The research to reduce the transient grounding resistance of communication protection system with resistance matching method

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Abstract. In this paper, we study reducing the transient grounding resistance (TGR) of communication protection system with resistance matching method. We set single or double matching layers surround the grounding rod and change their sizes and conductivity to get the laws about reducing the TGR peak and stable value. The finite-difference time-domain (FDTD) method is adopted for calculating. For the single matching layer, both of the peak and stable value of the vertical grounding rod TGR reduce, compared with normal case, as matching layer exists when the conductivity of matching layer is larger than that of ground. For the double matching layers, the TGR value will reduce even more than single matching layer case when the conductivity of outer matching layer is larger than that of ground.

1. Introduction

For communication protection system, the grounding is one of the methods to reduce the lightning electromagnetic pulse coupling and provide a discharge path for coupling and lightning current to the ground. Hence, the grounding is an important measure to enhance the protection ability of electric and electrical equipment and has been studied for many years. The transient characterization [1-3] and reduction of the grounding resistance [4-5] are two important aspects of the grounding problem research. Moreover, the FDTD method is a common way to analyze the grounding problems and often adopted for numerical calculation [2-3]. K. Yamamoto et al use the FDTD method to research the effectiveness and problems of deeply buried grounding electrodes [6]. R. Xiong et al study the TGR of angle iron, flat and square electrode by algorithm improvement with less computational memory and time [7-10].
In this paper, we comprehensively research the issue of reducing the TGR of grounding system from a new point of view. We take the vertical grounding rod for an example and adopt resistance matching way to reduce its TGR value. The FDTD method is adopted for numerical calculation. To our best knowledge, this content has not been discussed in the published literature.

The paper is organized as follows. In Section II, the matching method is briefly described. Section III introduces the FDTD calculation model. The numerical analysis of single and double matching are discussed in Section IV. Finally, some general conclusions are given in Section V.

2. The matching method discussion

We research the issue of reducing the grounding system TGR from the view of resistance matching. The single port net, which is shown in Fig.1, is a kind of transmission line net in the microwave net theory and single dipole antenna is the representative one. As is shown in Fig.2, the coaxial line can be the input end of single dipole antenna and the antenna with free space constitute the passive component of single port net. The voltage between the inner and outer conductor of coaxial line can supply power for the single dipole antenna. Then, we can change the structure of the antenna to realize resistance matching and radiate more energy. If the lifting line and grounding rod can be regarded as microwave component, the grounding rod and ground can be treat as single port net when lightning current discharge into ground through grounding rod, that is, lifting line is input end, grounding rod and ground constitute the passive component of single port net.

![Fig.1: The single port net block diagram](image1)

We adopt vertical grounding rod for analyzing in this paper. The vertical grounding rod and its lifting line are shown in Fig.3. The vertical grounding rod can be regarded as single dipole antenna, the lifting line is the coaxial line which supply power, and the ground is equal to free space. Compare single dipole antenna with vertical grounding rod, we can learn that the antenna radiate electromagnetic wave to the free space while grounding rod discharge current into the ground. Just as the single dipole antenna can radiate more energy with resistance matching, the current that discharge into the ground through grounding rod will increase if the resistance matching between ground and grounding rod realize. Then, the purpose of reducing the grounding rod TGR will also achieve.

![Fig.2: The single dipole antenna](image2)
3. The FDTD calculation model

In this part, we adopt the FDTD method to analyze the resistance-reducing method of resistance matching. The computational model is shown in Fig. 5. Fig. 5 (a) shows the side view of the model and Fig. 5 (b) is the platform. The reference electrode, connecting line, lifting line, grounding rod and ground constitute a discharge circuit. In Fig. 5 (a), L = 20 m is connecting line length, L1 = 10 m is the transient voltage integrating path length, h = 0.5 m is the connecting height above the ground and the lifting line height, and h1 = 1.0 m is the reference electrode length.

We select homogenous ground which has constant electrical parameter in our simulations. The ground conductivity is σ1 = 0.001 S/m, and the relative permittivity is εr1 = 9.

Two layers of matching medium are set around the grounding rod. The vertical metal grounding rod is adopted and has square cross section. l1 = 2 m is the ground rod vertical length and d1 = 0.2 m is the length of a section side. l2 and d2 are the inner layer matching medium vertical length and its section side length, respectively. σ2 is the inner layer medium conductivity, εr2 is the inner layer medium relative permittivity. l3 and d3 are the outer layer matching medium vertical length and its section side length, respectively. σ3 is the outer layer medium conductivity, εr3 is the outer layer medium relative permittivity. And εr1 = εr2 = εr3 = 9. The space step is Δs = 0.1 m and the time step Δt = Δs / 2c, where c is the lightning speed in the vacuum.
The double exponential function $I(t)$ of 1.2/50μs with inner resistance 50Ω is selected as the excitation resource, which can be modeled by

$$I(t) = I_0 \left( e^{-\alpha t} - e^{-\beta t} \right)$$  \hspace{1cm} (1)

Where $k = 1.043$, $I_0 = 5.4 \text{ kA}$, $\alpha = 14730 \text{ s}^{-1}$, $\beta = 2.08 \times 10^6 \text{s}^{-1}$ and the normalized waveform of resource is shown in Fig.6.

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**Fig.5**: The TGR computational model, (a) side view, (b) platform

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**Fig.6**: The normalized waveform of resource
The point resource and forced excitation resource join technology are adopted in the calculation, as shown in Fig.7. The excitation resource can join as voltage or current resource and we select the latter one in this paper. The joining way of current resource is following equation (2) to amend the magnetic fields around the point resource.

\[
\begin{align*}
H_x^{n+1/2}(i, j + \frac{1}{2}, k) &= H_x^{n-1/2}(i, j + \frac{1}{2}, k) + I^n I (4\Delta s) \\
H_y^{n+1/2}(i + \frac{1}{2}, j, k) &= H_y^{n-1/2}(i + \frac{1}{2}, j, k) - I^n I (4\Delta s) \\
H_x^{n+1/2}(i, j - \frac{1}{2}, k) &= H_x^{n-1/2}(i, j - \frac{1}{2}, k) - I^n I (4\Delta s) \\
H_y^{n+1/2}(i - \frac{1}{2}, j, k) &= H_y^{n-1/2}(i - \frac{1}{2}, j, k) + I^n I (4\Delta s)
\end{align*}
\]

(2a)  
(2b)  
(2c)  
(2d)

Where \(I_n\) is the value of current resource at time \(n\), \(\Delta s\) is space step.

The computational domain should be terminated for the limited internal storage of computer. The excitation resource we adopted is a single pulse with low frequency band and have low request to the absorbing boundary condition, so we select interpolation absorbing boundary condition which can be realized easily and occupy very few internal storage, as shown in Fig.8 and equation (3).

\[
E_i = 2E_{i+1} - E_{i+2}
\]

(3)

The TGR is the ratio of transient voltage \(V_t\) and transient current \(I_t\), and can be defined as

\[
R_t = \frac{V_t}{I_t}
\]

(4)
As is shown in Fig.9, the electric field of every cell can be regarded as homogeneous and the voltage $V_j$ between the two sides of a cell can be defined as [11]

$$V_j = -E_j \cdot \Delta s$$

(5)

The transient voltage $V_t$ can be obtained by integrating the voltage along the air-ground interface from the lifting line to the absorbing boundary and the integrating direction is parallel to the y-direction in Fig.5.

$$V_t = \sum_{i=1}^{NPS} V_j$$

(6)

Where $V_j$ is the voltage in the air-ground interface, NPS is the mesh index of lifting line projection point on the ground, NPL is mesh index of absorbing boundary point.

As shown in Fig.10, according to Ampere circuital theorem, the transient current of any point of lifting line can be defined as

$$I_i = \sum_{i=1}^{NPS} H_{j} \cdot \Delta s$$

(7)

4. Numerical analyze and discussion

In this section, we discuss the effect of matching layer on the TGR value of the vertical grounding rod. The number, conductivity, size of matching layer are considered.

4.1. The influence of single matching layer

4.1.1. The matching layer conductivity

Set single matching layer surround the vertical grounding rod and keep medium vertical length $l_2 = 2.2m$, section side length $d_2 = 0.4m$. The result is shown in Fig.11 and compared with the normal case without matching layer.
It can be seen from the Fig.11 that the matching layer can affect both of the peak and stable value of the vertical grounding rod TGR. The peak and stable value of TGR reduce as the matching layer conductivity increase. The peak value of TGR reduces for adding matching layer and the effect of reducing resistance is very obvious.

4.1.2 The effect contrast of medium vertical length and section side length on TGR
In this part, we keep the single matching layer conductivity $\sigma_2 = 0.01\text{S/m}$ and invariable. Then we contrast the result of $d_2 = 0.6\text{m}$, $l_2 = 2.2\text{m}$ and $d_2 = 0.4\text{m}$, $l_2 = 2.4\text{m}$ with $d_2 = 0.4\text{m}$, $l_2 = 2.2\text{m}$, respectively, which is shown in Fig.12.

We can learn from Fig.12 that both of the peak and stable value of TGR reduce as the matching layer vertical length $l_2$ and section side length $d_2$ increase, but the extent is different. The adding of $d_2$ can reduce more TGR value than that of $l_2$.

4.1.3 The matching layer section side length $d_2$
Keep the single matching layer conductivity $\sigma_2 = 0.01\text{S/m}$ and $l_2 = 2.2\text{m}$ and set $d_2 = 0.4\text{m}$, $0.6\text{m}$, $0.8\text{m}$, $1.0\text{m}$ respectively. The calculated result is shown in Fig.13.
The Fig.13 shows that both of the peak and stable value of the vertical grounding rod TGR reduce as the matching layer section side length $d_2$ increase and the decrement is decrease. We can see that the TGR value is relative to the contact area between matching layer and ground and the effect of section side length $d_2$ is nonlinear.

4.1.4 The matching layer vertical length $l_2$

Keep the single matching layer conductivity $\sigma = 0.01 \text{S/m}$ and $d_2 = 0.4 \text{m}$ and set $l_2 = 2.2 \text{m}, 2.4 \text{m}, 2.6 \text{m}, 2.8 \text{m}$ respectively. The calculated result is shown in Fig.14.

The Fig.14 shows that both of the peak and stable value of the vertical grounding rod TGR reduce as the matching layer vertical length $l_2$ increase and the effect is not obvious. The contact area between matching layer and ground is 3.68 m$^2$ when $l_2 = 2.2 \text{m}$, 4 m$^2$ when $l_2 = 2.4 \text{m}$, 4.32 m$^2$ when $l_2 = 2.6 \text{m}$ and 4.64 m$^2$ when $l_2 = 2.8 \text{m}$. We can see that the contact area between matching layer and ground increase slowly as vertical length $l_2$ increases.

The peak and stable value of the vertical grounding rod TGR with single matching layer existing is shown in Tab.1.
**Tab.1:** The peak and stable value of the vertical grounding rod TGR with single matching layer

| Parameter setting | TGR peak value (Ω) | TGR stable value (Ω) |
|-------------------|--------------------|----------------------|
| \( d_2 \) (m)    | \( l_2 \) (m)     | \( \sigma_2 \) (S/m) |
| normal            | 46.89              | 36.45                |
| 0.4               | 0.0005             | 50.59                |
|                   | 0.005              | 38.06                |
|                   | 0.01               | 35.76                |
|                   | 0.02               | 34.27                |
| 0.6               | 0.01               | 30.92                |
| 0.8               | 0.01               | 27.41                |
| 1.0               |                    | 24.71                |
| 0.4               | 0.01               | 34.68                |
| 2.4               |                    | 34.63                |
| 2.6               |                    | 34.23                |
| 2.8               |                    | 25.67                |

4.2. The influence of double matching layer

In this part, we talk about the effect of double matching layer on the TGR of the vertical grounding rod and mainly focus on the matching layer conductivity. The size of matching layer is inner layer \( d_2 = 0.4 \) m, \( l_2 = 2.2 \) m and outer layer \( d_3 = 0.6 \) m, \( l_3 = 2.4 \) m. We calculate two kinds of situation, one is keeping \( \sigma_2 = 0.01 \) S/m and setting \( \sigma_3 = 0.0005 \) S/m, \( 0.005 \) S/m, \( 0.02 \) S/m, the other is keeping \( \sigma_3 = 0.01 \) S/m and setting \( \sigma_2 = 0.0005 \) S/m, \( 0.005 \) S/m, \( 0.02 \) S/m. The results are shown in Fig.15 and Fig.16.

We can learn from Fig.15 that both of the peak and stable value of the vertical grounding rod TGR reduce, compare with normal case, as single matching layer exists. The TGR value will reduce even more than single matching layer case, and the conductivity of outer matching layer must be larger than that of ground. Moreover, the TGR value will reduce with the \( \sigma_3 \) increasing when \( \sigma_2 \) and \( \sigma_3 \) are invariants.

![Fig.15: The TGR of vertical grounding rod with no, single and double matching layers](image-url)
Fig. 16: The TGR of vertical grounding rod with no and double matching layers

Fig. 16 shows that both of the peak and stable value of the vertical grounding rod TGR reduce greatly, compare with normal case, as double matching layer exists. The TGR value will reduce with $\sigma_2$ increasing when $\sigma_1$ and $\sigma_3$ are invariants.

The peak and stable value of the vertical grounding rod TGR with double matching layer in Fig.15 and Fig.16 are shown in Tab.2.

Tab.2: The peak and stable value of the vertical grounding rod TGR with double matching layer

| Parameter setting | TGR peak value (\(\Omega\)) | TGR stable value (\(\Omega\)) |
|-------------------|---------------------------|-----------------------------|
| $\sigma_2$ (S/m)  | $\sigma_3$ (S/m)          |                             |
| normal            | 46.89                     | 36.45                       |
| single matching layer | 35.76                 | 27.13                       |
| $\sigma_2$=0.01S/m | $\sigma_3$=0.01S/m      |                             |
| 0.01              | 0.0055                    | 36.05                       |
|                   | 0.005                     | 30.66                       |
|                   | 0.02                      | 27.74                       |
| 0.0005            | 0.01                      | 34.97                       |
| 0.005             | 0.01                      | 30.26                       |
| 0.02              |                          | 28.11                       |

5. Conclusions

In this paper, the single and double matching layer cases are discussed and we can draw the following conclusions.

For single matching layer:
1) The matching layer can affect both of the peak and stable value of TGR. The peak and stable value of TGR reduce as the matching layer conductivity increase.
2) All the TGR waveforms are similar and the rise edge of waveforms become gentle. In addition, the conductivity of matching layer must larger than that of ground, otherwise the value of TGR will become larger.
3) Both of the peak and stable value of TGR reduce as the matching layer vertical length and section side length increase, but the extent is different. The adding of section side length can reduce more TGR value than that of vertical length. The effect of vertical length is not obvious and the effect of section side length is nonlinear.

4) The increasing of contact area between matching layer and ground can reduce the TGR value of ground rod effectively.

5) The most effective way of reducing the TGR is increasing the matching layer section side length; secondly, the matching layer conductivity; finally, the matching layer vertical length.

For double matching layer:
1) Both of the peak and stable value of the vertical grounding rod TGR reduce greatly, compare with normal case, as double matching layer exists.
2) The TGR value reduce even more than single matching layer case when the conductivity of outer matching layer is larger than that of ground.
3) The TGR value will reduce with the conductivity of outer matching layer increasing when inner layer and ground conductivity are invariants.
4) The TGR value will reduce with the conductivity of inner matching layer increasing when outer layer and ground conductivity are invariants.
5) We can get smaller TGR peak and stable value when inner matching layer conductivity is less than outer layer one for the same set of matching layer conductivity, but the difference is not obvious.

**Competing Interests**
The authors declare that there is no conflict of interests regarding the publication of this paper.

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6. References

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