Optimum Design of Grounding System in Uniform and Non-Uniform Soils Using ANN

O. E. Gouda
Electric Power and Mach., Faculty of Eng. Cairo Univ., osama241@hotmail.com
G. M.Amer
Benha high institute of technology, dr_ghada11@hotmail.com
T. M.EL-Saied
Benha high institute of technology, tamer18@hotmail.com
Correspondence Email: dr_ghada11@hotmail.com

ABSTRACT

Grounding of electrical substations for safety and neutral point by ground rods and grid provides the lowest economical feasible ground resistance in the path of the expected fault current to ground.

In the recent years Artificial Neural Networks (ANNs) have attracted much attention and many interesting ANN applications have been reported in power system areas, due to their computational speed, the ability to handle complex non-linear functions, robustness and great efficiency, even in cases where full information for the studied problem is absent. In this paper, several ANNs were addressed to evaluate apparent soil resistivity and design parameters of ground system for the predetermined grounding resistance value and soil resistivity without any need of complex calculations. These ANN are used to select the optimum dimensions and geometry of grounding system required for obtaining satisfactory ground resistance, and step and touch potentials.

Keywords: Grounding; earthing; rods; non-uniform soil; ANN; grounding grids; grounding impedance.

1. INTRODUCTION

ARTIFICIAL NEURAL NETWORKS

The ANNs represent a parallel multi layer information processing structure. The characteristic feature of these networks is that they consider the accumulated knowledge acquired during training and respond to new events in the most appropriate manner, giving the experience gained during the training process. The model of the ANN is determined according to the network architecture, the transfer function and the learning rule [1].

The basic unit of an ANN is the neuron, which is represented as a node. The name feed-forward implies that the flow is one way and there are not feedback paths between neurons. The initial layer, where the inputs come into the ANN is called the input layer and the last layer where the outputs come out of the ANN, is denoted as the output layer. All other layers between them are called hidden layers [1].

Each network has been constructed using different structures, learning algorithms and transfer functions in order best generalizing ability to be achieved. Actual input and output data, collected from different high voltage plant and simulation program based on IEEE standard, were used in the training, validation and testing process. A comparison among the neural networks results and simulations was performed in order to get accurate ANN design.

This ANN are used as useful tool designing and analysis of grounding system in power plants which is paramount important safety aspect in electrical installations.

2. APPLICATIONS FOR OPTIMUM DESIGN OF GROUNDING SYSTEM BY USING ANN

2.1 Evaluation of Soil Resistivity of Two Layers Using ANN

To design most economical grounding systems, it is necessary to obtain accurate value of the resistivity on the site; the goal is to develop a neural network architecture that could evaluate the apparent soil resistivity of double layer soil.

In this study two layer soil environment with upper layer thickness d1, soil resistivity of upper layer ρ1 and second layer resistivity ρ2 and the apparent soil resistivity ρa could be calculated by the relation [2-4]

Three parameters that affect apparent soil resistivity are selected as the inputs to the neural network, while as the output ρa is considered. These data are presented in table 1

Table 1 ANN Architectures

Input Variables	Output Variables
soil resistivity of upper layer ρ1	apparent soil resistivity ρa
soil resistivity of second layer ρ2	
Upper layer thickness d1	

Each ANN model is determined according to its structure, the transfer function and the learning rule, which are used in an effort to learn the network the fundamental characteristics of the examined problem. The learning rules and the transfer functions are used to adjust the network's weights and biases in order to minimize the sum-squared error. The structure of the networks i.e. the number of hidden layers and the number of nodes in each hidden layer, is generally decided by trying varied combinations for selecting the structure with the best generalizing ability amongst the tried combinations. In general one hidden layer is adequate to distinguish input data that are linearly separable, whereas extra layers can accomplish nonlinear separations [5,6]. This approach was followed, since the selection of an optimal number of hidden layers and nodes for the FF network is still an open issue, although some papers have been published in these areas.

In this work, several FF ANN models were designed and tested. These are combinations of two learning algorithms, three transfer functions and many different structures selected among others due to their best generalizing ability in comparison with the all other tried combinations. The used learning algorithms were the Gradient Descent and the Levenberg-Marquardt, while the transfer functions were the hyperbolic tangent sigmoid the logarithmic sigmoid and the pure-line (table 2).

Finally a comparison among these neural networks is performed and the most suitable network selected and applied

Table 2 Designed ANN Models

Structure	Learning Algorithm	Transfer Function
3/49/1	Levenberg-Marquardt Gradient Descent	- Logarithmic Sigmoid -Linear -Linear

The results of ANN are closed to the simulation and field measured values as shown in Table 3.

Table 3 Results of ANN and simulation

Input Variables			Apparent soil Resistivity by [1]	Apparent soil Resistivity evaluated using ANN	% of Error
ρ1	ρ2	d1	equation	ANN	
10	10	0.5	10	9.9857	-0.14
10	80	1	65.895	65.9	0.01
10	90	0.5	87.646	87.644	0.00
20	10	0.5	10	10.005	0.05
20	10	1	10.089	10.094	0.05
20	110	0.5	109.14	109.14	0.00
30	190	1	164.99	164.99	0.00
30	200	0.5	197.47	197.47	0.00
30	200	1	171.9	171.9	0.00
40	10	0.5	10	10.006	0.06
40	120	0.5	119.81	119.81	0.00

40	120	1	114.55	114.54	-0.01
50	80	0.5	79.983	79.981	0.00
50	100	1	97.842	97.838	0.00
60	110	1	108.04	108.05	0.01
60	200	1	189.26	189.26	0.00
70	10	0.5	10	10.004	0.04

2.2 Optimum Design of Driven Rods Grounding System Using ANN

Ground rods are frequently used in-groups connected in parallel and maybe with grids when the ground resistivity is too high to be satisfactory. of course, current following through any member of such a group will raise the potential of all other members; consequently, the apparent average ground resistance for the individual members of such a group will always be higher than the ground resistance of a similar rod when it is applied alone. This effect is a function of the number of rods and their spacing [8-10].

In practice, it is desirable to drive ground rods deep into the ground to reach more conductive soil. The following equation could be used to calculate the equivalent resistance for n electrode according to IEEE [7,9,10]

$$R_n = (\frac{\rho_a}{2n\pi L}) \cdot (\ln(\frac{8L}{d_2}) - 1 + 2k_1(\frac{L}{\sqrt{A}}) \cdot (\sqrt{n} - 1)^2) \quad (1)$$

Where ρa is the apparent soil resistivity as seen by the ground rod, in case of uniform soil equal ρ1 **Ω-**m, n=number of ground rods placed in parallel area A, L and d2 are the length and diameter of the driven rods in meter respectively, K1= constants related to the geometry of the system could be obtain from the equation

$$K_1 = 1.41 - (0.04) \cdot X \quad (2)$$

X is length to width ratio

ANN for grounding system design using driven rods has two inputs, R which is the required ground system resistance and the apparent soil resistivity ρa and has two output, n which is the number of ground rods and this number rounded as it should be integer value and the length of driven rods in meter L.

The results of ANN and the designed values are shown in Table 4

Table 4 Results of ANN and the designed

Input Variables		**Designed values**		**ANN Results**		**% of Error**	
R	**ρa**	**N**	**L**	**n_{ANN}**	**L_{ANN}**	**n**	**L**
5.7435	100	3	6	3	5.7	0	-5
6.6751	100	3	5	3	5.2	0	4
8.1321	100	3	4	3	4.4	0	10
8.6153	100	2	6	2	5.2	0	-13
10.013	100	2	5	2	4.3	0	-14
11.197	100	3	3	3	3.1	0	3
11.487	200	3	6	3	5.5	0	-8
12.198	100	2	4	2	3.6	0	-10
13.35	200	3	5	3	5.3	0	6
16.264	200	3	4	3	4.5	0	13
16.796	100	2	3	2	3.2	0	7
17.231	100	1	6	1	5.4	0	-10
17.231	200	2	6	2	5.1	0	-15
17.231	300	3	6	4	5.6	33	-7
20.025	100	1	5	1	5.7	0	14

20.025	200	2	5	2	4.9	0	-2
20.025	300	3	5	3	5.5	0	10
22.395	200	3	3	3	3.3	0	10
22.974	400	3	6	4	5.6	33	-7
24.396	100	1	4	1	4.3	0	8
24.396	200	2	4	2	3.5	0	-13
24.396	300	3	4	3	4.4	0	10
25.846	300	2	6	2	5.2	0	-13
25.934	100	3	2	4	2.1	33	5
26.7	400	3	5	3	5.4	0	8
28.718	500	3	6	4	5.7	33	-5

2.3 Optimum Design of Grid Grounding System Using ANN

2.3.1 Design of equal spaced grid using ANN.

I- First part to design grounding system using equally space grid design and it include 2 ANN.

a) first one to evaluate maximum allowable touch voltage for 70kg body and determine the total safe length of grid conductors needed in case of equal space grid and [11,12]

b) Second ANN evaluate the number of conductor in each direction (vertical/horizontal) required for an equally spaced grid where L1 and L2 are the side lengths of the grid, n1 is the number of conductors in parallel with the x axis and n2 is the number of conductors in parallel with the y axis, N_t is the sum of n1 and n2, Table 5 shows the inputs and outputs of the two ANN.

Table 5 Inputs and outputs of the two ANN

	Input Variables	Output Variables
First ANN	ρ is the resistivity of the uniform soil	Etouch70 Max allowable touch voltage
	I_s is fault current.	L Total conductor length required for safe design
Second ANN	L1, L2	n1,n2,N_t
	L	

Applying the proposed ANN for equal space grid design over four different field parameters shown in Table 6

Table 6

	CASE A ρ =400, ρ_S=3000,hs=.1,I_s=10000		**CASE B** ρ=600, ρ_S=2000,hs=.1,I_s=15000	
Area available for design	100 X 100 m	170 X 60 m	100 X 70 m	120 X 120 m
Max allowable touch voltage	844.5 V	844.5 V	665 V	665 V
L Total conductor length required for safe design	4736m	4736m	13530m	13530m
N1	24	27	68	56
N2	24	58	96	56
N_t	48	85	164	112
Em	765	793	318	441
Es	261	507	1295	479

2.3.2 Design of unequal spaced grid using ANN.

II- Second part to design grounding system using unequally space grid design and it include 2 ANN.
a) First ANN evaluates the percentage of grounding grid material that will be saved using unequal spacing, where λ is the percentage of the saved grounding grid material.

b) Second ANN evaluate the number of conductor in each direction (vertical/horizontal) required for an unequally spaced grid Table 7 shows the inputs and outputs of the two ANN.

Table 7

	Input Variables	Output Variables
First ANN	N	λ
Second ANN	λ	n1',n2',N'

Variation of the value of λ with the total number of conductors in parallel are shown in fig.1.

The maximum reduction in grounding material achieved when the number of parallel conductors are closed to ten

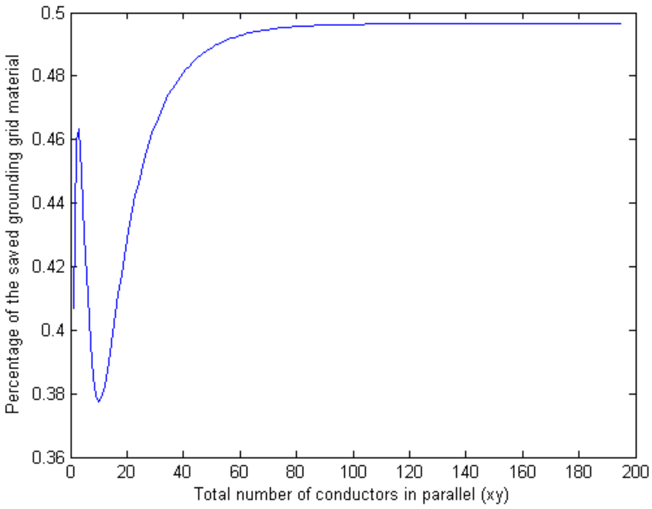

Figure 1: The influence of number of conductors in parallel to percentage of the saved grounding grid material.

2.3.2.1 Evaluation of optimum compression ratio in case of uniform soil

The gradient of earth surface potential above the large equidistant substation is big, and the leakage current densities of those conductors are not uniform.

To equalize the potential on the earth surface, and to ensure the safety of equipments and people, it is very essential to distribute grounding grids in exponential law to reduce the gradient of earth surface potential. The calculation equation of the optimum compression ratio is analyzed based on inequipotential model, and occurs when the difference of maximum and minimum touch voltage reaches a minimum these equation used for training the ANN model [13,14]. The result of this study can be used to design different area grounding grids, and determine the rational numbers of grounding conductors, which can equalize the leakage current density and decrease touch voltage on the earth surface markedly.

Table 8 shows the architectures of ANN used to calculate the optimum compression ration for uniform soil.

Table 8 ANN Architectures

Input Variables	Output Variables
L is average length of side.	C is the optimum compression ratio
N' is the conductors number.	
ρ is the resistivity of the uniform soil	

Table 9 shows the designed ANN models

Table 9 Designed ANN Models

Structure	**Learning Algorithm**	**Transfer Function**
3/13/1	Levenberg-Marquardt	- Logarithmic Sigmoid -Linear -Linear

In the uniform soil, current is injected in the center of grounding grids. When all other conditions are not changed. Fig2 to 4 show the influence to the optimum compression ratio C of the length of side of quadrate grounding grid, the soil resistivity; and the conductors number of grid in some direction, respectively, the obtained results are summarized in table 10

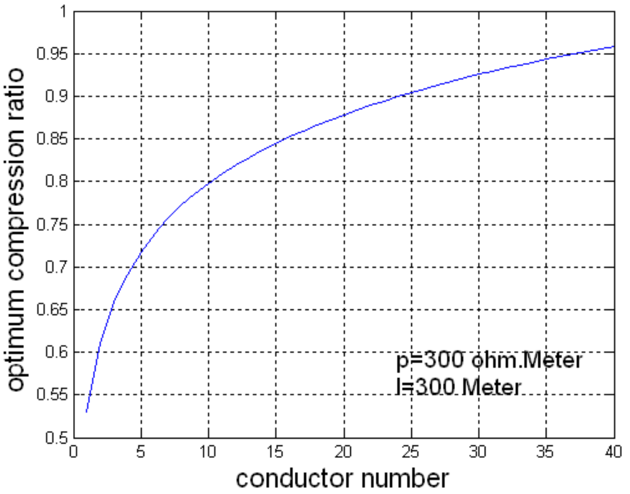

Figure 2: The influence of the conductor number

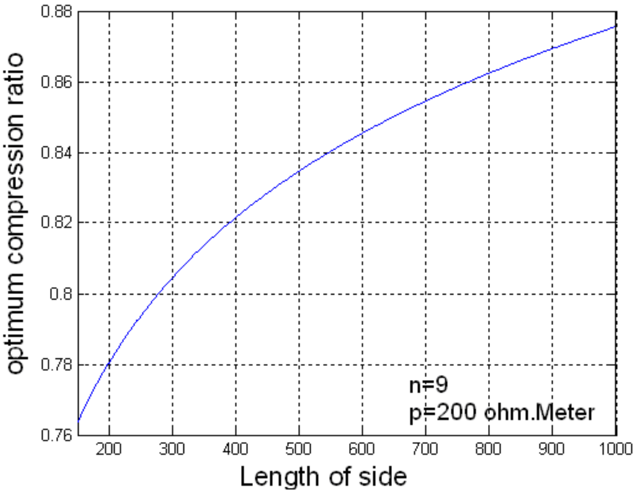

Figure 3: The influence of the length of side of grounding grid

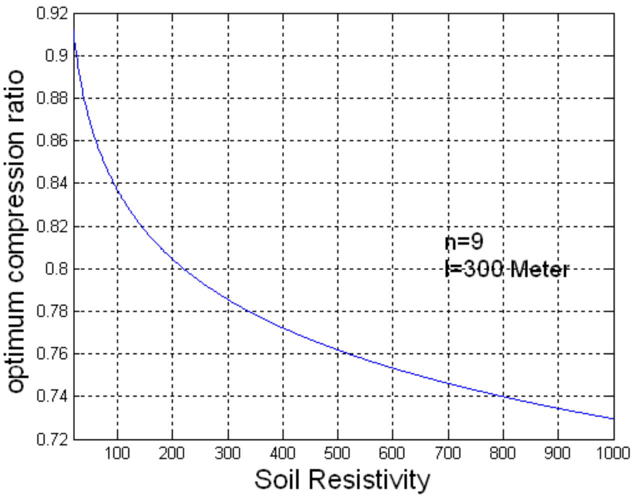

Figure 4: The influence of the soil resistivity

Table 10

N’	L	P	C_{ANN}
3	50	100	0.60338
3	300	600	0.5204
6	50	100	0.68376
6	300	600	0.60046
9	50	100	0.73097
9	300	600	0.6473
12	50	100	0.76381
12	300	600	0.68055
15	50	100	0.7893
15	300	600	0.70629
18	50	100	0.81095
18	300	600	0.72746

2.3.2.2 Evaluation of optimum compression ratio in case of non-uniform soil

Table 11 shows the architectures of ANN used to calculate the optimum compression ration for two layer soil.

Table 11 ANN Architectures

Input Variables	**Output Variables**
L is average length of side.	C is the optimum compression ratio
N’ is the conductors number.	
k is the reflection factor of the two layer soil	
H is the thickness of upper layer soil	

Table 12 shows the designed ANN models

Table 12 Designed ANN Models

Structure	**Learning Algorithm**	**Transfer Function**
4/13/1	Levenberg-Marquardt	- Logarithmic Sigmoid -Linear -Linear

Fig 5 to 7 show the influence to the optimum compression ratio C of the length of side of quadrate grounding grid, the reflection factor; and the conductors number of grid in some direction, respectively, the obtained results are summarized in table 13

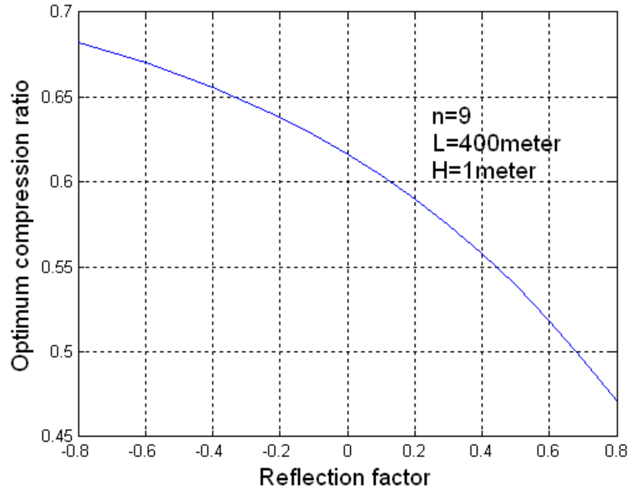

Figure 5: The influence of the reflection factor

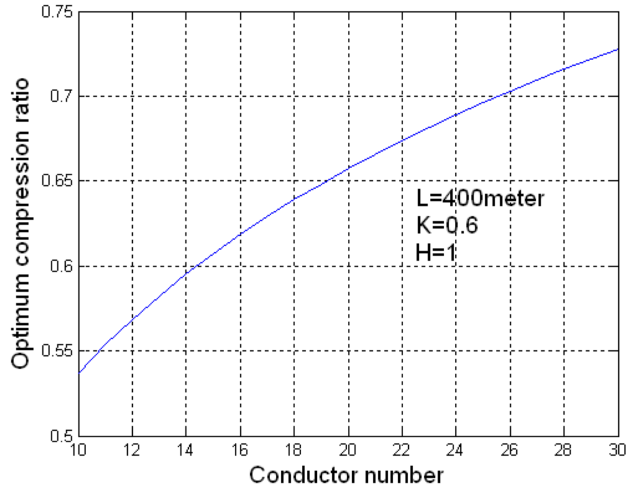

Figure 6: The influence of the conductor number

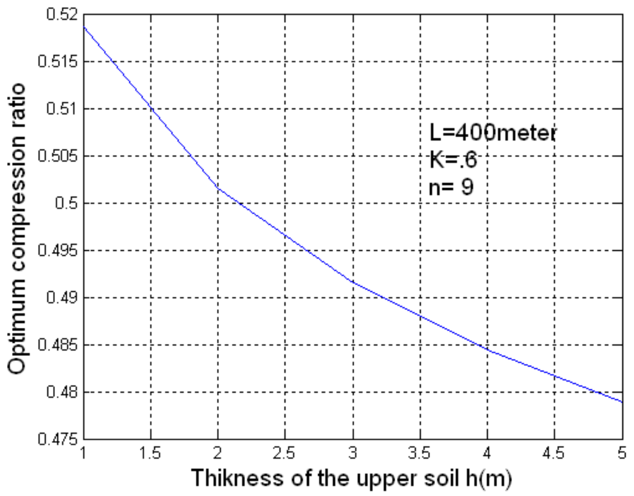

Figure 7: The influence of the upper layer thickness

Table(13)

N’	L	k	H	C_{ANN}
6	600	-0.8	2	0.71925
6	250	0.8	4	0.49061
6	250	0.8	5	0.4851
9	550	-0.1	4	0.71834
9	350	0.8	3	0.56814
9	250	-0.8	4	0.77259
9	250	0	3	0.7141
12	600	0.4	3	0.7055
12	250	0	4	0.75698
15	600	-0.3	5	0.82111
15	300	0	3	0.80284
15	250	-0.2	1	0.85153

2.3.3 Neural network validation and testing

Using El-Alameen substation as Field data to compare it with the result of the suggested ANN as case study

Field data as follow

V=66kV /22kV, Area=90 X 42 meter, Soil Resistivity = 4.71 ohm.meter, Crashed rock Resistivity = 8000 ohm.meter and Crashed rock depth= 0.1 meter

Obtained results are summarized in table 14 and it includes step and mesh voltage due to site parameters and ANN parameters [15]

Table 14 Comparison between field data and ANN results

	EL-Alameen field design	**ANN result**
n1	16	16
n2	8	8
Total conductors length L	1392m	1392m
Max allowable touch voltage 70kg	1964V	1883V
Emesh	280V	280V
Estep	63.9V	63.9V
Rg	.04 Ohm	.04 Ohm

CONCLUSION

(1) The paper describes an artificial neural network method for the apparent soil evaluation of two layers, result are close to several conventional analytical methods.
(2) The proposed ANN grid design obtained results are almost identical to the field observation data collected.
(3) The presented methodology can be used by electric power utilities as a useful tool for the design of electric power systems ground and calculation of apparent soil resistivity.
(4) Using ANN in design of ground system reduces the calculation time at the same accuracy level.

REFERENCES

[1] L. Ekonomou, I.F. Gonos and I.A. Stathopulos, “Application and Comparison of Several Artificial Neural Networks for Evaluating the Lightning Performance of High Voltage Transmission Lines”, International Symposium on High Voltage Engineering, August, 2005

[2] J.H. Schon, “Physical Properties of Rocks: Fundamentals and Principles of Petrophysics’’. Pergamon, Handbook of Geophysical Exploration, Vol 18, 1998
[3] Trevor Charlton: “Substation Earthing-shedding light on the black art”, IEE Seminar, Birmingham, March 2000.
[4] A.Thabet: “Grounding systems of electric substations in non-uniform earth structure with new analysis”, M.Sc.thesis, High Institute of Energy, Aswan, 2002.
[5] R. Lippmann, An introduction to computing with neural nets. IEEE ASSP Magazine, vol. 4, no. 2, pp. 4-22, 1987.
[6] K. Hornik, “Some new results on neural network approximation”. Neural Networks, vol. 6, pp. 1069- 1072, 1993.
[7] IEEE 80-2000, “Guide for Safety in AC Substation Grounding”, IEEE, 2000.
[8] EA TS 41-24, “Guideline for the Design, installation, Testing and Maintenance of Main Earthing Systems in substations” Electricity Association, 1992.
[9] T. Takahashi, and T. Kawase:” Calculation of earth resistance for a deep driven rod in a multi-layer earth structure”, IEEE, Trans., Vol.PWRD-6, No.2, April1991, pp.608-614.
[10] IEEE std 1422-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power System.
[11] Dawalibi, F. Barbeito, N, “Measurements and computations of the performance of grounding systems buried in multilayer soils”, IEEE, power delivery Trans., Vol.6, Oct.1991, pp.1483-1490.
[12] L.Hung, X.Chen, H.Yan, “study of unequally spaced grounding grids”, IEEE, power delivery Trans., Vol.10, Apri l995, pp.716-722.
[13] Du Zhongdong1, Yao Zhenyu2, Wen Xishan1, Xu Hua3,” The Optimum Design of Grounding Grid of Large Substation”, International Symposium on High Voltage Engineering, August, 2005
[14] Weimin Sun, Jinliang He, Yanqing Gao, Rong Zeng, Weihan Wu, Qi Su ,"Optimal design analysis of grounding grids for substations built in nonuniform soil", ”, IEEE, power System Technology, Vol.3, Dec.2000, pp.1455-1460.
[15] Jiri George Sverak: ”Progress in Step and Touch Voltage Equations of ANSI/IEEE Std 80 Historical perspective”, IEEE transactions on power delivery, Vo.13.No.3.July1998.