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Research on Grounding Characteristic of Offshore Wind Turbine with Tripod Foundation

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***Abstract*——Offshore wind farm, constructed in places with few tall structures around, to exploit high wind conditions. As a result, the wind turbines are more vulnerable to be struck by lightning. A timely fault current release channel, provided by low grounding resistance, will offer effective protection for the human body and electrical equipment, to avoid the security risks caused by lightning or short circuit fault current. In this study, electromagnetic transient simulation of grounding analyses for offshore wind turbines with steel tripod foundations was carried out. Various affecting factors including depth of seawater caused by tide, soil characteristics and size parameter of tripod foundation was taken into consideration using CDEGS software. The result of the simulation shows that, the factor, depth of seawater, plays the most crucial role in grounding characteristics above all influencing factors**

Keywords- grounding impedance; tripod foundation; offshore wind turbine; CDEGS software

I. INTRODUCTION

The offshore wind power technology had a huge development in the past twenty years. According to the Global Wind Energy Council, the total installed capacity of wind power around the world reached a massive 60 000 MW at the end of 2005, a 12-fold increase in comparison to 1995 [1]. By the end of 2005 this number has reached a massive 100 GW [2]. Tripod foundation, a new adaption of the traditional monopole foundation, is the most favorable offshore foundation in terms of light weight and great stability [3]. Due to the hostile environment in offshore wind farm, the lightning and typhoons are main risks that wind turbine subjected to in recent years in which damages caused by lightning are particularly serious, as is measured by T. Sorense et al. [4]in Denmark, Bill Chun Piu Lau et al. [5]in Hong Kong and Japanese wind power industry reports by NEDO[6]. The high voltage potential rise, caused by high grounding impedance, will cause damages to wind turbines when struck by lightning. Most of the breakdowns and malfunctions of the electrical and control systems inside wind turbine are caused by the voltage rise of the grounding system due to the lightning strike according to statistics by Yanagawa. S in Japan[7]. Owing to the difficulty of installation in offshore area, there is not specialized grounding system designed for improving the grounding conditions for offshore wind turbines.

Wind turbines are rapidly becoming important generators connecting to existing electrical power network. As a result, wind turbines should be regard as other power system elements that required meeting the standards for reliability. The development of lightning protection systems for wind turbines has increased in importance in the last 10 years and which culminated in the production of an International Standard in 2010 [8]

It has been shown that, analysis on soil layered structure, resistance reduction in areas with high soil resistivity and accurate measurement of ground resistance of ground system, are all main issues related to the ground system in electrical network, as is claimed by He Jinliang [9] and Zeng Rong [10] in Tsinghua University. Some researchers investigate on factors affecting soil electrical resistivity, for example, Zhou Mi et al. [11] use a soil box in laboratory to measure the influencing factors including soil water content, soil porosity, pore fluid composition, and temperature, Vilson Luiz Coelho [12] confirms that the soil moisture has great influence on resistivity, but it also shows that variations in moisture due to rainfall conditions affect only the superficial layers. Thus, in intertidal area, the soil resistivity of superficial layers varies greatly because of the flowing tide and falling tide.

As for calculation methods for grounding impedance, some researchers use numerical calculation method to divide ground system to obtain the conductor current in each section such as Sun.W.M [12] , Zhang.X.L:[13] and Kostic, M.B.[14]. Recently, CDEGS software, launched by SES of Canada, famous for accuracy calculation result by electromagnetic theory, have been tools used to design of the grounding system or research on electromagnetic interference by researchers such as Rugthaicharoencheep, N. [15], Dawalibi, F.P.[16], A Puttarach [17] and so on.

In this paper, the grounding characteristics of offshore wind turbines with tripod foundation are studied by CDEGS simulation software. Influencing factors including depth of seawater, soil resistivity, thickness of claypan, size and different material of tripod foundations and depth the pile pumped into ground are taken into consideration.

II. OVERVIEW ON OFFSHORE WIND FARM AND WIND TURBINE WITH TRIPOD FOUNDATION

The first offshore wind power project in China, the East China Sea Bridge 100MW wind farm, apply the tripod foundation structure in offshore and intertidal area. The typical tripod foundation is as shown in Fig.1. The sea area where average water depth is 5 to 15m, is a soft based seafloor of the silt. The formation characteristics of the East China Sea Bridge wind farm are as shown in TABLE I. Based on the field survey of wind farm in the installation zone[18], upper soli part displays the properties of the clay; lower part displays the properties of the gravel. Due to the different water content which will affect soil resistivity of claypan greatly, the range of the soil resistivity will fluctuate from 10 to 1500 Ω.m, and its thickness, based on the local geological data, ranges from 10 to 30 m. Fig.2 shows the schematic diagram of and tripod foundation and its installation environment.

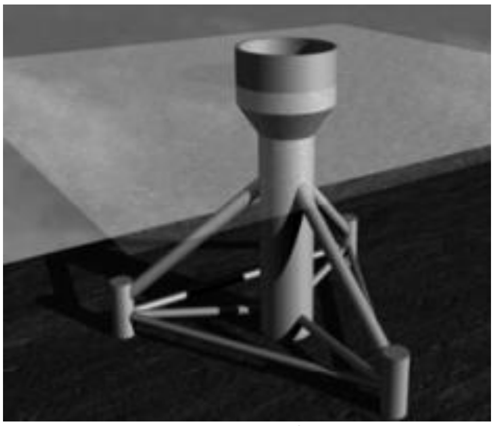


Fig.1. Typical tripod foundation

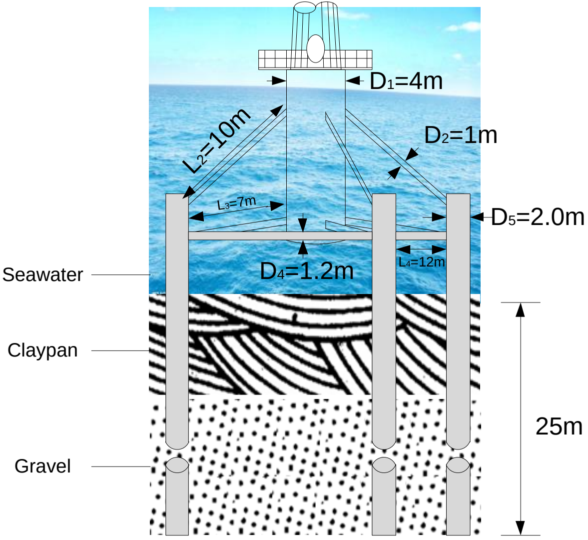


Fig.2. schematic diagram of and tripod foundation and its installation environment

TABLE1 THE FORMATION CHARACTERISTICS OF THE EAST CHINA SEA BRIDGE WIND FARM

Name of soil	Average thickness(m)	Compressibility (Mpa^{-1})	Vid ratio
Silt	0.43	0.74	High
mucky silty clay	3.83	0.87	high
silt clay	10.67	1.36	High
clay	4.06	0.87	High
silty clay	10.60	0.50	Medium
Sand silt	3.75	0.18	Medium-low
silt	11.19	0.13	Medium-low
Coarse sand	Can not detect	0.08	Low

III. MEASUREMENT AND SIMULATION CALCULATION

During the summer of 2014, both peak currents and electrical field of location systems data were obtained on 47 triggered lightning return strokes in 8 lighting flashes. Note that there were 37 return strokes detected in 5 flashes successfully. And 10 M-components within 500 microseconds after return stroke were examined in this paper.

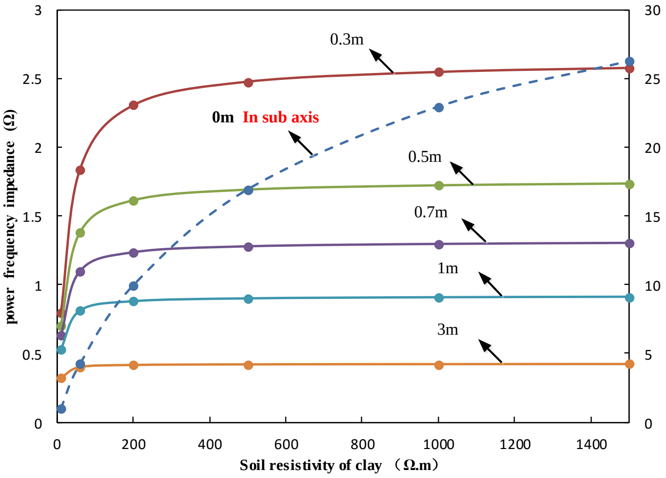
The influencing factors and representing symbols are as follows in TABLE 2.

TABLE2 INFLUENCING FACTORS AND REPRESENTING SYMBOLS

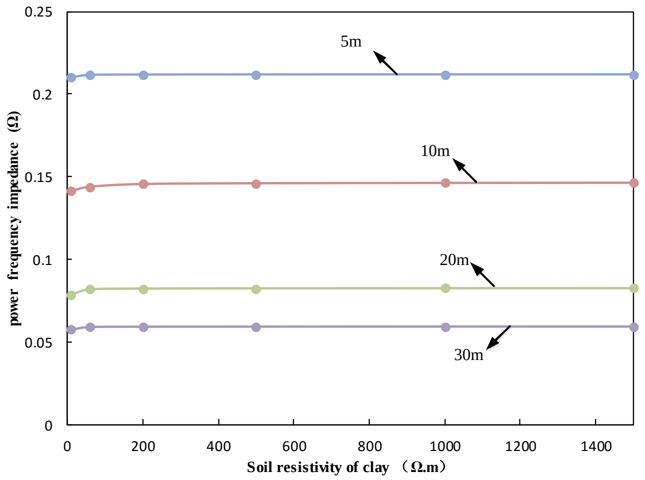
The symbols	The influencing factors
ρ_1 (Ω.m)	Soil resistivity of claypan (Ω.m)
ρ_2 (Ω.m)	Soil resistivity of gravel layer(Ω.m)
h_1(m)	Depths of seawater (m)
h_2(m)	Thickness of claypan (m)
Z_1 (Ω)	Power frequency grounding impedance (Ω)
Z_2 (Ω)	Impulse grounding impedance (Ω)
ΔZ_1 (Ω)	Change value of power frequency grounding impedance (Ω)
ΔZ_2 (Ω)	Change value of impulse grounding impedance (Ω)

A. *The influence of soil resistivity of claypan*

In this part, it is calculated at when h2=10m, ρ2=1000Ω.m. 0 shows relations between Z1, Z2 and ρ1 in different depths of seawater h1.



(a) Relations between ρ_1 and Z_1



(a) Relations between ρ_1 and Z_2

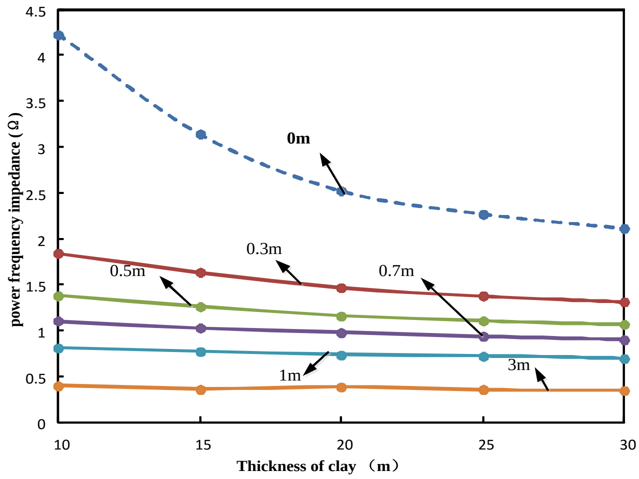
Fig.3. Grounding impedance with soil resistivity of claypan in different depth of seawater

According to Fig. 3：

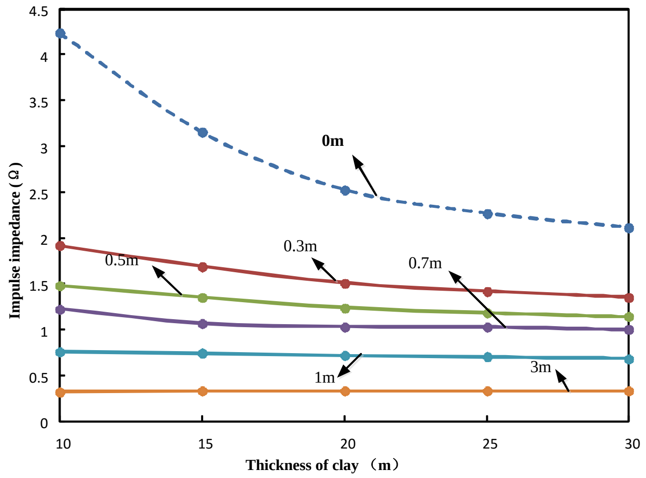
1) Z1 and Z2 increase with the increase of ρ1 in different depth of seawater.
2) Z1 and Z2 are affected by ρ1 more easily when h1≤0.7m. If ρ1 increases from 60 to 1500Ω.m, when h1=0m, ΔZ1=26.26Ω (change rate is 521%) ΔZ2=22.06Ω (change rate is 522%); when h1=0.3m, ΔZ1=0.74Ω (change rate is 40.2%) ΔZ2=5.474Ω (change rate is 286.14%).
3) Z1 and Z2 will not change with the change of soil resistivity in the clay layer when h >3m.

B. *The influence of the thickness of claypan*

In this part, it is calculated at when ρ1=60Ω.m, ρ2=1000Ω.m. Fig.4 shows relations between Z1, Z2 and h2 in different depths of seawater h1



(a) Relations between h_2 and Z_1



(b) Relations between h_2 and Z_2

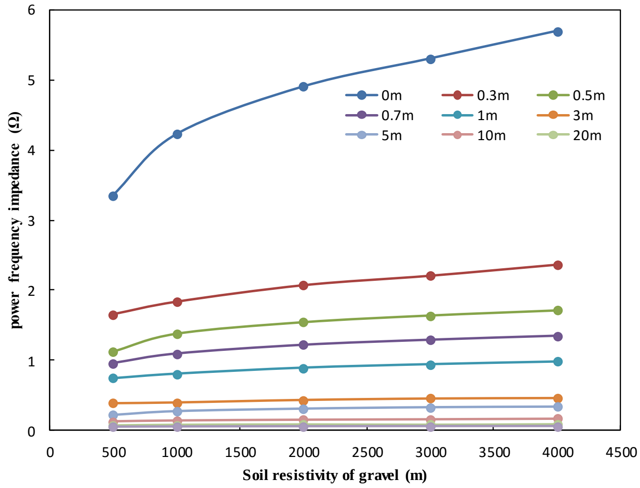
Fig.4. Grounding impedance with the thickness of claypan in different depth of seawater

According to Fig.3：

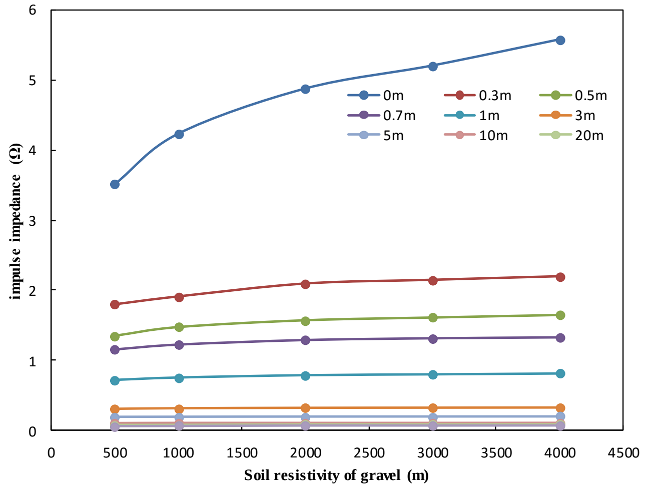
1) Z1 and Z2 decrease with the increase of h2 in different depth of seawater.
2) Z1 and Z2 are affected by h2 more easily when h1<0.7m. If h2 increases from 10 to 30m, when h1=0m, ΔZ1=2.11Ω (change rate is 49.9%) ΔZ2=2.12Ω (change rate is 50.1 %);
3) When h1⩾0.7m, h2 increases from 10 to 30m, Z1 and Z2 remain basically unchanged. It means the degree of h2 effects Z1 and Z2 decrease.

C. *The influence of the resistivity of gravel*

In this part, it is calculated at when ρ1=60Ω.m, h2=10m. Fig.5 shows relations between Z1, Z2 and ρ1 in different depths of seawater h1.



(a) Relations between ρ_2 and Z_1



(b) Relations between ρ_2 and Z_2

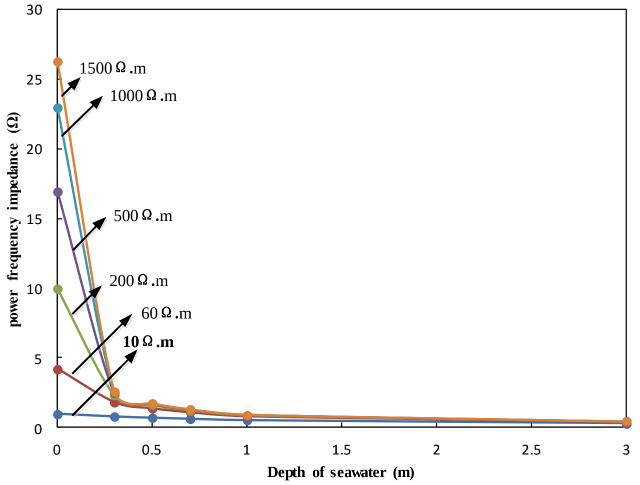
Fig.5. **Grounding impedance with soil resistivity of gravel in different depth of seawater**

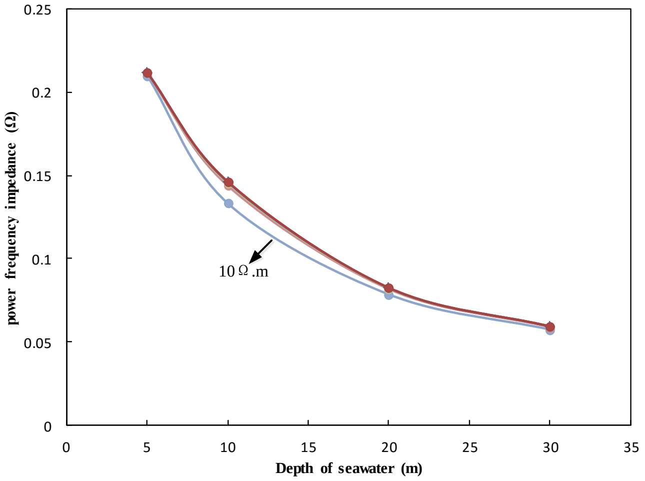
According to Fig. 5:

Z1 and Z2 increases with the increase of ρ2 in different depth of seawater. Z1 and Z2 are affected by h2 more easily when h1≤0.3m.

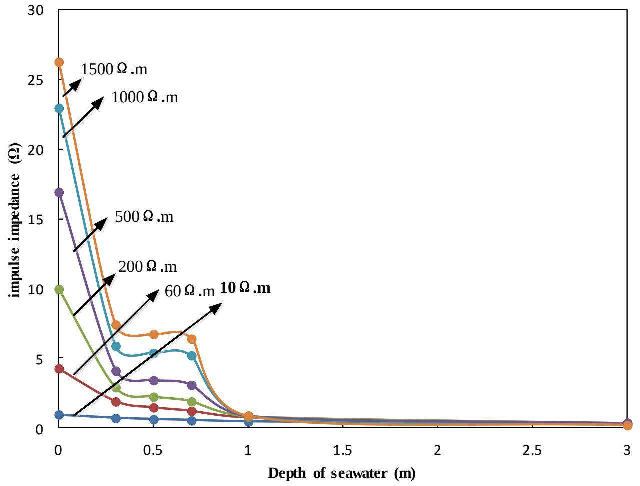
D. The influence of the resistivity of gravel

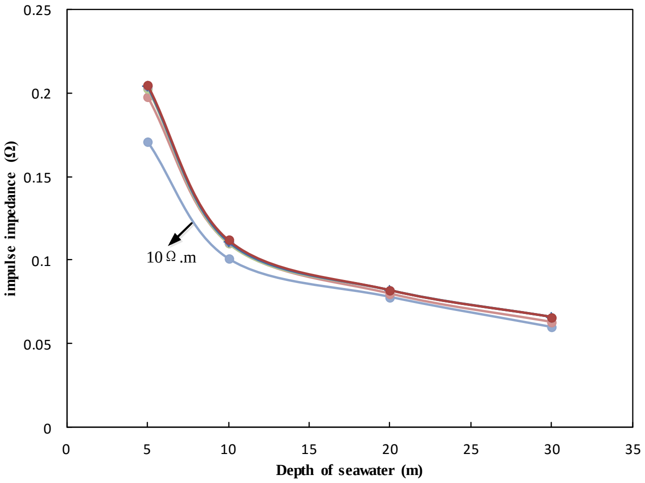
In this part, it is calculated at when ρ2=1000Ω.m, h2=10m. Fig.6 shows relations between Z1, Z2 and h1 in different depths of seawater h1.





(a) Relations between h_1 and Z_1





(b) Relations between h_1 and Z_2

Fig.6. **Grounding impedance with depth of seawater in different soil resistivity of claypan**

According to Fig. 6:

Take curve that represent ρ1=1000Ω.m for example, When h1=0m, Z1=22.94Ω, Z2=22.96Ω, When h1=0.3m, Z1=2.54Ω, Z2=5.87Ω, When h1=5m, Z1=0.21Ω, Z2=0.20Ω. In the process of h1 increasing from 0 to 0.3m, the amplitude and speed of the decreasing of Z1 and Z2 are remarkable in the different condition of soil characteristics. And distance between each curve decreases gradually with the increase of that means the degree those different soil characteristics affecting the value of grounding impedance become less obvious.

E. The influence of structure parameter of tripod

In this part, it is calculated at when ρ2=1000Ω.m, h2=10m. 0 shows relations between Z1, Z2 and h1 in different depths of seawater h1. TABLE 3 TABLE 4 and TABLE 5 show the influence of the depth that driven pile drilled into ground, the different diameter and the different material of the driven pile respectively.

TABLE 3 INFLUENCING OF THE DEPTH THAT DRIVEN PILE DRILLED INTO GROUND

	The depth that driven pile drilled into ground (m）				
	10	15	20	25	30
Power frequency impedance (Ω)	4.53	4.49	4.45	4.41	4.36
Compared with 10m	—	-0.88%	-1.77%	-2.65%	-3.75%

(a) Power frequency grounding characteristics

	The depth that driven pile drilled into ground (m）				
	10	15	20	25	30
Impulse impedance (Ω)	4.06	4.02	3.96	3.92	3.84
Compared with 10m	—	-0.99%	-2.46%	-3.45%	-5.42%

(b) Impulse grounding characteristics

TABLE 4 INFLUENCING OF DRIVEN PILE DIAMETER

	The diameter of driven pile (m）					
	1	2	3	4	5	6
Power frequency impedance (Ω)	4.45	4.33	4.26	4.20	4.16	4.12
Compared with 1m	—	-2.70%	-4.27%	-5.62%	-6.52%	-7.42%

(a) Power frequency grounding characteristics

	The diameter of driven pile (m）					
	1	2	3	4	5	6
Impulse impedance (Ω)	3.96	3.78	3.67	3.59	3.53	3.48
Compared with 1m	—	-4.55%	-7.32%	-9.34%	-10.86%	-12.12%

Impulse grounding characteristics

TABLE5 INFLUENCING OF DRIVEN PILE MATERIAL

	The material of driven pile (m）	
	Copper	Steel
Power frequency impedance (Ω)	4.45	4.45
Compared with copper	—	0%

(a) Power frequency grounding characteristics

	The material of driven pile (m）	
	Copper	Steel
Impulse impedance (Ω)	3.96	3.96
Compared with copper	—	0%

Impulse grounding characteristics

From the calculation result:

All these three influencing factors have similar effects on power frequency and impulse grounding impedance:

1) Grounding impedance reduce as the increase of drilling depth and diameter;

2) Grounding impedance will not be affected by material of driven pile.

IV. CONCLUSION

1) The power frequency and impulse grounding impedance of offshore wind turbine with tripod foundations are affected by the depth of seawater the most, significantly in 0-5m depth of seawater. The grounding impedance will gradually decrease and finally become stable finally as the sea level continues to decrease.

2) The grounding impedance will increase with the increase of soil resistivity in the clay pan and gravel layer. Furthermore, the correlation will be more remarkable as the decrease of depth of seawater, especially in low tidal region in intertidal zones.

3) The grounding impedance will decrease with the increase of soil thickness of the clay pan. Furthermore, the correlation will be more remarkable as the decrease of depth of seawater, as is similar with conclusion 2.

4) The drilling depth and diameter of driven pile have little influence on the power frequency and impulse grounding impedance; however, the grounding impedance will not be affected by the material of driven pile.

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