Performance of HVDC Ground Electrode in Various Soil Structures

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Abstract--**This paper discusses and compares HVDC ground electrode design methods in various soil structures. A number of cases are selected based on existing HVDC ground electrodes in order to compare the conventional simplified design method (Method A) with a more advanced grounding design method using a specialized engineering software (Method B). Various soil structures considered include horizontally layered soils, vertically layered soils and finite volume soils. In all cases studied, grounding grid resistances, current distributions, earth surface potentials and touch/step voltages are computed and compared. The results of Method B are also compared with measurements.**

For the cases studied in this paper, it is found that the step voltages computed by Method A are usually lower than those obtained using Method B. This is especially true for a horizontal linear electrode for which the step voltages near the end of electrode could be underestimated by as much as 48%. The results presented in this paper provide useful insight and information for accurately designing DC ground electrodes in various soil structures.

Index Terms-- **HVDC Systems, Grounding, Earthing, Safety**

I. INTRODUCTION

HVDC has proved to be well suited to specific applications such as long-distance power transmission. Today, there are more than 60 HVDC projects worldwide, transmitting more than 50GW of power [1,2]. Presently, a number of major HVDC projects are taking place in China. The increased utilization of HVDC transmission systems has created the need for accurate methods to design and evaluate the performance of HVDC grounding systems.

The design of HVDC ground electrodes involves many fundamental parameters, such as the electrode configuration, as well as the soil structure and characteristics. In the past (maybe still at present), the electrode design was carried out using conventional simplified or empirical methods, in which the soil is approximated by a uniform medium and the computations of ground electrode resistance and potential gradients are carried out based on analytical formulae. When the uniform soil approximation is no longer valid (e.g., electrodes near a river or the sea) or the ground electrode configuration contains irregularities, such methods may result in unsafe or overdesigned grounding systems… or both!

These situations may endanger human life and destroy electrical equipment or lead to unjustified additional costs, particularly in the case of large ground electrodes, or both.

In this paper, the design of HVDC electrodes is compared between the conventional simplified method (Method A) and a more advanced grounding design method (Method B) using a specialized engineering software [3,4].

The following representative cases are selected based on Appendix A of [5] and [6]:

- Ring and star electrodes in uniform and horizontally layered soils.
- Horizontal linear electrode in a finite volume soil (this could represent electrodes placed near a river).
- Deep vertical electrodes in a vertically layered soil (this could represent electrodes placed near the sea).

In all cases, grounding grid resistances, current distributions, earth surface potentials and touch/step voltages are computed and compared with the computed results and measurement results in [5,6].

II. HVDC GROUNDING DESIGN METHODS

Unlike grounding systems of HVAC system, which are designed only for a fault condition, HVDC ground electrodes are designed for normal, emergency and fault conditions [5,6]. Since a HVDC system may operate in one of three operation modes, namely monopolar, bipolar and homopolar, its ground electrode is required to provide an earth return circuit, permitting the current to flow into the earth in a monopolar mode or other modes involving current discharge into the soil. Because of the large magnitude (on the order of kA) and great duration (days) of the ground return current, the design of a DC ground electrodes involves many aspects, ranging from electrical and thermal properties of the design to safety of people and animals in a large area around the electrode, and adverse effects (for example, corrosion aspects) on metallic utilities in the vicinity of a ground electrode [7,8]. These aspects are discussed in details in [5,6]. In this paper, we will focus on the electrical aspects of the design for the cases compared.

A. Conventional Simplified Methods (Method A)

In these methods, an equivalent uniform soil is usually assumed, based on soil resistivity measurements made throughout the site. Since HVDC grounding electrodes are usually huge and far apart, the deep soil characteristics throughout a very large area must be used for realistic predictions. The following formulae are used for computing the resistances of electrodes in a uniform soils [5,6]:

Ring electrode: $$R_e = \frac{\rho}{\pi^2 D}\ln\frac{4D}{b} \qquad (1)$$

Horizontal linear electrode: $$R_e = \frac{\rho}{\pi l}\left(\ln\frac{2l}{b} - 1\right), \quad h << l \qquad (2)$$

Vertical linear electrode: $$R_e = \frac{\rho}{2\pi l}\left(\ln\frac{4l}{d} - 1\right), \quad l >> d \qquad (3)$$

where:

R_e = electrode ground resistance, Ω
ρ = soil resistivity, Ω-m
D = diameter of ring, m
l = total length of conductor, m
$b = \sqrt{dh}$, m
d = diameter of conductor, m
h = burial depth of center of conductor, m

For an array of linear or vertical electrodes or a star electrode, detailed expression are provided in [5,6] to account for resistances due to the mutual coupling between different electrode elements.

The permissible touch and step voltages to which an individual may be subjected when the electrode is energized by the DC return current are determined, based on standards such as IEC Standard 479-1, 479-2 and IEEE Standard 80. Based on IEEE Standard 80, the maximum tolerable step voltage for a human being is

$$E_{Step} = I_b(1000 + 6\rho_s) \qquad (4)$$

where I_b is the maximum permissible body current and ρ_s the surface soil resistivity. When a current I is injected into a horizontal electrode of length *l*, buried at a depth of *h,* the maximum potential gradient is given by [5]:

$$E_{\max} = \frac{\rho I}{2\pi l h} \qquad (5)$$

B. Computer-Aided Method with CDEGS (Method B)

The engineering module MALZ of the CDEGS software is used for this study [3,4]. A moment method, accounting for the longitudinal resistances of the conductors, is used to compute the scalar potentials created at any point in the soil by any type of grounding system made of a network of arbitrarily oriented interconnected conductors. Various soil structures can be modeled, including horizontal multilayer soils, vertical multilayer soils, horizontal and vertical cylindrical soils, hemispherical soils and arbitrary finite-volume soils. The software can be used to model coated ground conductors, each with different coating characteristics (i.e., coating resistivity, thickness, etc.), if desired. Thus, insulated HVDC ground cables and coated pipes can be accurately represented. This method avoids inconsistent or erroneous designs and facilitates the development of optimum grounding systems at a minimum cost.

In the following, representative examples of HVDC electrode design in various soil structures are selected to compare both methods. Note that details of these electrode designs, as performed using the conventional simplified method (Method A), can be found in [5,6] and their related references. All touch voltages reported in Method B will be based on a maximum reach of 3 m from ground electrode conductors.

III. RING ELECTRODE IN HORIZONTALLY LAYERED MULTILAYER SOIL

The Rice Flats ring electrode, 10.6 km south of Celilo, the southern terminal of the DC Pacific Intertie, is chosen in this example [5,6]. The maximum permissible step voltage is 8.5 V, which is based on a 6 mA body current limit and a 70 ohm-m uniform soil (see Equation 4). Fig. 1 shows the configuration of the ring modeled in Method B. The rated current of 1800 A is distributed along the ring by insulated conductors which are spaced about 3.5 m apart, as described in [6]. A profile is selected to examine the step voltages crossing the ring, starting 100 m inside the ring. The computation points are spaced 0.1 m apart.

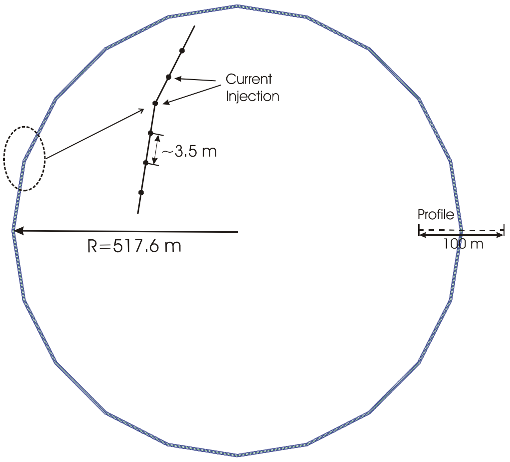

Fig. 1. Rice Flats ring electrode modeled in Method B.

Tables I-III present the ground electrode design parameters and computation results, based on Methods A and B. The multilayer soil model (Multilayer Soil 1) in Table II is taken from Appendix A of [5]. The soil data in [5] indicate a 70.0 Ω-m resistivity for depths in the range of 0-1.5 m, 36 Ω-m in the range of 12-15 m, and 100.0 Ω-m in the range of 210-300 m. Since there are no data for depths in the range of 1.5-12m, the thickness of the top layer soil (70.0 Ω-m) is assumed to be 12 m, as a conservative approach. Similarly, the 100 Ω-m resistivity is used for the bottom layer, starting at a depth of 15 m. The computed value of 0.064 Ω, based on this multilayer soil, is still lower than the measured resistance of 0.105 Ω [5]. In order to match the measured value, the bottom layer resistivity has to be increased. Table III shows another multilayer soil (Multilayer Soil 2), created by subdividing the bottom layer into two layers. A 500 Ω-m soil is introduced, starting at a depth of 300 m. The computed resistance is now 0.104 Ω. Table III shows that the GPR of the electrode increases significantly, while the maximum touch voltage and step voltages remain about the same (on the other hand, the touch voltage as a percentage of the electrode GPR is reduced in this case).

Table I
THE RING ELECTRODE AT RICE FLATS DESIGNED WITH METHOD A

Electrode Characteristics					
Radius: 517.6 m; Equivalent Conductor Radius: 0.382 m (0.6 m by 0.6 m coke section); Burial Depth: 1.524 m					
Soil Model					
70 Ω-m uniform					
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
102	0.057	0.228	N/A	N/A	4.0 V

Table II
THE RING ELECTRODE AT RICE FLATS DESIGNED WITH METHOD B (MULTILAYER SOIL 1)

Soil Resistivity (Ω-m)			**Depth (m)**		
70			12		
36			15		
100			Infinite		
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
116	0.064	0.233	112	15.4	4.4 V

Table III
THE RING ELECTRODE AT RICE FLATS DESIGNED WITH METHOD B (MULTILAYER SOIL 2)

Soil Resistivity (Ω-m)			**Depth (m)**		
70			12		
36			15		
100			300		
500			Infinite		
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
186	0.104	0.233	183	14.5	4.4 V

To illustrate the influence of soil layering on step voltages, Multilayer Soil 3 is created from Multilayer Soil 1, by reducing the 70.0 Ω-m top layer thickness from 12 m to 2 m (the electrode is buried in the 70.0 Ω-m soil). Fig. 2 shows step voltages computed along the profile indicated in Fig. 1. The step voltages are reduced in this soil structure.

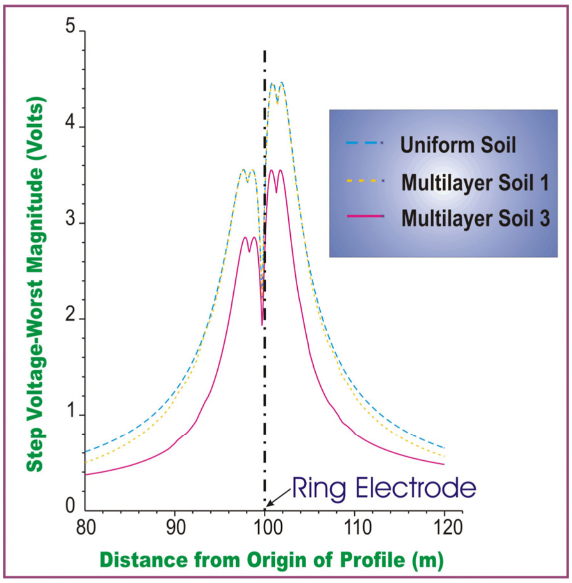

Fig. 2. Step voltages crossing the ring on 20 m either side.

IV. STAR ELECTRODE IN HORIZONTALLY LAYERED MULTILAYER SOIL

The modified star electrode, 7.6 km south of the Benmore Power Plant, of the New Zealand North Island-South Island link is chosen. The design of this electrode represents a case where the layout of electrodes becomes irregular, due to land restrictions. Fig. 3 shows the electrode used in the Method B computer model. It is created from Fig. 31 of [6]. The rated current of 1200 A is distributed by insulated conductors which are spaced about 10 m apart. The soil data in [5] indicate a 490.0 Ω-m resistivity for a depth in the range of 0-0.3 m, 32.1 Ω-m in the range of 0.3-10.8 m, and 100.0 Ω-m in the range of 10.8-150 m. The measured resistance is somewhere between 0.22-0.32 Ω.

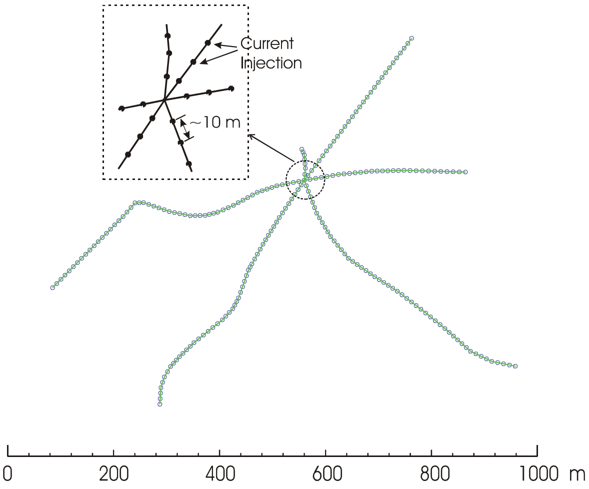

Fig. 3. Modified star electrode at Benmore (traced based on Fig.31 of [6]).

Tables IV-VI compare the ground electrode designs based on the two methods. Tables IV and V show the results computed with Methods A and B, respectively, for a 61.5 Ω-m uniform soil. They show that the maximum step voltage computed with the more accurate method, 7.2 V, is significantly higher than that computed with the simplified method, i.e., 4.9 V. The resistance from Method B is lower. Using the three-layer soil model (Table VI) from [5] (assuming a 100 Ω-m bottom layer resistivity), the resistance, 0.101 Ω is about 10% lower than the 0.11 Ω obtained with Method A. Fig. 4 shows the step voltages at 10 m on either side of the ground electrode, on both sides, in this soil model. The maximum step voltage (6.44 V) is again higher than the value obtained with Method A and also higher than the highest measured value of 5 V [6]. In order to match the measured resistance, a four-layer soil model is created from the three-layer in Table VI, by assuming a bottom layer resistivity of 800 Ω-m, starting at a depth of 150 m. This soil is created because: (a) the resistance of a large electrode such as this one is mainly determined by the resistivity of the bottom layer; (b) no soil data is available from [5] at depths greater than 150 m. The new computed resistance is now 0.21 Ω and the maximum step voltage is 7.5 V.

TABLE IV
THE STAR ELECTRODE DESIGN AT BENMORE BY METHOD A

Electrode Characteristics					
Arm length: varying from 50-475 m; Equivalent Conductor Radius: 0.323 m (0.51 m by 0.51 m coke section); Burial Depth: 1.778 m					
Soil Model					
61.5 Ω-m uniform					
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
136	0.113	0.27	N/A	N/A	4.9 V

TABLE V
THE STAR ELECTRODE DESIGN AT BENMORE BY METHOD B (61.5 Ω-M UNIFORM SOIL)

Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
106	0.088	0.926	105	39	7.2 V

TABLE VI
THE RING ELECTRODE DESIGN AT RICE FLATS BY METHOD B (THREE-LAYER SOIL MODEL [5])

Soil Resistivity (Ω-m)			Depth (m)		
490			0.3		
32.1			10.8		
100			Infinite		
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
121	0.101	1.309	120	30	6.4 V

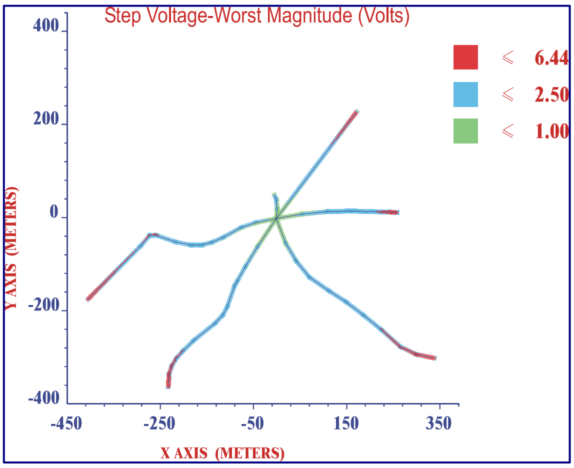

Fig. 4. Step voltages above portion of star ground electrode at Benmore (three-layer soil model in Table VI used).

V. HORIZONTAL LINEAR ELECTRODE IN FINITE VOLUME SOIL

Linear electrodes must be used when only a long and narrow strip of land is available. As compared with the ring and star electrodes, the linear electrode occupies less land, but has a larger current density near the ends of the electrode, resulting in greater step voltages at these locations (a ring electrode offers the smallest maximum electrode current density). The horizontal linear electrode design in Chapter 7 of [5] is studied in this section. Two cases are studied with Method B: (a) the electrode buried in a 50 Ω-m uniform soil; (b) the electrode is assumed to be placed 20 m away from a river, which is modeled as a finite volume of soil. Fig. 5 shows the configuration of the electrode placed near the river. The 100 m wide river is represented by a horizontal finite volume soil model. The water in the river has a low resistivity of 10 Ω-m. As shown in Fig. 5, the four horizontal electrodes are spaced 7.5 m apart and buried at a depth of 2.25 m in a native soil with a resistivity of 50 Ω-m. The spacing and the burial depth are based on the final design in [5], which provides safe step voltages. The rated current of 1250 A is distributed along the electrodes by insulated conductors which are spaced 11.65 m apart.

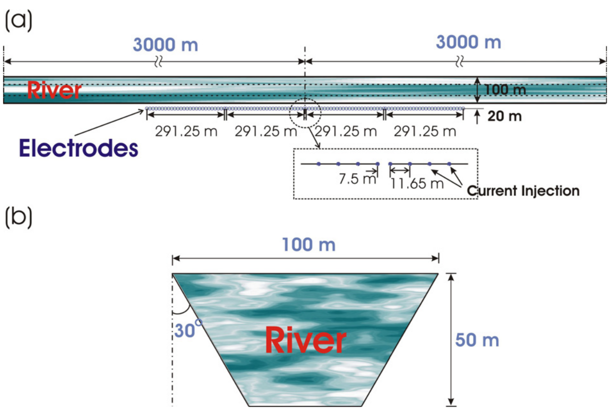

Fig. 5. (a) Horizontal linear electrode near a river; (b) Cross-section of a river modeled in a finite volume soil.

Table VII presents the ground electrode designed with Method A. Tables VIII and IX present computation results from Method B, for the uniform and finite volume soil, respectively. Fig. 6 shows the worst step voltages (1 m from the ground electrode on both sides). Profile 11 is above the electrode which leads to the highest step voltages. The results show the end effects of the leakage current distribution in the linear electrode. The GPR and resistance of the electrode in Table VIII agree very well with those in Table VII, as expected. However, the maximum step voltage 3.79 V computed by Method A is about 48% lower than the maximum step voltage of 5.6 V computed using in Method B, which is slightly higher than the maximum step voltage threshold of 5.4 V/m used in this design [5]. Fig. 6 indicates that the step voltages are underestimated by Eq. (5) near the end of the electrode and overestimated near the center of the electrode.

TABLE VII
THE LINEAR ELECTRODE DESIGN IN CHAPTER 5 OF [5]: METHOD A

Electrode Characteristics					
Length: 1165 m; Equivalent Conductor Radius: 0.318 m (0.5 m by 0.5 m coke section); Burial Depth: 2.25 m					
Soil Model					
50 Ω-m uniform					
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
112	0.0898	N/A	N/A	N/A	3.79 V

TABLE VIII
THE LINEAR ELECTRODE DESIGN IN CHAPTER 5 OF [5]: METHOD B (UNIFORM SOIL)

Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
110	0.0878	0.843	100.3	48	5.6 V

TABLE IX
THE LINEAR ELECTRODE DESIGN IN CHAPTER 5 OF [5]: METHOD B
(FINITE VOLUME SOIL)

Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
106	0.0846	0.823	96	47	5.5 V

When the river is modeled by a finite volume soil (see Fig. 5), the electrode resistance and step voltages are reduced slightly (see Table IX). Fig. 7 shows step voltages in the vicinity of the river. The maximum value is 0.99 V, near the river bank close to the electrode. In the water, the step voltages drop quickly to below 0.42 V.

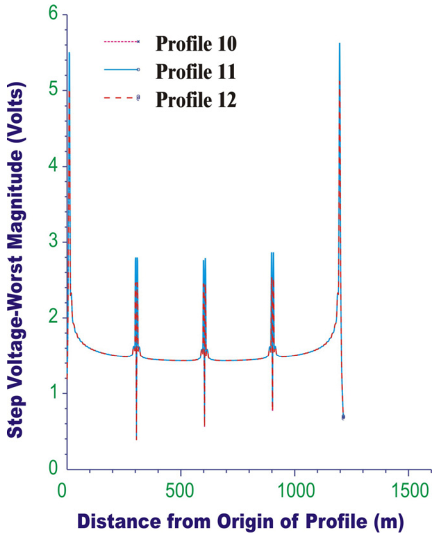

Fig. 6. Step voltage along a linear ground electrode.

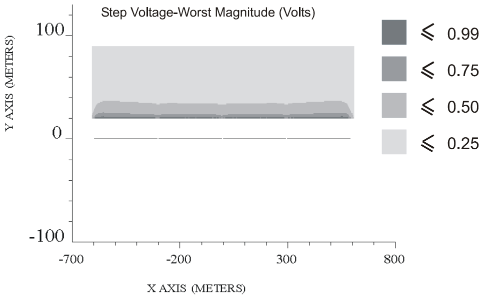

Fig. 7. Step voltages in river represented by finite volume soil.

VI. SHORE ELECTRODE IN VERTICALLY LAYERED SOILS

In this section, we will discuss how to model a shore electrode in a vertically layered soil, which simulates a seashore. We select the Danish seashore anode design of the Konti-Skan link as an example. The objective is to compare the computation results using Method B with the measurements.

The Danish seashore anode contains an array of 25 vertical electrodes or ground wells placed along the seashore, about 20 m inland. Details of the design can be found in [5,6]. The resistance of the electrode is calculated to be 0.04 Ω, which is also the measured value. The greatest surface voltage gradient is 2 V/m near the outmost electrodes. The highest gradient measured in the sea at the normal shore line is 0.3 V/m [6].

In our computer model, a conductor network model is set up based on Fig. 33 of [6]. Fig. 8 shows the configuration of the electrode. Each ground well is represented by a vertical conductor with a radius of 0.637 m and a length of 3.5 m. It represents an equivalent of the 1m×1m×3.5m coke bed. The 25 wells are spaced 5 m apart, except for the last three wells at both ends. As indicated in Fig. 8, the spacings are reduced to 4 m (between Wells 2 to 3, and 23 to 24) and

3 m (between Wells 1 to 2, and 24 to 25), in order to better distribute the leakage current throughout the electrode system. The rated current of 1000 A is distributed to each well by an insulated wire, which has a cross section of 25 mm^2.

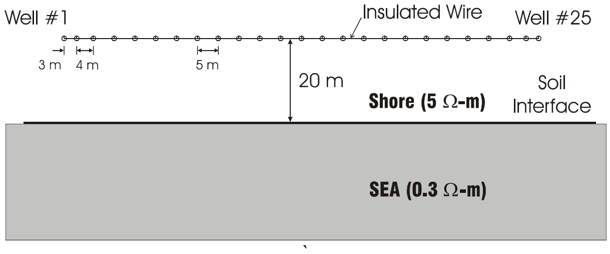

Fig. 8. Configuration of shore electrode.

The seashore is represented by a 2-layer vertical soil. The land has a resistivity value in the range of 1.5-8 Ω-m and the seawater has a resistivity in the range of 0.25-0.3 Ω-m. The 25 wells are buried in the high resistivity land layer, 20 m away from the soil/seawater interface (see Fig. 8).

Table X presents the computation results, based on a 5 Ω-m for the soil. The computed resistance increases to 0.065 Ω if 8 Ω-m is used for the land. Fig. 9 shows the step voltages around the electrode (50 m on both sides). The maximum step voltage occurs near the ends of the electrode. This value is about 4 times higher than the measured value of 2 V. The step voltages in the sea are presented in Fig. 10. The maximum value is 0.06 V, which is smaller than the maximum measured value 0.3 V [6].

TABLE X
THE DANISH ANODE DESIGN OF KONTI-SKAN LINK BY METHOD B

Soil Resistivity (Ω-m)			Layer		
5			Upper		
0.3			Lower		
Computation Results					
GPR (V)	Resistance (Ω)	Maximum			
		Current Density (A/m^2)	Earth Potential (V)	Touch Voltage (V)	Step Voltage (V)
41	0.041	3.404V	40	21	8.0 V

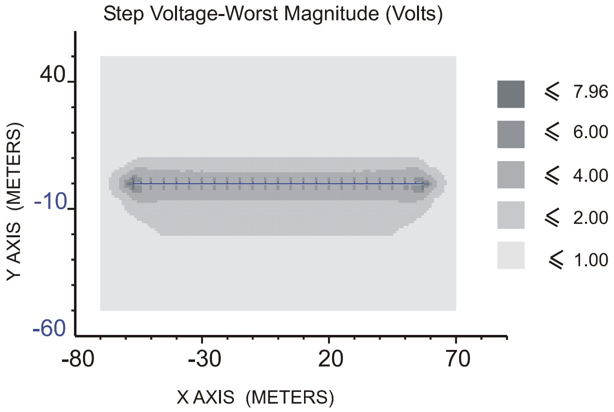

Fig. 9. Step voltage around the electrode.

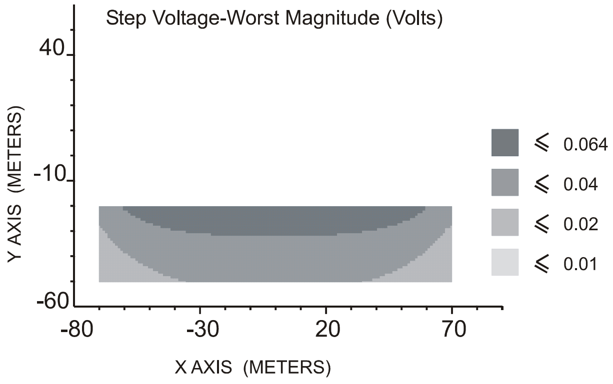

Fig. 10. Step voltages in the sea.

VII. CONCLUSIONS

This paper discusses and compares HVDC ground electrode design methods in various soil structures. A number of cases are selected based on existing HVDC ground electrodes, in order to compare the conventional simplified design method (Method A) with a more advanced grounding design method using a specialized engineering software (Method B). The various soil structures considered include horizontally layered soils, vertically layered soils and finite volume soils. In all cases studied, grounding grid resistances, current distributions, earth surface potentials and touch/step voltages are computed and compared. The results of Method B are also compared with the measurements.

For the cases studied in this paper, it is found that the step voltages computed by Method A are usually lower than those obtained using Method B. This is especially true for a horizontal linear electrode, for which the step voltages near the end of electrode could be underestimated by as much as 48%. The results presented in this paper provide useful insight and information for accurately designing DC ground electrodes in various soil structures.

VIII. REFERENCES

[1] J. Arrillaga, High Voltage Direct Current Transmission, IEE Power and Energy Series, 29, 2nd edition, 1998.

[2] B. Andersen, and C. Barker, “A new era in HVDC?” IEE Review, pp. 33-39,March 2000.

[3] F. P. Dawalibi and F. Donoso, “Integrated analysis software for grounding, EMF, and EMI,” IEEE Computer Applications in Power, vol. 6, no. 2, pp. 19-24, 1993.

[4] J. Liu, F. P. Dawalibi, J. Ma and R. D. Southey, “HVDC advanced analysis methods for grounding design and dc interference mitigation techniques” 2002 3rd International Symposium on Electromagnetic Compatibility (EMC’2002/Beijing), Beijing, pp. 202-206, May, 2002.

[5] EPRI EL-2020, *HVDC Ground Electrode Design*, August 1981.

[6] E. W. Kimbark, *Direct Current Transmission*, Volume I, Chapter 9, WILEY-INTERSCIENCE, 1971.

[7] A. W. Peabody and C. G. Siegfried, “Corrosion control problems and personnel hazard control problems caused

by HVDC and HVAC transmission systems on non-associated underground facilities," CIGRE International Conference on Large High Voltage Electric Systems, 1974.

[8] Report, "Full-scale stray-current test HVDC power transmission: the Dalles-Los Angeles," Dec. 1970.

IX. ACKNOWLEDEMENT

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X. BIOGRAPHIES

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