Model Research of Soil Structure Based on Demand of Lightning Protection Grounding

Li Doudou

(No.1 Middle School of Zhengzhou, Zhengzhou, Henan,450000)

Abstract： Soil resistivity is one of the major factors which affect grounding resistance, and plays an important role in the effect of lightning protection grounding. Based on genetic algorithms, this paper has established a resistivity model for common and simple layered soil and has been used together with the complex image method to analyze a 2-level structure soil. Comparison among the insitu measurements, calculations from international famous software package CDEGS and the results from our genetic model indicates that this method is valid and the complex image method is still effective in soil inversion application, and can invert all kinds of complicated layer of soil

Key Words: Lightning Protection, Soil Structure, Model

1 Introduction

Soil resistivity is one of the most important factors of affecting grounding resistance, so the design of lightning protection grounding must have an overall understanding of rock-soil resistivity of project site. In 1921, Schlumberger applied the underground substance's resistivity to actual measurement in France. He used this method to conduct current to underground known depth, then measure resistivities of different depths. This method is one of the most effective methods of studying underground shallow substance. It can detect underground substance and the range of geological structure resistivity from underground a few meters to several hundred meters. It even can help to distinguish underground substance category, overburden structure and bedrock depth, and determine sand, metal sediment underground water layer's thickness and depth, and detect faulted zone, etc.

The Designing of grounding device is according to measured soil resistivity to make grounding resistance meet lightning protection and normal operation of power equipments, and make the step voltage above grounding device meet the safety requirements of human body [2]. Grounding resistance of grounding device mainly is the function of deep soil resistivity, but touch voltage and step voltage mainly are the soil resistivity function of surface soil above grounding device.

Zhang Bo and Yang Huina at Tsinghua University used frequency domain electromagnetic field numerical calculation method to study substation grounding network, respectively [1]. The defect of this study was not to consider the effect of nonlinear electric breakdown caused by lightning surging current of soil surrounding grounding body. Lu Zhiwei deeply studied the numerical calculation methods to grounding network equipotential and unequal potential and the effects of power current to power station and substation grounding system [2].

M.NabLtnan introduced analytical calculation formulas of grounding resistance of compound grounding screen in 2-layer soil, touch voltage and step voltage [3]. Professor Y. L. Chow of Canada Waterloo University studied analytical calculation formulas of grounding resistance of horizontal grounding screen in uniform soil and 2-layer soil [4]. In 2004, Professor F. P. Dawalibi of Canada published detailed parameters analysis of 2-layer soil grounding system performance in Seventh International Science and Technology Development Conference. He studied performance of typical grounding system, including grounding resistance, step voltage, touch voltage and affected parameters of 2-layer soil, and proposed some problems need to be further studied [5].

Soil resistivity is an important parameter of lightning protection design, and it also is one of the important parameters to estimate grounding resistance, ground potential gradient, step voltage, touch voltage, and calculation of inductance coupling between adjoining power line and communication line. In addition, it is an important reference of analysing lightning disasters and summarizing lightning protection experience. Just because soil resistivity is crucial to grounding, , it is particularly critical to test soil resistivity and analyse the test data before grounding design and constructing. However, limited by current test method to soil resistivity, the obtained soil resistivity actually is apparent resistivity, not the real resistivity of actual soil layer. At present, it can determine soil layer, and approximate thickness and resistivity of each layer only through the numeric and experiential methods by using apparent resistivity obtained by test. In this paper, through comparing with analysis methods of measured data, I obtain a reasonable algorithm to different types of soil, and establish a reasonable soil structure model, which provide basic information for grounding design and construction.

2 Establishment of 2-layer Soil Structure Model Based on Genetic Algorithms

Soil resistivity is one of the major factors of affecting grounding resistance. Due to different soil types, water contents and chemical compositions, the soil resistivity can vary widely. Traditional grounding screen analysis method regard actually non-uniform soil as uniform structure. If grounding screen occupies a larger area, when failure happens, most of current will flow away through underground deep soil. Therefore before grounding network design, it need a better understanding to soil structure of network location from the consideration of resistivity.

1.1 Basis of Modeling

The soil resistivity measured by Venner Equidistant Four-pole Method is an apparent resistivity presented by whole action of uneven soil, not the true value of soil resistivity. The measured resistivity changes with the structure and measuring poles spacing. When the poles spacing is small, most of current flows away along surface soil, the measured apparent resistivity closes to actual resistivity of surface soil. With the poles spacing increasing, current will pass through deep soil, the measured soil resistivity will gradually reflect the situation of deep soil resistivity. So for the engineering, the spacing between 2 current measurement probe poles is refered as measured depth. Just because the soil apparent resistivity measured by Equidistant Four-pole Method changes with soil structure and poles spacing, according to constant electromagnetic field theory and mathematical methods, we can invert soil structure parameters by computational software through a set of apparent resistivity values..

The soil data measured by Venner Equidistant Four-pole Method is used as baisc data of establishing soil model. The measuring routing is shown in Figure 1.

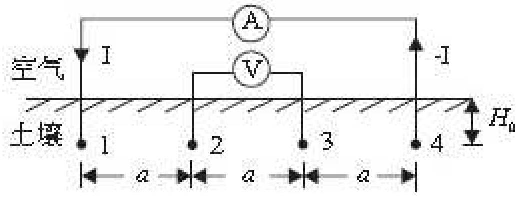

Figure 1 Routing of Venner Equidistant Four-pole Method

In the Figure 1, a is the spacing between measurement probe poles, H_0 is the depth of pole, poles of 1 and 4 are current poles, 2 and 3 are voltage poles. When the four poles are in the same straight line, the situation to the uniform soil is as follows [29]:

When H_0=0: $$\rho_a = \frac{2\pi a V_{23}}{I} \qquad (1)$$

When $H_0 \neq 0$, $V_{23} = \frac{\rho I}{4\pi}[\frac{1}{a} + \frac{2}{\sqrt{a^2+(2H_0)^2}} - \frac{2}{\sqrt{(2a)^2+(2H_0)^2}}]$ （2）

$$\rho = \frac{4\pi a \frac{V_{23}}{I}}{\frac{1}{a} + \frac{2}{\sqrt{a^2+(2H_0)^2}} - \frac{2}{\sqrt{(2a)^2+(2H_0)^2}}} \quad (3)$$

All formulas above are valid for only the uniform soil structure.

Figure 1 is refered as a horizontal multilayer soil model. Generally, it is assumed that the four poles are placed in the surface of shallow soil in the same level as the first layer. Soil resistivity is obtained by formula (1). Under the situation of multilayer soil, it is the apparent resistivity. Potential expression of point current source in first layer soil of surface is as follows [30]:

$$\phi = \frac{\rho_1 I}{4\pi}\int_0^\infty \{[1 + A_1(\lambda) + B_1(\lambda) J_0(\lambda_a)]\} d\lambda \quad (4)$$

When soil is horizontal multilayer, we can obtain potential V_{23} measured by Equidistant Four-pole Method from above formula as:

$$V_{23} = \frac{\rho_1 I}{4\pi}\int_0^\infty \{[1 + A_1(\lambda) + B_1(\lambda)]\cdot[J_0(\lambda_a) - J_0(2\lambda_a)]\} d\lambda \quad (5)$$

Substitute formula 5 into formula 1 and we can obtain:

$$\rho_a = a\rho_1 \int_0^\infty \{[1 + A_1(\lambda) + B_1(\lambda)]\cdot[J_0(\lambda_a) - J_0(2\lambda_a)]\} d\lambda \quad (6)$$

We can find by recursive method that undetermined coefficient $A_1(\lambda)$ and $B_1(\lambda)$ B(λ) are related to each layer resistivity and depth of multilayer soil, so apparent resistivity is the function of some parameters of soil. When h_0=0, formula 6 will become the following formula:

$$\rho_a = a\rho_1 \int_0^\infty \{[1 + B_1(\lambda)]\cdot[J_0(\lambda_a) - J_0(2\lambda_a)]\} d\lambda \quad (7)$$

The undetermined coefficient $A_1(\lambda)$ and $B_1(\lambda)$ B(λ) in formula 6 are spread by complex image method, so the apparent resistivity can be further simplified as follows:

$$\rho_a = a\rho_1(A + B) \quad (8)$$

$$A = \frac{1}{2a} + \frac{1}{\sqrt{a^2+(2H_0)^2}} - \frac{1}{\sqrt{(2a)^2+(2H_0)^2}} \quad (9)$$

$$B = \sum_{j=1}^{N} c_i[\frac{1}{\sqrt{a_j^2+d_i^2}} - \frac{1}{\sqrt{(2a_j)^2+d_i^2}} + \frac{1}{\sqrt{a_j^2+(d_i-2H_0)^2}} - \frac{1}{\sqrt{(2a_j)^2+(d_i-2H_0)^2}}] \quad (10)$$

In the formulas: a is the distance between poles; H_0 is the depth of electrode embedded in soil, c_i and d_i are the size and position of complex image source.

1.2 Establishment and Optimization of Objective Function

The establishment of objective function which measures m values of apparent resistivity, should be able to find a set of soil structure parameters to set up the following formula:

$$f(x')=\sum_{i=0}^{m}[\frac{\rho_{ci}-\rho_{mi}}{\rho_{mi}}]^2=\min \qquad (11)$$

where ρ_{mi} is the measured value when pole spacing is a_i ; ρ_{ci} is the calculated value by complex image method when pole spacing is a_i , x' is column vector, the expression is as follows:

$$x'=(H_1,H_2,\cdots,H_{n-1},\rho_1,\rho_2,\cdots,\rho_n) \qquad (12)$$

Objective function $f(x')$ is the relative variance of calculating soil resistivity ρ_{ci} and actually measuring soil resistivity, optimization purpose is to make variance minimize.

In the model, minimum variance can be achieved by improving genetic algorithm. Genetic algorithm replaces parameter space by encoding space, with fitness function as evaluation basis, with encoding groups as evolution basis, with genetic operation to groups bit string to achieve selection and genetic system to establish an iterative process [6-7]. In this process, by randomly regroup encoding bits to string important genes to make new generation of bit string set optimize the older , the individuals of group continue to evolve, gradually approach the optimal solution, and ultimately achieve the purpose of solving problem. In the process of soil parameters inversion calculation optimization, setting genetic algorithm parameters as resistivity and thickness of each layer solil; encoding method uses floating-point encoding method; fitness please see formula 11 $f(x')$. Three basic operators of genetic strategy respectively choose gamble selection operator, single-point matching crossover operator and random variation operator. The feature of genetic algorithm different with classical optimization algorithms is that, when used for solving optimization, genetic algorithm begins to optimizing from many initial points, and searches along multi-path to achieve the whole situation or quasi-whole situation optimize.

2 Validation of Model

Take as example a 2-layer soil. Table 1 lists a group of measuring results of soil apparent resistivity obtained with the Equidistant Four-pole Method. The results from the multi-layer soil apparent resistivity model and CDEGS package, respectively, are shown in Table 2 for the 2-layer soil structure. The genetic parameters chosen for compution are as follows: group size = 300, maximum algebra = 600, crossover probability = 0.68, mutation probability P= 4.95%.

Table 1 Measured apparent resistivity as a function of pole distance

Distance between pole (m)	1.0	5.0	10.0	25.0	50.0	80.0	120.0	200.0	300.0
Apparent resistivity Ω·m	32.6	35	41.6	70.1	100.2	113.5	138.5	212.6	261.5

Table 2 Calculated Results from the genetic model and CDEGS

Layer No.	Result from the genetic model		Results from CDEGS	
	Resistivity	Soil thickness	Resistivity	Soil thickness
1	34.33	20.28	37.15	21.3
2	301.45	∞	294.7	∞

Comparison of the resistivity measured and those calculated with the genetic model and CDEGS as a function of pole distance is shown in Figure 2.

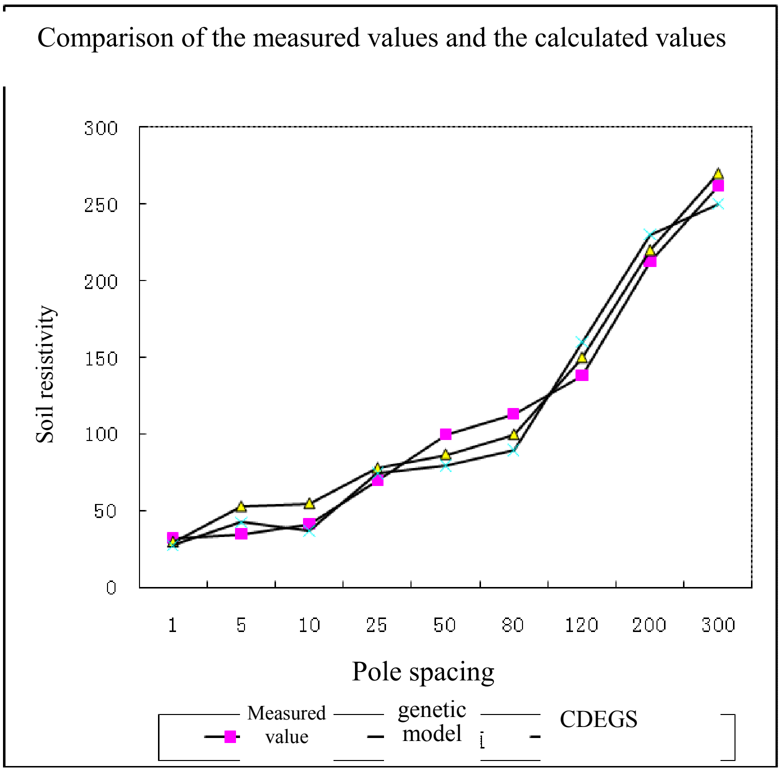

Table 2 Comparison between the measured and the calculated resistivity

3 Conclusion

The performance of grounding system is closely related to its surrounded soil resistivity and we can invert soil layered structure by analysing measured data according to measuring principle of soil resistivity. Though there are many methods for measuring soil resistivity, each has its own advantages and disadvantages. Different methods are aiming at different situations. The model suggested in the paper based on the genetic algorithm can invert soil layered structure. Comparison among the insitu measurements, calculations from international famous software package CDEGS and the results from our genetic model indicates that this method is valid.

References

[1] Yang Huina, Ground Model Determination and Grounding Screen Transient State Simulation Calculation: [Thesis of Ph.Degree], Tsinghua University, Beijing, 2003

[2] Lv Zhiwei, Calcualtion and Measurement of Large-scale Grounding Screen Power Frequency Grounding Parameters [Thesis of Ph.Degree], Wuhan University, 2004

[3] M. M. A Salama Y. L. Chow. A formula for resistance of substation grounding grid in 2-layer soil [J] IEEE Transactions on Power Delivery,1995，10(3):1255-1262.

[4] Y. L. Chow，M. M. A Salama. A simplified method for ca1cu1ating the substation grounding Grids resistance [J]. IEEE Transactions on Power Delivery, 1994,9(2):736-741

[5] F.P.Dawalibi, W.G.Finney. Transmission Line Tower Grounding Performance in Non Uniform Soil.IEEE Trans. on PAS,1980,99 (2);471-479.

[6] K.C.Tan,T.H.Lee,Y.J.Yang, et al. A Cooperative Coevolutionary Algorithm for Multiobjective Optimization .IEEE International Conference on Systems, Man and Cybernetics. 2004, :1926-1931.

[7] Takehiko t. calculation of earth resistivity for a deep-driven rod in a multi-layer earth structure[j] .IEEE transaction on power delivery, 1991, 6 (2): 608-614.