

# Influence of Grounding Material's Property on the Impulse Grounding Resistance of Grounding Grids

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**Abstract**—The conductor material properties such as resistivity and relative permeability have great influence on impulse grounding resistance of grounding grids in regular dimensions. The intensity of the influence is also different under different soil conditions. By building a 1:1 grounding model and using moment method, the paper gets a huge amount of numerical calculation results on the electromagnetic environment in an impulse current attack. Based on these results, influence of conductor resistivity, relative permeability and similar properties on impulse grounding resistance of grounding grids under different soil conditions are discussed. The final part of this paper also gives ground potential rise distribution on grounding grids of different conductor materials under an impulse current's attack. Calculation results show that when laying grounding grids in soil with higher resistivity, copper materials with relatively lower permeability and resistivity can be used, thereby greatly reducing the impulse grounding resistance of grounding grids.

**Keywords**—component; grounding grid; over-voltage; material properties; impulse grounding resistance; moment method

## I. BACKGROUND

High voltage transmission lines pass across mountains, rivers as well as villages and dessert for connecting tens of thousands of power plants, substations and power consumers together, thereby forming our power grid. Since the huge power grid is exposed outdoors and operated continuously, it always encounters lightning intrusion, insulation fault, personnel misoperation and other external disturbances. These disturbances result in production of impulse current and impulse over-voltage on failure points. Further it may cause damage on outer insulation of primary equipment, disturb the accurate action of communication device, and give rise to physical threat on site personnel through step potential difference and contact potential difference [1].

Correct laying and good maintenance of grounding grid in electric power facilities are of great significance in order to reduce above risks. By laying ground grids in the right way, we can let impulse current flow into ground with the most economical materials consumption. In addition, ground potential rise, step potential difference, contact potential difference and other indexes can be controlled within the scope prescribed by. Different countries have corresponding specifications and standards on grounding grid of power facilities. In various grounding specifications, grounding resistance is one of the most important parameters for assessing discharge effect of grounding grid. It generally refers to the resistance between the given point of a system, device or

equipment and the reference ground when current is leaked into the earth under the energization of given frequency [2-4].

Research on grounding properties of grounding grids has long been concentrated in power frequency grounding[5-6] Because the impulse grounding resistance can not be easily measured, and it can be greatly affected by impulse waveform, it rarely appears in design and acceptance procedures. In the engineering practice, it is deduced and judged that the impulse grounding resistance can perform well under the condition of lightning over-voltage or operating over-voltage if the grounding grid's power frequency grounding resistance meets the requirements of the standards. However, as there're richer studying tools and detailed researching needs for the over-voltage direction nowadays, it is becoming more important to have research on the impulse resistance of grounding grids.

The Chinese national standard for grounding was implemented since June 1, 2012[4]. Definition of impulse grounding resistance is specified in the code: grounding resistance is obtained according to impulse current which is discharged into the earth through grounding electrode, namely the ratio between grounding voltage peak value and current peak value on the grounding electrode. In the paper, influence of grounding material properties on the impulse resistance of regular dimension grounding grids are compared and analyzed according to the definition. Moment method and Fourier transform are also used to get the calculation results. Ground potential rise distribution on the grounding grid during an impulse current attack is briefly discussed in the last section of the paper, thereby guiding design and measurement in practical engineering.

## II. MODELING BASED ON MOMENT METHOD

Grounding grid of power facilities are generally horizontal mesh structures, usually made of galvanized steel or copper. In the paper, the established grounding grid model is shown in Figure 1. Because the radius of conductor is far less than its length thereof, moment method can be adopted for analyzing the whole electromagnetic environment.

In Figure 1, grounding grid is embedded for 0.8m, the peripheral size is 200m × 200m, and horizontal conductor spacing is 20m. Grounding conductor is equivalent to cylinder, and their cross section radius is 0.01m. Soil selected in the model is single layer homogeneous soil which relative dielectric constant is 1.0, without considering its ionization under impulse current function. 2.6/50μs impulse current is

adopted in order to provide typical significance for the research content.

When the impulse current is discharged, in order to understand the ground potential rise distribution in details through numerical calculation, six observation points from A to F are selected from model in Figure I, wherein A is the center of grounding grid, F is a corner point. Impulse current is discharged from A. Ground potential rise curves on the six observation points are calculated, thereby analyzing the potential distribution condition of the whole grounding grid. Impulse resistance of the grounding grid can be obtained through ground potential rise on point A.

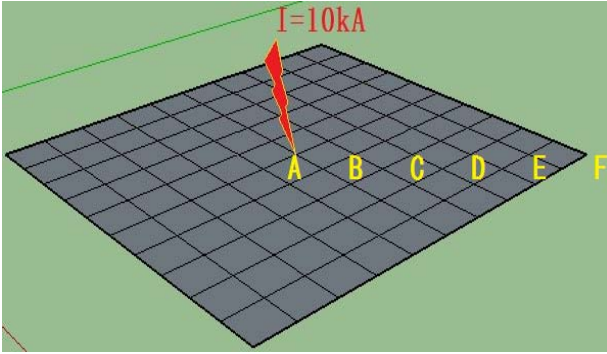


FIGURE I. GROUNDING GRID MODEL

### III. INFLUENCE OF CONDUCTORS' RESISTIVITY ON IMPULSE GROUNDING RESISTANCE OF GROUNDING GRID

Two cases of soil resistivity  $100\Omega\cdot m$  and  $1000\Omega\cdot m$  are respectively selected for calculation aiming at grounding model shown in Figure I. Relative permeability of grounding grid conductors is 1.0, and the resistivity is respectively  $1\times 10^{-8}\Omega\cdot m$ ,  $1\times 10^{-7}\Omega\cdot m$ ,  $1\times 10^{-6}\Omega\cdot m$  and  $1\times 10^{-5}\Omega\cdot m$ . 2.6/50 $\mu s$  impulse current with amplitude of 10kA is injected in the center of grounding grid. The ground potential rise curve of point A is calculated and shown in Figure II.

As is shown in Figure II, when 2.6/50 $\mu s$  impulse current is injected, ground potential rise on the grounding grid rapidly increases. Then, it exponentially decreases to form an impulse voltage waveform. Impulse voltage waveforms are similar under the soil condition of two resistivities. However, the amplitudes are different.

Impulse resistance of grounding grids with different conductor resistivities can be calculated according to definition. The results are shown in Table I.

Influence curve of grounding material's conductor resistivity on impulse grounding resistance can be obtained according to table I as shown in Figure III.

Figure III shows that impulse grounding resistance of grounding grids can be reduced by selecting conductor materials with lower resistivity. The effect can be more prominent under high soil resistivity conditions. In the soil with resistivity of  $100\Omega\cdot m$ , impulse grounding resistance of grounding grids can only be reduced by 1% when the material resistivity is lowered from magnitude  $10^{-6}$  to magnitude  $10^{-7}$ ; while in the soil with resistivity of  $1000\Omega\cdot m$ , impulse

grounding resistance of grounding grids can be reduced by 8% or so under same circumstances. It is obvious that if the practical project encounters bad soil condition, impulse grounding resistance of the grounding grid can be greatly lowered by using conductor materials with low resistivity, and the impulse grounding properties can be improved.

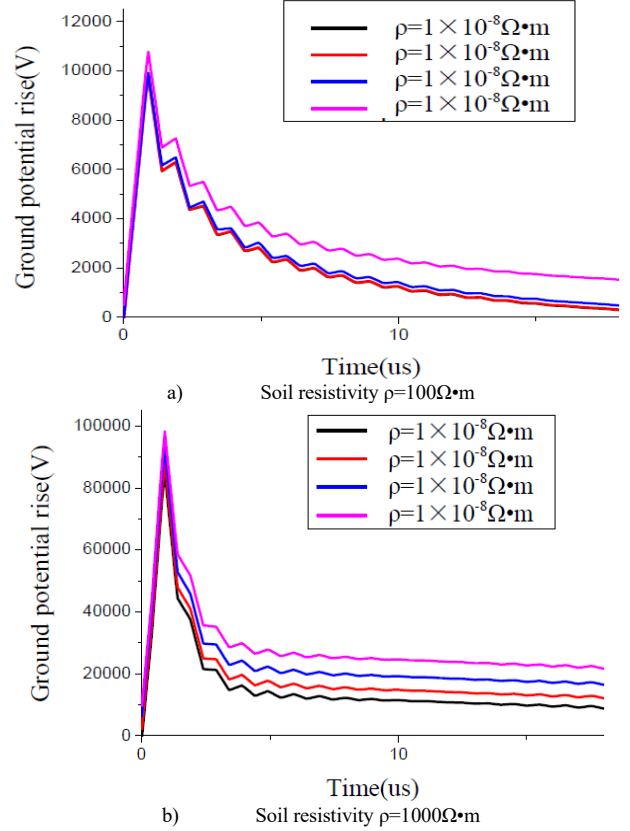


FIGURE II. GROUND POTENTIAL RISE ON GROUNDING GRIDS IN AN IMPULSE CURRENT ATTACK

TABLE I. IMPULSE GROUNDING RESISTANCE OF GROUNDING GRIDS WITH DIFFERENT CONDUCTOR RESISTIVITIES

Conductor resistivity( $\Omega\cdot m$ )	Impulse grounding resistance( $\Omega$ )	
	$\rho_{soil}=100\Omega\cdot m$	$\rho_{soil}=1000\Omega\cdot m$
$1\times 10^{-8}$	0.9811	8.5078
$1\times 10^{-7}$	0.9832	8.8509
$1\times 10^{-6}$	0.9921	9.3218
$1\times 10^{-5}$	1.0779	9.8316

### IV. INFLUENCE OF CONDUCTORS' RELATIVE PERMEABILITY ON IMPULSE GROUNDING RESISTANCE OF GROUNDING GRID

Two conditions of soil resistivity  $100\Omega\cdot m$  and  $1000\Omega\cdot m$  are respectively adopted for calculation aiming at the grounding model shown in Figure I. The conductor material resistivity of the grounding grid is  $1\times 10^{-7}\Omega\cdot m$ , relative permeability  $\mu_r$  is respectively chosen to be 1, 100, 1000 and 10000. 2.6/50 $\mu s$  impulse current with amplitude of 10kA is

injected in the center of grounding grid, and the ground potential rise curve of point A is calculated as shown in Figure IV.

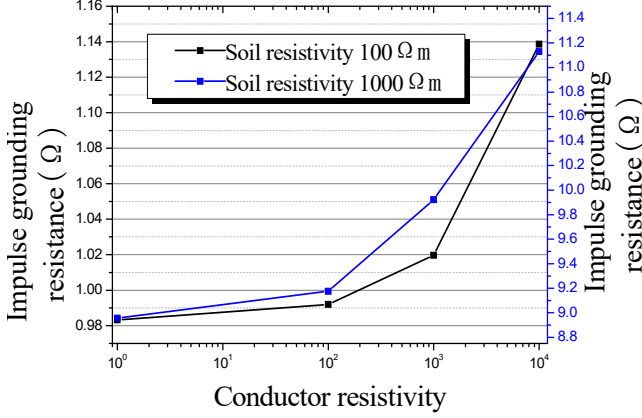


FIGURE III. INFLUENCE OF CONDUCTOR RESISTIVITY ON IMPULSE GROUNDING RESISTANCE

Impulse grounding resistance of the grounding grid under different material relative permeability is calculated according to definition as shown in Table II. Influence curve of grounding material conductor's relative permeability on impulse grounding resistance of grounding grid can be obtained according to Table II as shown in Figure V.

Calculation results of Figure V show that impulse grounding resistance of grounding grids can be reduced by selecting conductor materials with lower relative permeability. In the above example, when the conductor relative permeability is decreased from 10000 to 1, the impulse grounding resistance of grounding grid buried in soil with resistivity of  $100 \Omega \cdot m$  is reduced by 13.6%. The impulse grounding resistance of grounding grid buried in soil with resistivity of  $1000 \Omega \cdot m$  is reduced by 19.5%. It is obvious that impulse grounding resistance of grounding grid can be greatly lowered by using conductor with lower relative permeability regardless of soil conditions.

## V. GROUND POTENTIAL RISE DISTRIBUTION ON GROUNDING GRIDS UNDER THE EFFECT OF IMPULSE CURRENT

Section II of the paper shows that six observation points from A to F are arranged during establishment of the calculation model. They extended from current discharging point to the grounding grid corner points. Ground potential rise of all observation points are calculated when the conductor resistivity is respectively  $1 \times 10^{-8} \Omega \cdot m$ ,  $1 \times 10^{-7} \Omega \cdot m$ ,  $1 \times 10^{-6} \Omega \cdot m$  and  $1 \times 10^{-5} \Omega \cdot m$ . Soil resistivity is chosen to be  $100 \Omega \cdot m$  and  $1000 \Omega \cdot m$ . The results are shown in Figure VI.

Ground potential rise of observation points are calculated when the conductor relative permeability  $\mu_r$  is respectively 1, 100, 1000 and 10000. The soil resistivity is chosen to be  $100 \Omega \cdot m$  and  $1000 \Omega \cdot m$ . Results are shown in Figure VII.

By analyzing Figure VI and Figure VII, ground potential rise peak value of observation point B has been reduced to

lower than 5% compared with observation point A under the condition of soil resistivity  $100 \Omega \cdot m$ . The ground potential rise distributions are similar regardless of conductor resistivity and relative permeability: impulse voltage is limited within a very small space scope around the injection point. Ground potential rise peak value of observation point B is higher than 30% the value from observation point A under the condition of soil resistivity  $1000 \Omega \cdot m$ . The ground potential rise distribution shapes are kept constant if conductor resistivity or relative permeability is changed. It is obvious that soil resistivity is a main factor to affect impulse ground potential rise distributions on grounding grid.

When soil resistivity is lower, the current can be discharged into the earth more easily near the injection point of grounding grid. Therefore, the grounding grid far from the current injection point assumes smaller impulse voltage. Its flow scattering and voltage equalizing effects are small. When soil resistivity is high, impulse current can not be easily discharged into the earth, it can flow outwards to further distance along the conductor of grounding grid, the grounding grid can play higher voltage equalizing role, and voltage distribution on grounding grid will be evenner.

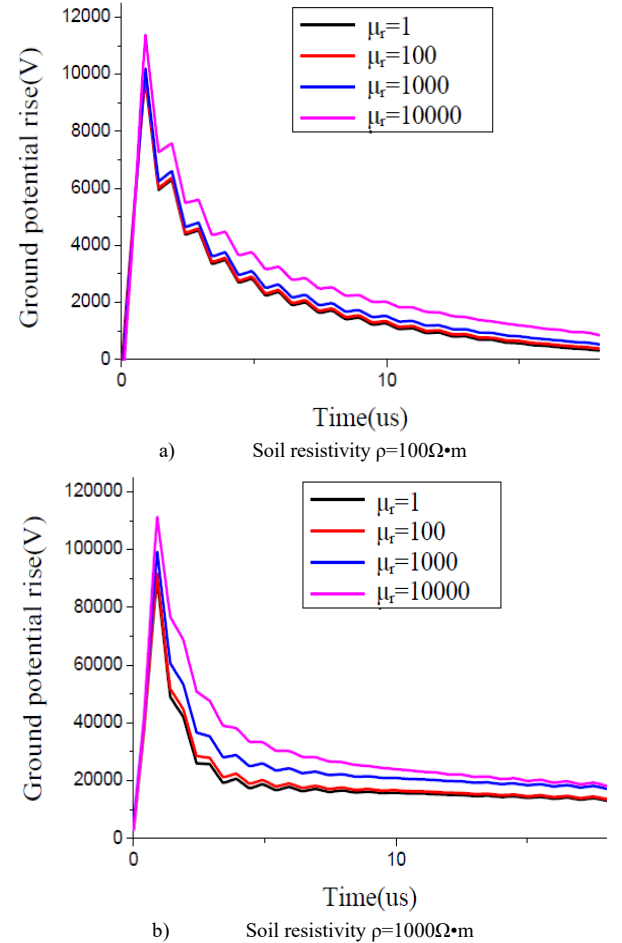


FIGURE IV. GROUND POTENTIAL RISE ON GROUNDING GRIDS IN AN IMPULSE CURRENT ATTACK

TABLE II. IMPULSE GROUNDING RESISTANCE WITH DIFFERENT CONDUCTOR RELATIVE PERMEABILITY

Conductor relative permeability	Impulse grounding resistance( $\Omega$ )	
	$\rho_{soil}=100\Omega\cdot m$	$\rho_{soil}=1000\Omega\cdot m$
1	0.9832	8.9568
$1\times 10^2$	0.9920	9.1763
$1\times 10^3$	1.0197	9.9214
$1\times 10^4$	1.1386	11.1299

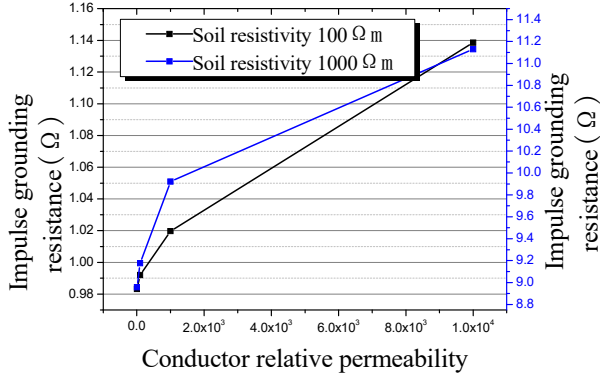


FIGURE V. INFLUENCE CURVE OF RELATIVE PERMEABILITY ON IMPULSE GROUNDING RESISTANCE

## VI. CONCLUSION

In the paper, moment method is used for calculation. Influence of resistivity and relative permeability changes of grounding grid's materials on the impulse grounding resistance under different conditions of soil resistivities is discussed. Ground potential rise on six observation points in the model are calculated, and the ground potential rise distribution on grounding grid under impulse current's injection are briefly analyzed.

1) The impulse grounding resistance of grounding grids can be greatly reduced by selecting conductor materials with low resistivity under the condition of higher soil resistivity. However, under same circumstances the resistivity reduction effect is not prominent if the soil resistivity is low.

2) Impulse grounding resistance can be greatly reduced under any soil condition by selecting conductors with low relative permeability to lay grounding grids.

3) Impulse resistance of grounding grids is the composite result of soil properties and grounding grids. Grounding grid has more prominent current equalizing and voltage equalizing functions with impulse current in area with higher soil resistivity.

Galvanized flat steel and copper are two major metal materials for laying grounding grids in practical projects. The resistivity of copper is lower than that of galvanized steel by nearly one magnitude at room temperature, relative permeability is lower than steel materials by 2~3 magnitudes. Therefore, impulse grounding resistance of grounding grid can

be greatly lowered by laying grounding grid with copper materials under the condition of bad soil environments.

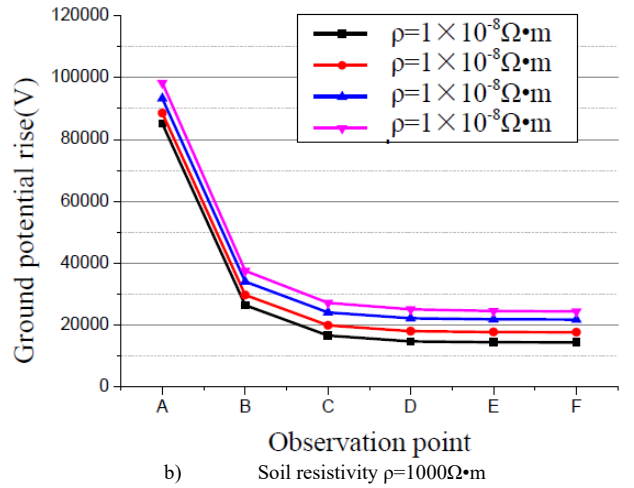
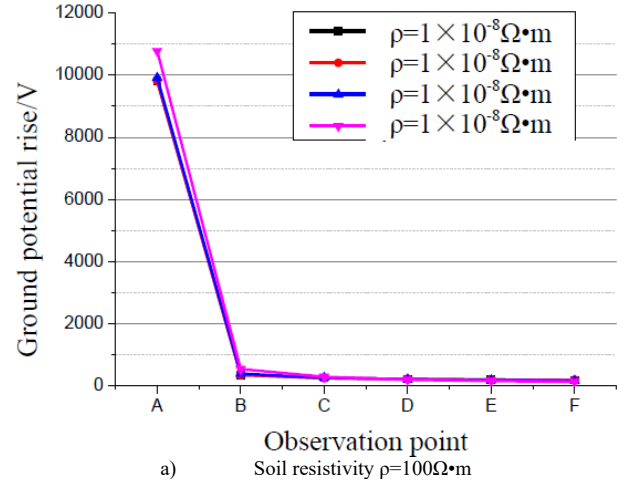
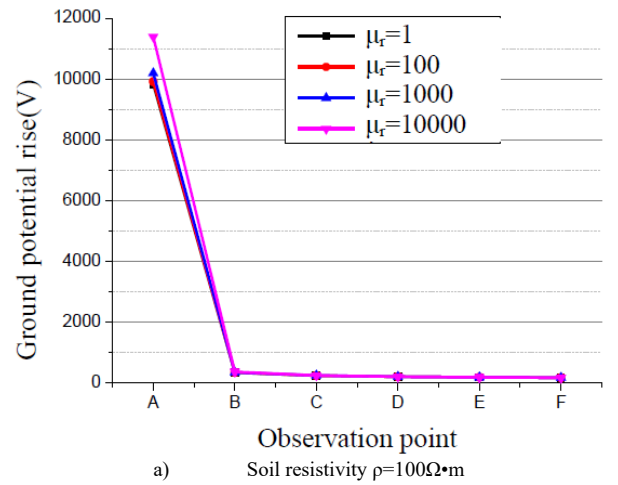


FIGURE VI. GROUND POTENTIAL RISE DISTRIBUTION ON THE GROUNDING GRIDS IN AN IMPULSE CURRENT ATTACK



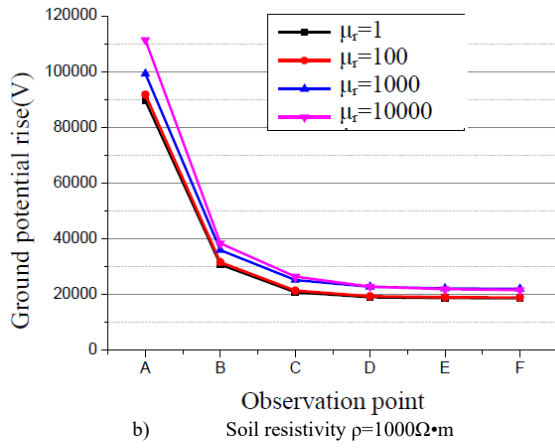


FIGURE VII. GROUND POTENTIAL RISE DISTRIBUTION ON GROUNDING GRIDS IN AN IMPULSE CURRENT ATTACK

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