The Design of 220kV Substation Grounding Grid with difference soil resistivity using wenner and Schlumberger Methods

Mohammed Abdaldaim Ibrahim, Lin li, and. Ping wang

State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing 102206, China

***Abstract*—This paper presents the design of 220kV substation grounding grid with difference resistivity soil according to horizontal and vertical two layer soil model is structure using the MALT program of CDEGS Software. The target of this paper is to minimize the touch and step voltages when the resistivity soil is high, in 220kV urban substation pending a direct lightning stroke. Also, it is shown that for a sensor located on the ground, close to 220kV substation, the magnetic field component vertical to the structure can also experience a considerable attenuation, perhaps due to the effect of the induced currents in the substation. The results are confirming by numerical simulations, obtained using NEC-4 and IEEE Guide for Safety in AC Substation Grounding. The step by step procedure for designing 220kV substation grounding grid has been presented for which design parameters were obtained by CDEGS Software.**

***Index Terms*— Resistivity soil, touch and step voltages, CDEGS Software.**

I. Introduction

IT IS well known that the electrical characteristics of the grounding networks require very high protection from the external effects for example lightning strikes. Therefore, the resistance of the soil to the different types has to be studied.

Furthermore, the analysis of the performance of substation grounding grids with difference soil resistivity using wenner and Schlumberger Methods has received a lot of attention from Researchers[1]-[2]-[3].The objective, of design for substation grounding grid it to include the reliability and safety of the operator in the placement of grounding fault in power system, estimated by the calculation of step and touch voltage critical and a maximum mesh. The modeling and simulation for this paper used by CDEGS (Current Distribution Electromagnetic Filed Grounding and Soil structure analysis) software. This software is a group of incorporated engineering software material designed to rightly resolve problems involving grounding, electromagnetic fields. The analysis was based on the soil resistivity variables and their effects on the design of the ground grid substation with a voltage of 220kV. We focused on two methods to reach the real values that help to reduce the increase of faults, which in turn to stop the substation or to cause human damage. This paper aims to present the design of grounding for analyzing the grounding system, must be the frequency is not variable and limited, which can be calculated or reduced using numerical methods that in turn eliminate the limits of storage and heterogeneous random. To have full stability in the substation and protect from all the effects resulting from the increase of frequency. The study has expanded in this field in recent years[4]- [5]-[6]. In this paper was considering the performance for (uniform, horizontal and vertical) soil by using CDEGS program at 220kV substation which was applied with using wenner and Schlumberger Methods. The mode used in the program was taken from the developed research for the maximum accuracy. The corresponding analysis was adopted to obtain the step and touch voltages for the grounding grid. It is now possible to compute the ground grid resistance, resistivity and ground potential rise (GPR) according to MALT program for CDEGS software.All the above procedures were represented by equations and simulations based on all the selected values in the design of 220kV substation grounding grid. The effects of lightning and its treatment methods were taken into account to ensure safety established. The aims depending on soil ionization and soil values difference with frequency can be used to account if the idea for a design to determine the symmetrical impedance is fit to consider them. In this task they were not believed because the goal was only the representation of the grounding by electrical circuits, regardless of the situations considered, approximations and boundary conditions used. In this paper, we have taken into consideration the consequences of the substation of natural factors such as lightning strike and work to reduce them to ensure the safety of all internal and external equipment.

II. DESIGN OF 220KV SUBSTATION GROUNDING GRID

The substation is designed according to the IEEE &NEC4 standards[7]-[8]. Adopted to reduce the damage caused by the lightning and excessive efforts that lead to negative effects on the substation and the human element. Assessment design of 220kV substation used MALT model of CDEGS, and adopt the optimal measures to procure the safety parameters such as the touch and step voltages. The area of the substation is 58.5 x36m, and the soil divided into two layers. The depth of first horizontal layer is 5 m, and the soil resistivity is variables between 100 to 5000 Ω•m for wenner Method, and the soil resistivity of the second horizontal layer is 100 Ω•m. The preliminary design of the substation grounding grid is shown in Fig.1.

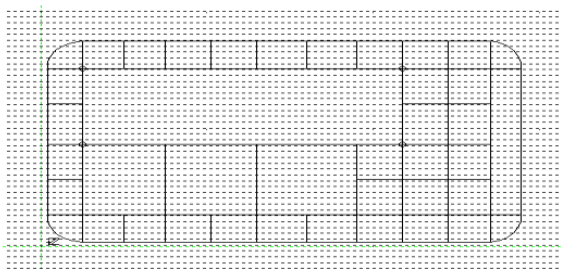

Fig1. Grounding grid 220Kv substation using CDEGS software.

A. Soil resistivity

The performance for the resistance was done by using MALT module of CDEGS program, is obtained by using differences value of resistivity, because this value was reduced the touch voltage. The touch voltage was very high for some standard value of surface soil resistivity it is so dangers for human but in high soil resistivity (3000-5000 Ω•m) [3]. That means this substation will be protected from the risk of touch voltage and lightning. In this substation, the conductor of the grounding grid can safety the 220kV substation on high resistivity.

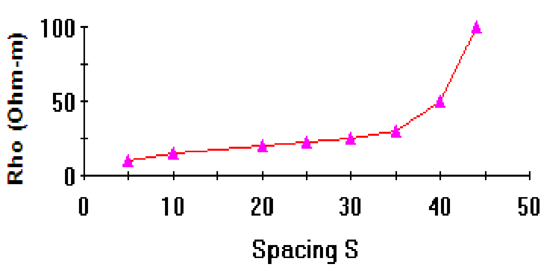

Fig.2. Resistivity soils with difference spacing using wenner method.

B. The resistance of ground grid (Rg)

The resistance of the ground grid (Rg) is given by[9].

$$R_g = \rho_2 / \sqrt{\pi / A} \, for \, \rho_2 \prec \rho_1 \prec h_b$$

$$R_g = \frac{(\rho_2\sqrt{\pi A}+h_1\rho_1\pi(23.16\ln(\frac{\rho_2}{\rho_1}+31.9)-78)*(1+1.95e^{-20\frac{h_1\sqrt{\pi}}{\sqrt{A}}}-0.3e^{-0.5\frac{h_1\sqrt{\pi}}{\sqrt{A}}})}{(4A+4h_1\sqrt{\pi A}(23.16\ln(\frac{\rho_2}{\rho_1}+31.9)-78*(1+1.95e^{-20\frac{h_1\sqrt{\pi}}{\sqrt{A}}}-0.3e^{-0.5\frac{h_1\sqrt{\pi}}{\sqrt{A}}})}$$

$$(\rho_2 \prec \rho_1, h_1 \geq h_b)$$

$$R_g = \frac{(\rho_2\sqrt{\pi A}+h_1\rho_1\pi(23.16\ln(\frac{\rho_2}{\rho_1}+31.9)-78)*(1+1.55e^{-15\frac{h_1\sqrt{\pi}}{\sqrt{A}}}-0.1e^{-0.25\frac{h_1\sqrt{\pi}}{\sqrt{A}}}+0.2e^{\frac{h_1\sqrt{\pi}}{\sqrt{A}}})}{(4A+4h_1\sqrt{\pi A}(23.16\ln(\frac{\rho_2}{\rho_1}+31.9)-78*(1+1.55e^{-15\frac{h_1\sqrt{\pi}}{\sqrt{A}}}-0.1e^{-0.25\frac{h_1\sqrt{\pi}}{\sqrt{A}}}+0.2e^{\frac{h_1\sqrt{\pi}}{A}})}$$

$$(\rho_2 \geq \rho_1) \quad (1)$$

In Fig.1 the purpose of design for the present work is to improve formulation to calculate with a sensible accuracy the grounding resistance of a rod in a homogeneous and two-layer soil. The result of this paper is two normal formulas to be used over with standard resistance formula (used to calculate the resistance rod in difference resistivity soil) For calculated grounding resistance and soil resistivity by wenner and Schlumberger Methods.In this paper, by using CDEGS software to simulate grounding grid in vertical and horizontal multi-layer soil under different conditions, consequently as to work out engineering equation and analyze its error range and presented to obtain the behavior of the test methods in all conditions, a theoretical analysis is made based on a two-layer soil status. Uniform soil and multilayer soil can be harmonized. The procedure explained the accurate computation of earthing suit resistance and the voltage profile. The obtained results have been established by comparison with other analytical and numerical methods[10]. Basic equations for calculation the resistances were developed in the introduction because they are the foundation of design and analysis. The theory used in the design depends on the electrodes with the least number of variables.

III. SAFETY CRITERIA FOR SUBSTATION GROUNDING DESIGN

In substation any human may be subjected to five shock situations namely, Step voltage, Touch voltage, Mesh voltage, Metal to metal touch voltage. Step and Touch voltage are applied to derive the safety criteria for Grounding grid design. A good grounding system must have the existing mesh and step voltages well below possible touch and step voltages respectively. The principal regard that is taken into account for substation grounding design is that under any condition actual step, and mesh voltages must not override the tolerable Voltage limit[11].

TABLE1
MEASUREMENT FOR EARTHING RESISTIVITY USED WENNER METHOD

Measure--ment number	Spacing (m)	Resistivity(Ω-m) (R)	calculated
R1	5	10	0.3
R2	10	15	0.2
R3	20	20	0.15
R4	25	22	0.14
R5	30	25	0.13
R6	35	30	0.12
R7	40	50	0.19
R8	45	100	0.4
R9	50	100	0.4

IV. MEASURING RESULTS AND ANALYSIS

The total soil resistivity data for different electrode by Wenner and Schlumberger configuration ware measured [12], too. All the resulted explain measured soil in the west -south of the substation are different from the results measured in the north-east of the substation; the intermediate data were shown in Fig.2. The analyzed results present the soil geological structure of the substation can be processed as two horizontal -vertical layers, the Distance from the left current probe to media interface line 11.531m.

TABLE2
LAYER CHARACTERISTIC FOR UNIFORM SOIL RESISTIVITY USED CDEGS SOFTWARE

Layer Number	Spacing (m)	Resistivity(Ω-m)	P.U	Ratio
1	Infinite	Infinite	0.0	1.0
2	26.56299	30000.00	-1.0000	0.26563E
3	1000	Infinite	0.94825	73.646

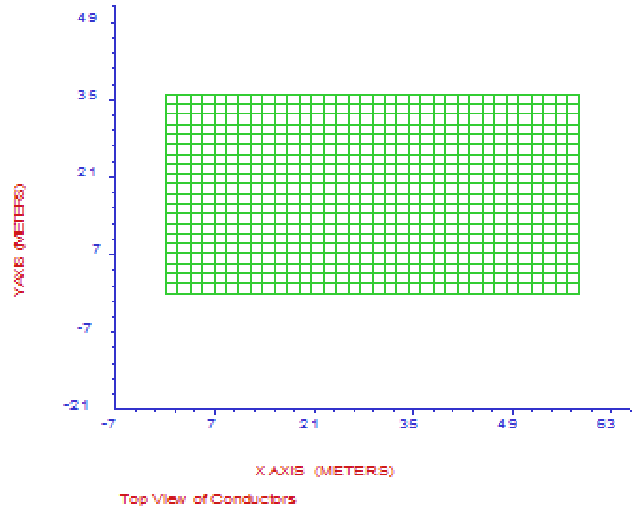

Fig. 3. Configuration for 220kV substation used MALT program.

All the discussion were derived based on [13]-[14]-[15], the utilization of grounding grid is defined as the random between the equivalent resistance and resistivity of two or more rod electrodes infinitely separated. The principle of the deep ground well is to lead protection the substation; furthermore, the deep ground for wenner and Schlumberger Methods can be used in high resistivity soil. in the process of analyzing results for the previous studies, which were based on the values of quality for high resistance, whenever it is high the possibility of design and stability of the substation is easy . Some researchers focused on increasing the depth of electrodes to avoid any similar failures.

TABLE 3
CONFIGURATION OF MAIN ELECTRODE

MALT-CDEGS software	
Original Electrical Current Flowing In Electrode	1000.0 A
Current Scaling Factor (SPLITS/FCDIST/specified)	1.000
Adjusted Electrical Current Flowing In Electrode	1000 A
Number of Conductors in Electrode	52
Number of Metallic Plates in Electrode	1
Resistance of Electrode System	0.71717
Total Number of Metallic Plates Elements	*476*
Total Buried Length of Main Electrode	*2488.5A*
Total Buried Area of Metallic Plates in Main	2106.0 m

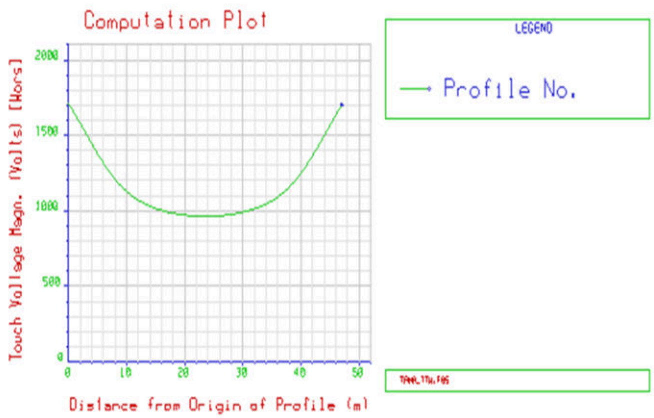

Fig. 4. Computation plot for Touch voltage used MALT program.

Advancement of the design methodology as follows: (a) the planning method can calculate the resistivity soil of ground rod buried in two layer soil. (b) All ground resistance and the step voltage can be decreased. In wenner method, the earth surface voltage and the touch voltage decrease as the depth of the buried ground rod increases. (c) The numbers of ground rods can be minimization if are buried deep. (d) A layer of high resistivity material, like as gravel is often high spread on the earth's surface over the ground grid rods to excess the resistance between the soil and the feet of persons in the substation [16]-[17].The layer of high resistivity material can be superficial.

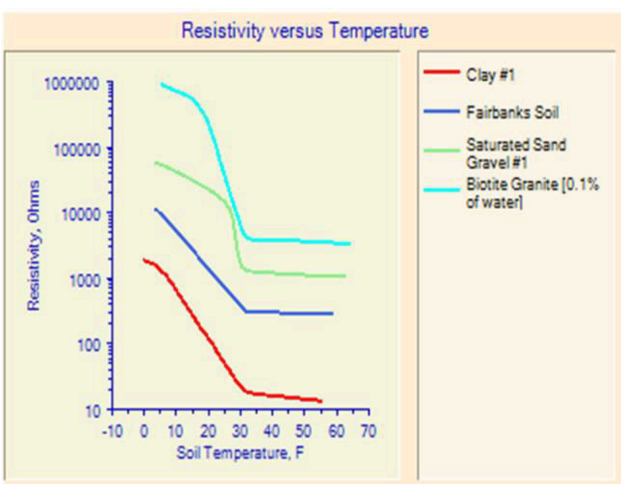

Fig.5. Chart between soil temperature and resistivity for differences soil by CDEGS software

TABLE 4
MAXIMUM ALLOWABLE GRID FOR TOW LAYER SOIL (10 TOP-100 BOTTOM)

Symbol	Max Allowable Value	Computed value	grid status
Grid Potential Rise	5000.0000 V	717.1670 V	**Acceptable**
Touch Voltage	180.3544 V	179.8463 V	**Acceptable**
Step Voltage-Within Grid	253.4711 V	15.6318 V	**Acceptable**
Step Voltage -Outside Grid	253.4711 V	15.7057 V	**Acceptable**

An analysis of the results showed in Table 4 indicate that the presence of rods in the horizontal and vertical reduced the step, touch voltage, and Grid Potential Rise more effectively the performance of substation optimization. Furthermore, when the aground grid has sufficient electrodes, it must be more effective in optimizing, its design than reproducible the electrode number. The process of increasing the electrodes in the design of the 220kV substation helps to reduce the external influences. All the selected values in the design were built by the broader representation of the conservative for a method of the network, which in turn avoided the substation causing the occurrence of any defect. Some previous studies were based on this method and ware taken[18]-[19]-[20].The soil resistivity interpretation, which was done by using MALT module of CDEGS program, is obtained by using the high value of resistivity because this value is reduced the touch voltage Since in table 4. the touch voltage is very high for some standard value of surface soil resistivity this voltage is very dangerous for human, however in high soil resistivity (10 -100 Ω•m) the touch voltage is reduced, that means the substation can be used in the system .furthermore the step voltage is good for all standard value of the system. In this substation, the conductor of the grounding grid can safety the 220kV substation for high resistivity. The maximum value of the current was estimated based on the resistance values that the substation needs to perform to repair the faults. The previous studies indicated the possibility of changing the current dependent on the grounding potential rise (GPR). In this paper, we tried to find logical solutions to solve the problems resulting from the soil were chosen suitable values for the resistance of the quality of the soil. All the forms in this paper indicate positive solutions to help in their implementation. .

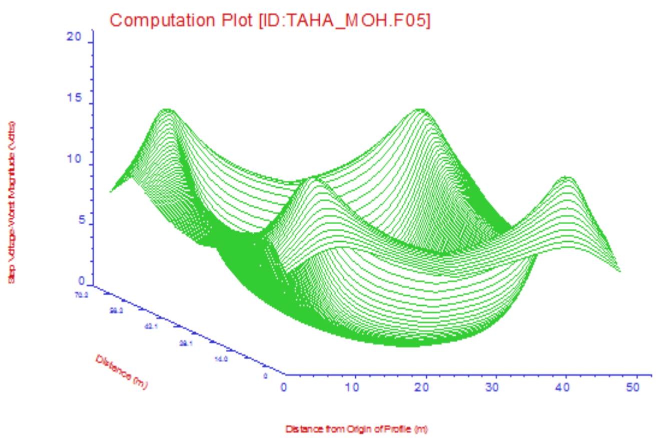

Fig.6. 3D- regular enhanced for Step voltage resulted used CDEGS software

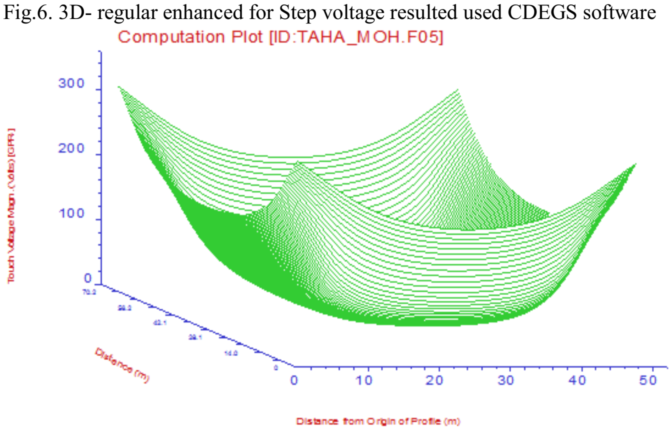

Fig.7. 3D- regular enhanced for Touch voltage resulted used CDEGS software.

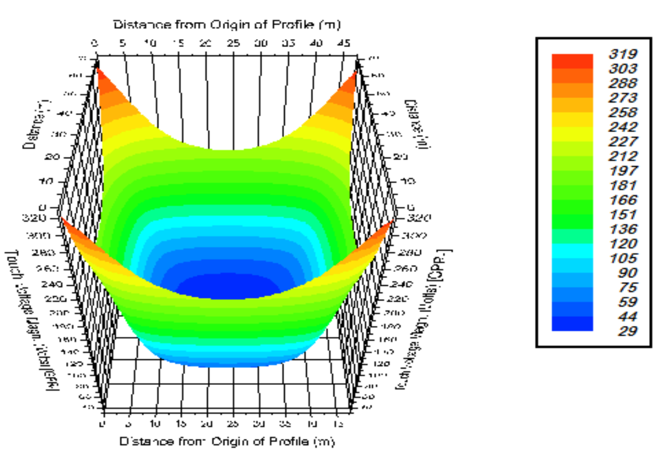

Fig.8. 3D- computation advanced for step voltage (GPR) by CDEGS software.

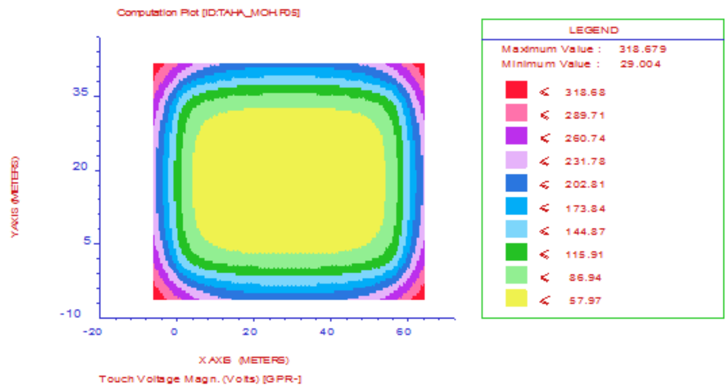

Fig.9. computation for Touch voltage Magnitude (GPR) by CDEGS software

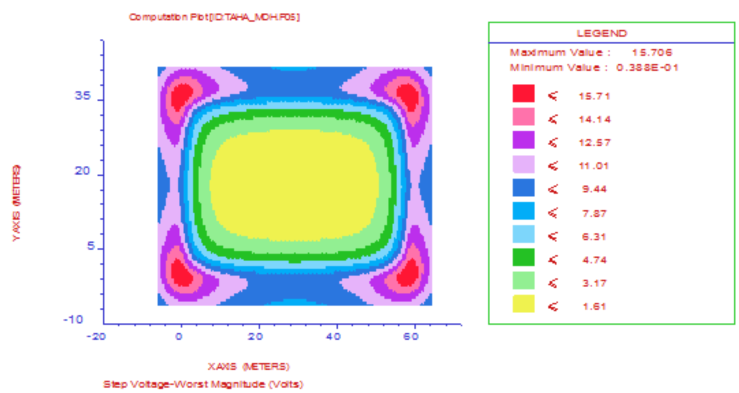

Fig.10. computation for Step voltage Magnitude (GPR) by CDEGS software

V. CONCLUSION

In this paper, we focused for design 220kV grounding grid substation with difference soil resistivity using wenner and Schlumberger Methods. In the design optimization process, the step by step transaction for designing earth grid has been presented for which the design parameters were obtained by CDEGS Software. It was detected that the touch and step voltage requires a high increase in the value of soil resistivity. We adopted the design of this substation to choose suitable values for quality resistance and resistivity soil to avoid risk for human and equipment. The high simulation method and the quantity full equations were used for this purpose. The suggested technique applies to high and combination earthing grounding systems furthermore with horizontal and vertical two-layer soil. The 220kV substation ware built models by the CDEGS software with the measured data accorded to analysis design , it results that the Wenner and Schlumberger method often takes a simple horizontal and vertically layered structure of upper two layers The consideration was considered that the earthing for grounding grid substation could be improved by decrease the grounding potential rise and resistance effect by controlling the distribution of current injected to the soil.

REFERENCE

[1] T. Takahashi, and T. Kawase, "Calculation of earth resistance for a deep-driven rod in a multi-layer earth structure," *IEEE Transactions on Power Delivery,* vol. 6, no. 2, pp. 608-614, 1991.

[2] J. Ma, F. Dawalibi, and R. Southey, "On the equivalence of uniform and two-layer soils to multilayer soils in the analysis of grounding systems," *IEE Proceedings-Generation, Transmission and Distribution,* vol. 143, no. 1, pp. 49-55, 1996.

[3] P. Lagace, J. Houle, Y. Gervais, and D. Mukhedkar, "Evaluation of the voltage distribution around toroidal HVDC ground electrodes in N-layer soils," *IEEE Transactions on Power Delivery,* vol. 3, no. 4, pp. 1573-1579, 1988.

[4] X. Long, M. Dong, W. Xu, and Y. W. Li, "Online monitoring of substation grounding grid conditions using touch and step voltage sensors," *IEEE Transactions on Smart Grid,* vol. 3, no. 2, pp. 761-769, 2012.

[5] M. Unde, and B. Kushare, "Grounding grid performance of substation in two layer soil–a parametric analysis," *International Journal of Engineering Sciences & Emerging Technologies,* vol. 1, no. 2, pp. 69-76, 2012.

[6] J. Trifunovic, and M. Kostic, "Analysis of the influence of imperfect contact between grounding electrodes and surrounding soil on electrical properties of grounding loops," *Electrical Engineering,* vol. 96, no. 3, pp. 255-265, 2014.

[7] J. Ma, F. Dawalibi, and R. Southey, "Effects of the changes in IEEE Std. 80 on the design and analysis of power system grounding." pp. 974-979.

[8] G. J. Burke, and A. J. Poggio, "Numerical electromagnetics code (NEC)-method of moments," *Rep. UCID18834, Lawrence Livermore Lab*, 1981.

[9] M. E. Rizk, M. Lehtonen, Y. Baba, and S. Abulanwar, "Performance of Large-Scale Grounding Systems in Thermal Power Plants Against Lightning Strikes to Nearby Transmission Towers," *IEEE Transactions on Electromagnetic Compatibility*, 2018.

[10] J. Ma, and F. P. Dawalibi, "Analysis of grounding systems in soils with finite volumes of different resistivities," *IEEE Transactions on Power Delivery,* vol. 17, no. 2, pp. 596-602, 2002.

[11] K. A. Vyas, and J. Jamnani, "Development of IEEE complaint software'economical substation grounding system designer'using matlab gui development environment," *International Journal on Electrical Engineering and Informatics,* vol. 4, no. 2, pp. 335, 2012.

[12] J. He, G. Yu, J. Yuan, R. Zeng, B. Zhang, J. Zou, and Z. Guan, "Decreasing grounding resistance of substation by the deep-ground-well method," *IEEE transactions on power delivery,* vol. 20, no. 2, pp. 738-744, 2005.

[13] I. Colominas, F. Navarrina, and M. Casteleiro, "A numerical formulation for grounding analysis in stratified soils," *IEEE Transactions on Power Delivery,* vol. 17, no. 2, pp. 587-595, 2002.

[14] I. Colominas, F. Navarrina, and M. Casteleiro, "Numerical simulation of transferred potentials in earthing grids considering layered soil models," *IEEE TRANSACTIONS ON POWER DELIVERY PWRD,* vol. 22, no. 3, pp. 1514, 2007.

[15] J. E. Lucius, J. D. Abraham, and B. L. Burton, *Resistivity Profiling for Mapping Gravel Layers that may Control Contaminant Migration at the Amargosa Desert Research Site, Nevada*: US Geological Survey, 2008.

[16] IEEE, *IEEE guide for safety in AC substation grounding*: IEEE, 2000.

[17] L.-H. Chen, J.-F. Chen, T.-J. Liang, and W.-I. Wang, "Calculation of ground resistance and step voltage for a buried ground rod with insulation lead," *Electric Power Systems Research,* vol. 78, no. 6, pp. 995-1007, 2008.

[18] E. Bendito, Á. Carmona, A. M. Encinas, and M. J. Jiménez, "The extremal charges method in grounding grid design," *IEEE transactions on power delivery,* vol. 19, no. 1, pp. 118-123, 2004.

[19] M. A. Elrahman, "An advanced technique for earthing system analysis," *IEEE Transactions on Power Delivery,* vol. 28, no. 1, pp. 268-275, 2013.

[20] L. Fengjiao, Y. Jiayan, S. Kai, L. Yanqing, L. Yueyu, and W. Yaoxi, "Research on optimizing visual soil resistivity test method based on a theoretical algorithm." pp. 1-6.

Mohammed Abdaldaim Ibrahim was born in Khartoum, Sudan, in 1985. He received the B.Sc. degree in Electrical & Electronic Engineering from the Omdurman Islamic University of Sudan in 2008, M.SC degree in Control Engineering from the ALNeelain University of Sudan in 2015. Where he is currently pursuing the Ph.D. degree in electrical engineering with the North China Electric Power University, Beijing, China. His current research interests include the optimized design of substation grounding grid and transmission line depending on parameter magnetic components and change variables.

Lin Li received the B.Sc. and M.Sc. degrees in automation from the Hebei University of Technology, Tianjin, China, in 1984 and 1991, respectively, and the Ph.D. degree in electrical engineering from the North China Electric Power University, Beijing, China, in 1997. He is currently a Professor with the Department of Electrical and Electric Engineering, North China Electric Power University, Beijing, China. His research interests include the theory and application of the electromagnetic--eld and electromagnetic compatibility of power systems.

Ping wang received the B. Sc. and M.Sc. degrees from North China Electric Power University, Baoding, Hebei, China, in 2004 and 2007, respectively, and the Ph.D. degree in electrical engineering from the North China Electric Power University, Beijing, China, in 2015. She is currently a lecturer with the Department of Electrical and Electric Engineering, North China Electric Power University, Baoding, China. Her main research interests are in the fields of electromagnetic compatibility, electromagnetic field theory and application.