farther away from the injection point, the conductor transient potential changes little.

(v) The effective area of the substation grounding grid increases with increasing soil resistivity, and its effective side length is usually only tens of meters.

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