Research of Earth Surface Potential Distribution of UHVDC Grounding Electrode Based on CDEGS

Jiang Wei, Liu Xi
Sichuan Electric Power Research Institute
Chengdu, China

Wu Guangning
School of Electrical Engineering
Southwest Jiaotong University
Chengdu, China

***Abstract*— When UHVDC transmission system works in monopole operation, DC flows through neutral point by ground and causes DC bias of transformers around UHVDC grounding electrode, which will threaten the operation security of transformers. Earth surface potentials distribution of some typical soil models, include losse soil and clay soil models in different season, are calculated in this paper. Different each soil layer's resistivity and thickness has different distribution of earth surface potentials. The relationship between each soil layer's resistivity and thickness and earth surface potential is analyzed. And some suggestions about selecting the address of UHVDC grounding electrode are given.**

Keywords- UHVDC grounding electrode; monopole operation; soil model; ground voltage

I. INTRODUCTION

China's growth in electricity demand getting great, especially in economically developed coastal areas, but China's hydropower is mainly concentrating in the southwest, and thermal power is mainly concentrating in the northwest, the uneven distribution of energy and load impel China's west to east power transmission project[1-4]. So vigorously exploiting hydropower and using UHVDC to transmit power to coastal economically developed areas is imperative. However, when the UHVDC transmission system works in monopole operation, DC flows through the neutral point by ground and causes DC bias of transformers around UHVDC grounding electrode, which will threaten the operation security of transformers [5-8]. Earth surface potential distribution of UHVDC grounding electrode is closely related to DC bias current. Therefore, it is necessary to research the earth surface potential distribution of UHVDC grounding electrode[9].

Earth surface potentials distribution of some typical soil models are calculated in this paper. According to the calculating results of horizontal layered soil models, the relationship between each soil layer's resistivity and thickness and earth surface potentials is analyzed. And some suggestions about selecting the address of UHVDC grounding electrode is given.

II. THEORETIC ANALYSIS OF EARTH SURFACE POTENTIAL OF HORIZONTAL LAYER SOIL MODEL

Because of gravity, there are different horizontal soil layers according to different densities. For example, during the sedimentary process, sedimentary rock form some horizontal soil layers, such as gravel layer, sand layer, clay layer and so on.

According to different soil resistivity, we build a multilayer soil model, illustrated in Fig.1.

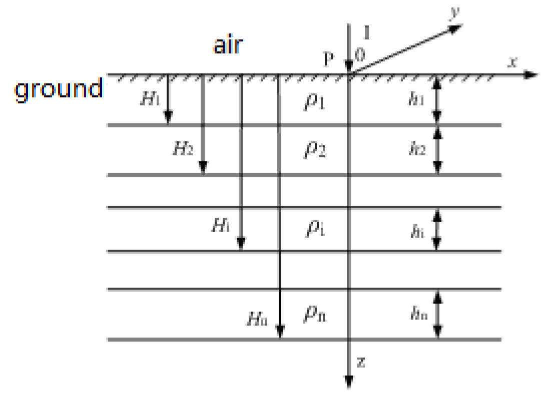


Fig.1 Horizontal layered soil model

Where, P is the address of the UHVDC grounding electrode. I is the DC flows into earth when monopole operation. So, in the coordinate system which the origin is P and Z axis is downward vertically, Laplace equation of earth surface potentials is following.

$$\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}+\frac{\partial^2 v}{\partial z^2}=0 \qquad (1)$$

We define $R(r)$ is the function of r, and $Z(z)$ is the function of z. Using separation of variables and Weber-Li Pushkin integral, resolution into series form. So, we get the surface potentials distribution of horizontal two layers soil model[10]

$$v_1=\frac{I\rho_1}{2\pi}[\frac{1}{\sqrt{r^2+z^2}}+2\sum_{n=1}^{\infty}\frac{K_{12}^n}{\sqrt{r^2+(2nh_1+z)^2}}] \qquad (2)$$

Where, K_{12} is soil refraction coefficient. $K_{12}=\frac{(\rho_2-\rho_1)}{(\rho_2+\rho_1)}$.

When we analysis the surface potentials distribution of horizontal three layers, assume $n=3$, $z=0$, and with the same method as surface potentials distribution of horizontal two layers soil model, we get the surface potentials distribution of horizontal three layers soil model as[10]

$$v_1 = \frac{I\rho_1}{2\pi}\int_0^{\infty}\frac{1-c(m)\exp(-2mh_1)}{1+c(m)\exp(-2mh_1)}J_0(mr)dm \qquad (3)$$

Where,

$$a = 1+K_{23}\exp(-2mh_2)\,, b = 1-K_{23}\exp(-2mh_2)\,,$$

$$c(m) = \frac{(\rho_2-\rho_1 a/b)}{(\rho_1+\rho_2 a/b)}, \quad K_{23} = \frac{(\rho_3-\rho_2)}{(\rho_3+\rho_2)}.$$

III. Analysis of Influence of Soil Structure on Earth Surface Potential Distribution

A. Build UHVDC Grounding Electrode Model

The UHVDC grounding electrode is double-ring grounding electrode. Its internal radius is r=500m, and its external radius is R=700m. The depth of the electrode is h=3.5m. The diameter of its grounding conductor is 70mm. Conductivity is $\sigma=1\times10^7$ S/m. Permeability is $\mu_r=200$. And relative permittivity is $\varepsilon_r=1$.

When UHVDC transmission system works in monopole operation, soil is part of circle. So it is also very important to build soil model.

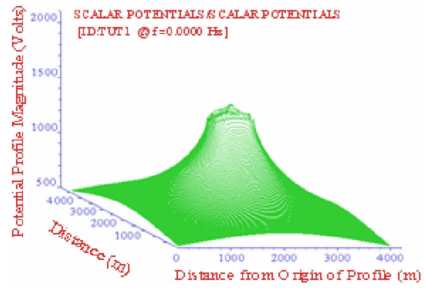
B. Earth surface potential distribution with typical double layers soil model

Usually, horizontal layered soil model is used in the area with better geological condition, such as plain region. It is known to us that losse soil and clay soil is the typical soil of Northern China and Southern China respectively. And water content is quit different between wet and dry season. So, four typical double layer soil models are built, which are shown as Table Ⅰ.

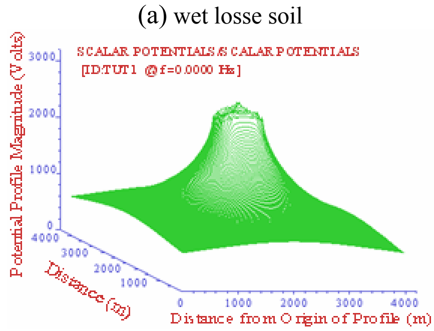
TABLE Ⅰ TYPICAL DOUBLE LAYER SOIL MODELS

models	surface layer (Ω.m)	Deep layer (Ω.m)	thickness of surface layer (m)
wet losse soil	100	5000	100
dry losse soil	250	5000	100
wet clay soil	300	5000	100
dry clay soil	1000	5000	100

Based on software CDEGS, when the UHVDC grounding electrode current is 4A, we got the calculation results of earth surface potential distribution of those four models, illustrated in Fig.2 and Fig.3.



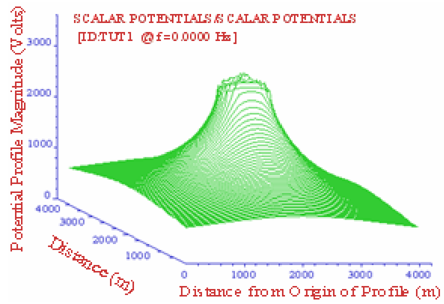
(a) wet losse soil



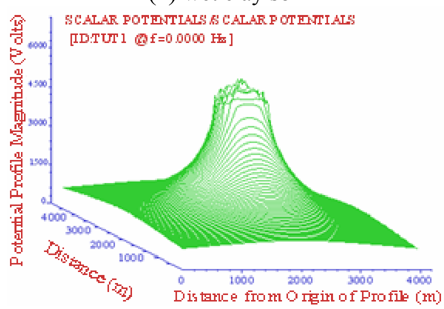
(b) dry losse soil

Fig.2 Earth surface potential distribution of double layer losse soil models

From Fig.2, we can see that the earth surface potential nearby grounding electrode is sharply decreased with double layer losse soil models. The peak voltage of wet losse soil model is 1545.43 V. That of dry losse soil model is 2822.75 V. Those two peak voltages have larger difference. So, it is not neglected that water content is a important factor to the earth surface potential distribution of losse soil. And, we must strengthen monitor and protection in wet season.



(a) wet clay soil



(b) dry clay soil

Fig.3 Earth surface potential distribution of double layers clay soil models

From Fig.3, we can see that the peak voltage of wet clay soil model is 3159.08 V, while the peak voltage of dry clay soil model is 6214.8 V. The peak voltage of clay soil model is higher than that of losse soil. Water content has great influence on earth surface potential distribution of clay soil. Therefore, we should take effective protection in dry season of Southern transformer substations.

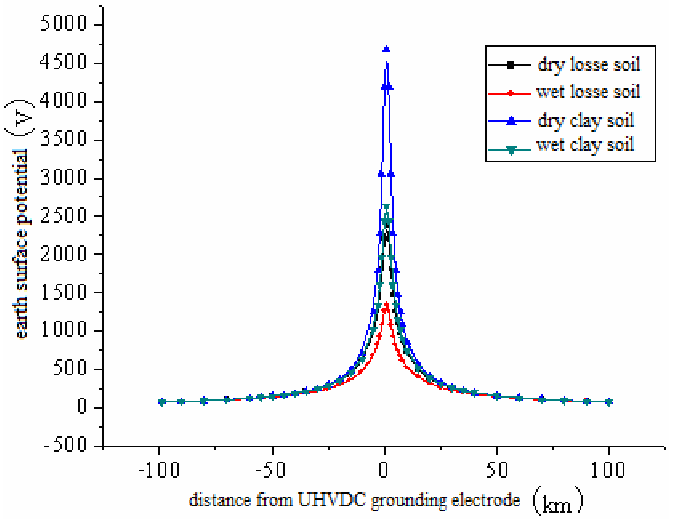


Fig.4 Earth surface potential distribution of four soil models

When the protective measure of DC bias is designed, the most serious condition should be taken into account. The earth surface potential distributions of four soil models are shown in Fig.4. It is known from the Fig.4 that the earth surface potential of dry clay soil is the highest, while that of wet losse soil is the lowest. Far from 50 km, the earth surface potentials of four soil models are very low, only several tens ampere, and the four potentials distribution are very near.

C. Influence of resistivity and thickness on earth surface potential distribution

There are four layers for typical earth layered structure. The first layer is the Humus layer, which resistivity is among 10～1000 $\Omega\cdot m$, and its thickness is from several meter to several tens meter. The second layer is the Holocene layer. Its resistivity is among 100～400 $\Omega\cdot m$, and its thickness is 1～4km. The third layer is the Original rock layer, which resistivity is among 1000～20000 $\Omega\cdot m$ and thickness is 10～30km. The last layer is the layer of Earth's internal heat, which has good conductivity with low resistivity. When we build soil model, we think the thickness of the layer of Earth's internal heat is ∞. Because the Humus layer is small thickness, we combine the top and second layer into a layer, which resistivity is within the scoop of the Humus layer and the Holocene layer. We have known that it is a scoop for resistivity and thickness of each layer. Therefore, influence of resistivity and thickness on earth surface potential distribution is analyzed in the following parts.

A horizontal three layers soil model is built with different soil resistivities of the first layer (Table II). The thickness of the first layer is set to 3km, and the second layer is 20km. We define that the resistivity of the second layer is 10000 $\Omega\cdot m$, and that of the third layer is 2 $\Omega\cdot m$. The UHVDC grounding electrode current is 4kA.

TABLE II HORIZONTAL THREE LAYERS SOIL MODEL WITH DIFFERENT ρ1

Parameter / layers	resistivity ($\Omega\cdot m$)					thickness **(km)**
first	50	100	200	300	400	3
second	10000					20
third	2					∞

Based on grounding analysis software CDEGS, we can get the results of earth surface potential distribution when the first layer soil resistivities are 50 $\Omega\cdot m$, 100 $\Omega\cdot m$, 200 $\Omega\cdot m$, 300 $\Omega\cdot m$ and 400 $\Omega\cdot m$ respectively (illustrated in Fig.5).

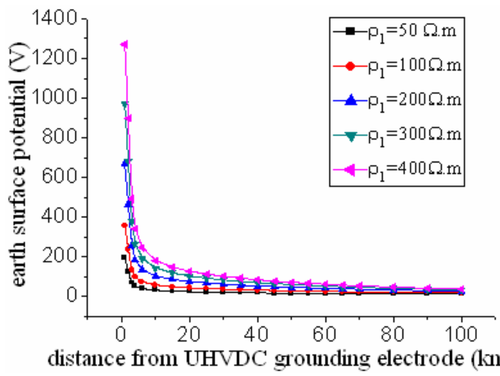


Fig.5 Earth surface potential distribution with different ρ1

As shown in Fig.5, the first layer soil resistivity has larger influence on earth surface potential distribution. The earth surface potential is increased with its resistivity increased. When the first layer soil resistivity is 50 $\Omega\cdot m$, the maximal earth surface potential is 198.37 V. While the resistivity is increased 400 $\Omega\cdot m$, that potential is increased 1270.94 V, which is increased 6.4 times.

To analyze the influence of thickness of the first layer on earth surface potential distribution, a horizontal three layers soil model is built with different thickness of the first layer (TableIII). We set that the thickness of the first layer are 0.5 km, 1 km, 2 km, 3 km and 4 km respectively.

TABLEIII HORIZONTAL THREE LAYERS SOIL MODEL WITH DIFFERENT h_1

Parameter / layers	thickness **(km)**					resistivity ($\Omega\cdot m$)
first	0.5	200	2	3	4	3
second	20					10000
third	∞					2

With this soil model, we can calculated the earth surface potential when the UHVDC grounding electrode current is 4kA (illustrated in Fig.6).

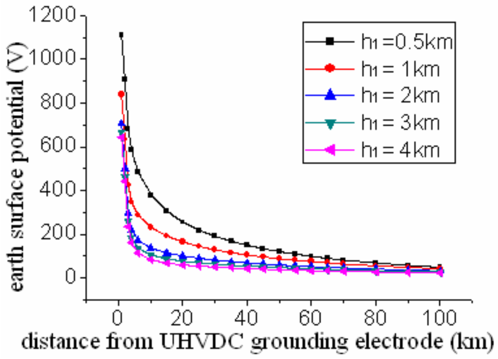


Fig.6 Earth surface potential distribution with different h1

We can see from Fig.6 that more thinner the first layer soil is, more higher the earth surface potential is. The influence of thickness of the first layer on earth surface peak potential is weaker than that of resistivity. However, The influence range of thickness of the first layer is farther than that of resistivity. When h_1 =0.5km the earth surface potential at 50km from UHVDC grounding electrode is 120.296 V. While h_1 =4km the earth surface potential at 50km from UHVDC grounding electrode is 37.66 V. The former is 3.19 times of the latter. The influence of thickness of the first layer on earth surface peak potential can be neglected beyond 100km.

A horizontal three layers soil model is built with different soil resistivities of the second layer, to analyze the influence of resistivity of the second layer on earth surface potential distribution (TableⅣ). The second layer soil resistivities are respectively 1000 $\Omega \cdot m$, 5000 $\Omega \cdot m$, 10000 $\Omega \cdot m$, 15000 $\Omega \cdot m$ and 20000 $\Omega \cdot m$. The UHVDC grounding electrode current is 4kA.

TABLEⅣ HORIZONTAL THREE LAYERS SOIL MODEL WITH DIFFERENT ρ2

Parameter / layers	resistivity ($\Omega \cdot m$)	thickness (km)
first	200	3
second	1000 5000 10000 15000 20000	20
third	2	∞

The calculated results are illustrated in Fig.7.

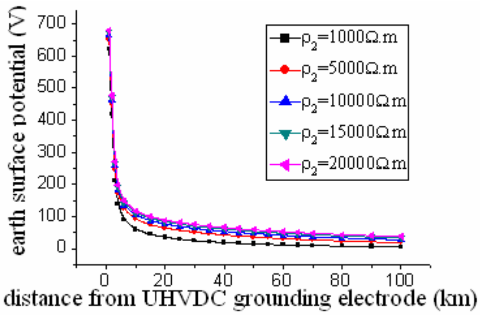


Fig.7 Earth surface potential distribution with different ρ2

As shown in Fig.7, more bigger resistivityl of the second layer soil is, more higher the earth surface potential is. The influence of the second layer resistivity on earth surface peak potential is very weak. When ρ_2 =1000 $\Omega \cdot m$, the maximum earth surface potential is 621.4 V. While ρ_2 =20000 $\Omega \cdot m$, that potential is increased 679.5 V, which is only increased 1.09 times. But the influence range of resistivity of the second layer is very far. When ρ_2 =1000 $\Omega \cdot m$, the earth surface potential at 100km from UHVDC grounding electrode is 5.2 V. While ρ_2 =20000 $\Omega \cdot m$, that potential is 37.2 V, which is only increased 7.15 times.

To analyze the influence of thickness of the second layer on earth surface potential distribution, a horizontal three layers soil model is built with different thickness of the second layer (TableⅤ). We set that the thickness of the second layer are respectively 10 km, 20 km and 30 km. The UHVDC grounding electrode current is 4kA.

TABLEⅤ HORIZONTAL THREE LAYERS SOIL MODEL WITH DIFFERENT h_2

Parameter / layers	thickness (km)			resistivity ($\Omega \cdot m$)
first	3			200
second	10	20	30	10000
third	∞			2

The calculated results are illustrated in Fig.8.

We can see from Fig.8 that more deeper the second layer soil is, more lower the earth surface potential is. When h_2 =10km, the peak earth surface potential is 656.6 V. While h_2 =30km, the peak earth surface potential is 668.6 V. The difference of both peak potentials is only 12V. The influence range of thickness of the second layer is very far. When h_2 =10km, the earth surface potential at 100km from UHVDC grounding electrode is 19.2 V. While h_2 =30km, that potential is 31.5 V. The difference of both the potentials is 12.3V.

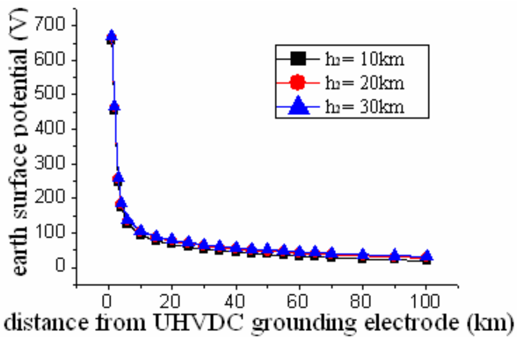


Fig.8 Earth surface potential distribution with different h2

IV. CONCLUSION

(1) Though calculate four soil models, include losse soil models and clay soil models in rainy season and dry season, it known to us that the earth surface potential of dry clay soil is the highest, while that of wet losse soil is the lowest. Far from 50 km, the earth surface potentials of four soil models are only several tens ampere, and they are very near.

(2) The first layer soil resistivity has larger influence on earth surface potential distribution, while the influence of the second layer resistivity on earth surface peak potential is very weak but the influence range is very far. When ρ_1 is increased from 50 $\Omega \cdot m$ to 400 $\Omega \cdot m$, the peak earth surface potential is increased 6.4 times. When ρ_2 is increased from 1000 $\Omega \cdot m$ to 20000 $\Omega \cdot m$, the peak earth surface potential is only increased 1.09 times. The earth surface potential is decrease when h_1 is increase. And the earth surface potential is increase when h_2 is increase. The influence of h_1 on earth surface peak potential is weaker than that of ρ_1, but the influence range of h_1 is farther than that of ρ_1. The influence of h_2 on earth surface peak potential is also very weak.

(3)It is suggest that the following things should be considered when selecting UHVDC grounding electrode. Firstly, the soil resistivity of grounding electrode address should be selected as small as possible. For example, the soil is alluvial soil or clay soil. Secondly, the region of grounding electrode address should be abundant rainfall, and should not be harsh dry season. Finally, the thickness of surface soil layer with low resistivity should as small as possible, and the thickness of deep soil layer with high resistivity should as large as possible.

REFERENCES

[1] Dizheng Kuai, Da Wan, Yun Zhou. "Analysis and handling of the impact of geomagnetically induced current upon electric network equipment in DC transmission," Automation of Electric Power Systems,2005,29(2), pp81-82.

[2] L. Zeng. "Impact of HVDC ground electrode current on the adjacent power transformers," High Voltage Engineering. 2005, 31（4）, pp57-58.

[3] Mingxin Wang, Qiang Zhang. "Analysis on influence of ground electrode current in HVDC on AC power network," Power System Technology, 2005, 29(3), pp9-15.

[4] J. Lu. "Analysis of effects of DC earthed pole on earth surface potential distributions," High Voltage Engineering. 2006, 32（9）,pp55-58

[5] Villas J E T, Portela C M. "Correction to calculation of electric field and potential distributions into soil and air media for a ground electrode of a HVDC system," IEEE Trans on Power Delivery, 2004, 10 (19), pp. 904-905

[6] DL/ 437-1991, HVDC grounding Technology Guide [S].

[7] C. E. Caroli, N. Santos, D. Kovarsky, et al. ITAIPU HVDC Electrodes : Interference Considerations and Potential Curve Measurements During Bipole II Commissioning. IEEE Transactions on Power Delivery, 1990, 5(3) : 1583-1590

[8] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[9] X. Chen. Grounding. Chongqing: Chongqing University Press. 2002

[10] J He. Power System Grounding. Beijing: Science Press. 2007.