Factors Affecting Transient Response of Grounding Grid Systems

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Abstract: Grounding system behavior under transient condition is investigated. Transmission line approach has been chosen to simulate the buried grounding system under lightning condition Different models of buried grounding grids have been studied under lightning conditions. Sensitivity analysis of soil parameters and grounding grid dimensions have been studied to understand the effect of each parameter on the performance of grounding systems subjected to lightning.

Keywords: Grounding, Transient, lightning, Ground Potential Rise.

1. Introduction

The transmission line approach is a better choice for the present study. Unfortunately, the development of this approach was not as fast as that of circuit and electromagnetic field approaches. As of now, all the transmission line approaches were limited to model simple grounding systems, i.e., counterpoise wires or single grounding rods.
Consequently, from scope of this study, it becomes necessary to improve transmission line approach for modeling transient behavior of grounding systems for engineering application. The conventional transmission line approach with parameters (*L, C, and R*) will be extended from a single grounding wire/rod to grounding grids. The grounding systems are structured with good conductors. Every conductor is assumed to be a lossy transmission line. It is also assumed that the radius of the conductors is much smaller than the buried depth and the length of the wire. The conductor is characterized by its electrical properties and dimensions. The soil is modeled as a linear and homogeneous half space characterized by resistivity, relative permittivity and permeability, thus making the soil a lossy medium. The current is partly flowing along the conductors, and partly dissipating from its surface into the soil in a radial direction. For the moment, the ionization of the soil is not considered. The skin effect (internal loss) of the conductor is neglected, as the losses in the soil are much larger than the internal loss. An infinite uniform transmission line approach, similar to the one used by Mazzetti et.al. [2], is used in the simulation. Also, the transmission line parameters are frequency independent. It means the parameters are constant for a given lightning stroke. On the other hand, practical grounding systems have some conducting structure above the ground (e.g., air-termination, and down conductors of the lightning protection system), in addition to the buried conductors. Any electromagnetic coupling between the over ground system and underground system are not considered. Besides, the vertical conductor that system is also not considered.

2. Modeling of Grounding System for Lightning Studies

2.1 Equivalent Circuit of a Horizontal Grounding Grid on Lightning Condition

Ground grids are considered complex arrangement and many research efforts have been made to explain the performance of grounding impedance of the ground grid under lightning [3,4] The program ATP-EMTP is used, the software widely used by power engineer for transient analysis [5].
Using the formula mentioned in [6, 7] to calculate the grid parameters.

$$R = \rho\left[\frac{1}{l} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]\Omega \qquad (1)$$

Where **R** is the resistance of the grid, ρ is the soil resistivity $\Omega.m$, **A** is the area of the grid, and ***l*** is the total length of the grid.

$$C = \frac{\varepsilon \cdot \rho \cdot 10^{-9}}{36\pi R}\ \Omega \qquad (2)$$

Where C is the capacitance of the grid, ε is the permittivity of soil.

$$L_1 = \frac{2l''}{3 \cdot 10^{-7}} \ln\frac{2l''}{r''}\ \ \mathrm{H} \qquad (3)$$

Where $\mathbf{L_1}$: is the inductance of the main wire, ***l"*** is the length of the main wire, and ***r"*** is the main wire radius.

$$L_2 = \frac{2l'''}{3 \cdot 10^{-7}} \ln\frac{4l'''}{r'''}\ \ \mathrm{H} \qquad (4)$$

Where $\mathbf{L_2}$ is the inductance of the grid conductors, ***l'"*** is the side length of the grid, and ***r'"*** is the grid wire radius.

2.2 Grids under Testing

Different tested grids CS01, CS16 and CS64, are shown in figure (1) and their dimensions are tabulated in table 1

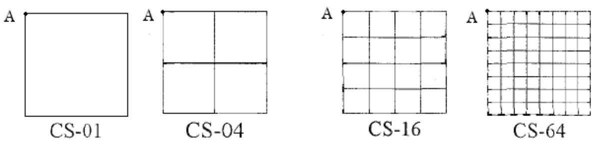

Fig.(1) Different number of meshes for square grids

Table (1) Parameters of the four square grids

	Area m*m	n (number of parallel conductors)	N (number of meshes)	D(space between conductors)
CS01	10*10	2	1	10
CS04	10*10	3	4	5
CS16	50*50	5	16	12.5
CS64	100*100	9	64	12.5

The radius of the horizontal grounding grid conductor is 10mm, the grid is buried at 0.6m depth in the soil with ε =50 and ρ=100 $\Omega.m$, the injected current impulse at point A in each grid has the formula $I(t) = 12000 \cdot (e^{-27000.t} - e^{-5600000.t})$, the peak value of the current impulse is about 12kA. [2]
The RLC parameters of the grids under study tabulated in 5 are given in table 2. Figures (2-a) and (2, b) give the transient impedance of different grids under testing.
Figures (2-c) and (2-d) present results of the transient voltages at injection point for different grids as response to the fast lightning current impulse.

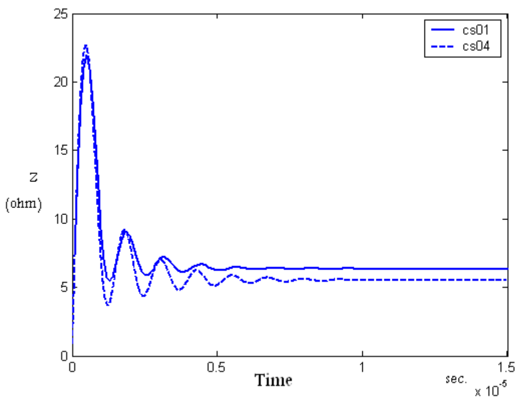

Fig.(2-a) Transient impedance for CS01 and CS04 grids

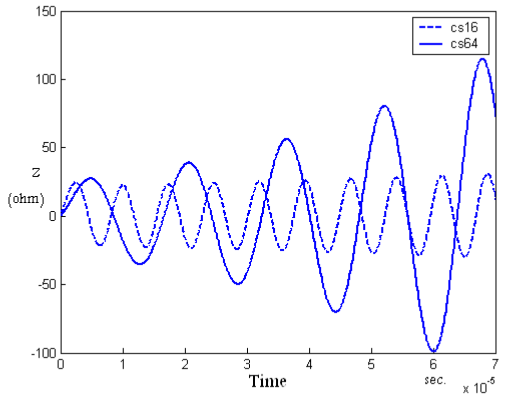

Fig.(2-b) Transient impedance for CS16 and CS64 grids

From figure (2-b) it is noticed that the oscillation of the ground system transient impedance increase due to the increase of inductance and capacitance of the ground system and decrease of the ground system resistance, i.e. the increase of grid dimensions increase the capacitance and inductance of the ground system and reduces the ground system resistance and this lead to oscillation of the transient impedance of the ground system. during the 70 μsec period shown in figure (2-b) the impedance of CS16 oscillates nine cycles, while the impedance of CS64 oscillate for four cycle only .

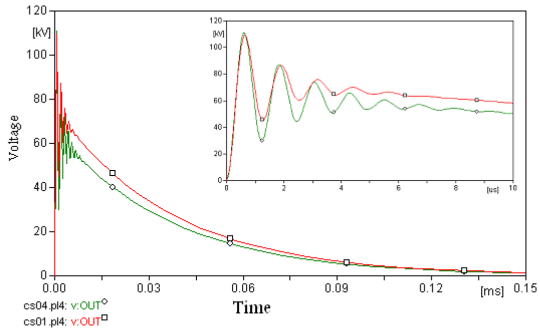

Fig.(2-c) Voltage wave form for CS01 and CS04 grids

Table (2) RLC values for each grid configuration for

ρ=100 $\Omega.m$

	R (Ω)	L_1 (H)	C (F)	L_2 (H)
CS01	6.499	2.396e-005	6.802e-09	5.529e-006
CS04	5.665	2.396e-005	7.803e-09	5.529e-006
CS16	1.071	1.412e-004	4.125e-08	3.301e-005
CS64	0.496	3.010e-004	8.896e-08	7.064e-005

From Fig.(2-c) it is noticed that the maximum values of the transient voltages of CS01 and CS04 are approximately equal The difference may be after the first beak, this in agreement with [8] ,but it is not the same in case of CS16 and CS64 due to the high numbers of meshes especially in CS64.In general it is noticed that as the area of the grid increases the voltage magnitude decreases, after 6μsec from the beginning of the lightning impulse, peak voltage appear over CS01 is about 78kV and over CS04 is about 60kV. The transient impedance of CS01 and CS04 are shown in figure (2-a) the peak value for CS01 is 23Ω then settle to 6.5Ω after 10 μsec, for CS04 the peak value is 22Ω then settle to 5.5Ω after 10 μsec.

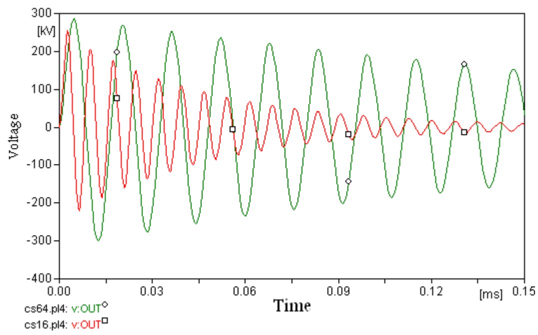

Fig.(2-d) Voltage wave form for CS16 and CS64 grids

3. Sensitivity Analysis of Soil Parameters and Grounding Grid Dimensions

All the parameters of the grounding system, such as the soil relative permittivity , soil resistivity , and the conductors' diameter, are related to the electric circuit elements parameters, so the influence of these parameters on the transient impedance of the grid and transient voltages that appear on the grids will be investigated

Figure (3-a) shows the transient impedance for tested grids CS01 and CS04 for ρ=100 Ω.m and 400 Ω.m , figure (3-b) shows the transient impedance for tested grids CS16 and CS64 for ρ=100 Ω.m and 400 Ω.m .The transient voltages response for CS01, CS04, CS16 and CS64 are shown in figure (4-a) for ρ=100 Ω.m , in case of ρ=400 Ω.m results are shown in figures (4-b).

Table 3 shows the values of Lumped RLC circuit for each grid configuration for ρ=400 Ω.m .The Influence of the soil resistivity results of fast lightning current impulse applied to the grounding grids with radius of the horizontal grounding grid conductor is 10mm, the grid is buried at 0.6m depth in the soil with ε =50.

Table (3) RLC values for ρ=400 Ω.m

	R (Ω)	L (H)	C (F)	L_2 (H)
CS01	25.996	2.396e-005	6.802e-09	5.529e-006
CS04	22.663	2.396e-005	7.803e-09	5.529e-006
CS16	4.2866	1.412e-004	4.125e-08	3.301e-005
CS64	1.9877	3.010e-004	8.896e-08	7.064e-005

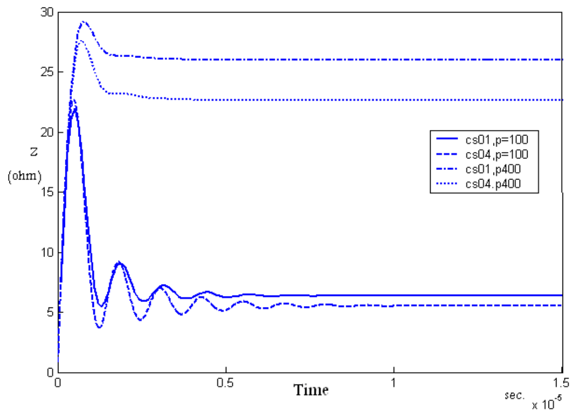

Fig.(3-a) Transient impedance for CS0 and CS04 grids for ρ=100,400 Ω.m

As shown in figure (3-a) for the grid CS01 when the soil resistivity equals 100 Ω.m the peak value of the transient impedance was (23Ω) 350% of the transient impedance after 10 μsec (6.5Ω) while in case of soil resistivity equals 400 Ω.m the peak value of the transient impedance was (28Ω) 107% of the transient impedance after 10 μsec (26Ω).

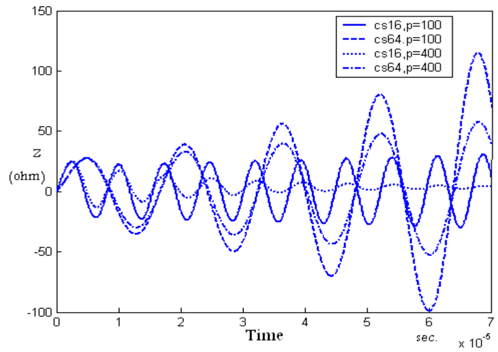

Fig.(3-b) Transient impedance for CS16 and CS64 grids for ρ=100,400 Ω.m

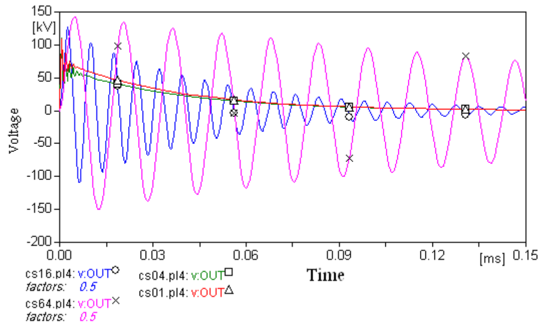

Fig.(4-a) Voltage wave form for ρ=100 Ω.m

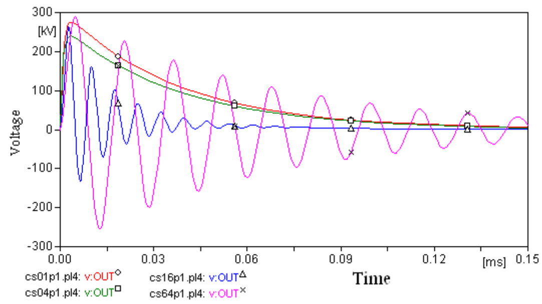

Fig.(4-b) Voltage wave form for ρ=400 Ω.m

Comparing table 2 and table 3 together gives the following conclusion , when the soil resistivity is changed from 100 Ω.m to 400 Ω.m only the resistive part of the grounding system RLC model changed while capacitive and inductive parts does not change and due to this changes the results of the simulation change as shown in figures (7-a,b) the voltage magnitude for CS01 and CS04 after 6μsec from the beginning of the lightning impulse change from 65kv and 54.5kv to 264kv and 230kv respectively also the voltage oscillation at the beginning of the lightning impulse is damped as the resistance of the ground system increased. For CS16 and CS64 the voltage magnitude at the beginning of the lightning impulse does not changed while the oscillation of the voltage wave form is damped faster due to the increase of the resistive part, the number of complete cycles oscillation during the simulation time 150 μsec for CS64 does not change (9 cycles) while for CS16 the oscillation damped after 9 cycles instead of 20 cycles.

3.1 The Influence of the Soil Permittivity

The relative permittivity is changed from ε =9 to ε =36 respectively and ρ is fixed =100 $\Omega.m$ shown in figures (5-a,b), (6-a,b), (7-a,b) and (8-a,b).for different grids under testing .Table 4 gives the values of Lumped RLC circuit for each grid configuration for ε =9.

Table (4) RLC values for ε =9

	R (Ω)	L_1 (H)	C (F)	L_2 (H)
CS01	6.499	2.396e-005	1.224e-09	5.529e-006
CS04	5.665	2.396e-005	1.404e-09	5.529e-006
CS16	1.071	1.412e-004	7.425e-09	3.301e-005
CS64	0.496	3.010e-004	1.601e-08	7.064e-005

Table 5 gives the values of Lumped RLC circuit for each grid configuration for ε =36.

Table (5) RLC values for ε =36

	R (Ω)	L_1 (H)	C (F)	L_2 (H)
CS01	6.499	2.396e-005	4.897e-09	5.529e-006
CS04	5.665	2.396e-005	5.618e-09	5.529e-006
CS16	1.071	1.412e-004	2.970e-08	3.301e-005
CS64	0.496	3.010e-004	6.405e-08	7.064e-005

It is noticed that increasing the soil relative permittivity increases the capacitance of the ground system.

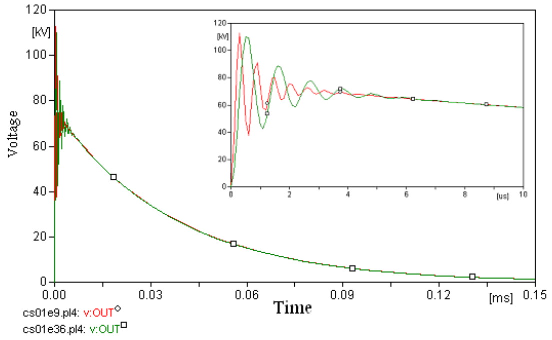

Fig.(5-a) Voltage wave form for CS01, ε =9 and 36

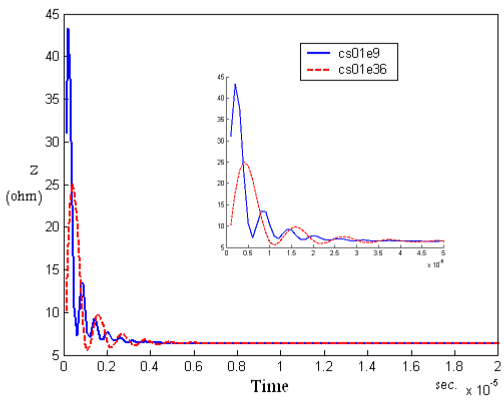

Fig.(5-b) Transient impedance for CS01, ε =9 and 36

From figures (5-a) and (6-a) it is notice that the change in the soil permittivity from ε =9 to 36 lead to small phase shift in the transient voltage response for CS01and CS04 grids (about 0.5 µsec.).Also from figure (8-b) the peal value of the transient impedance reduced from about 43 Ω to 25Ω and this is due to the increase of the capacitance value of the ground system, which gives low resistance in transient and high frequency cases as the impedance of the capacitance is inverse proportional to its capacitance ($x_c = \dfrac{1}{Jwc}$).

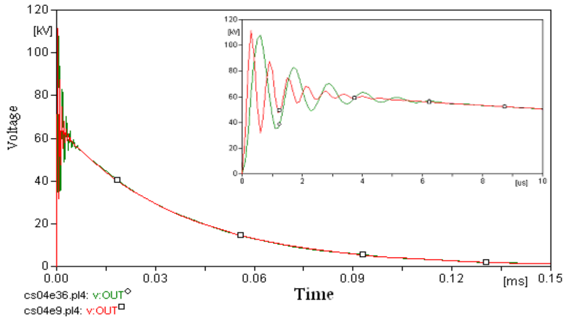

Fig.(6-a) Voltage wave form for CS04, ε =9 and 36

Also figure (6-b) the peak value of the transient impedance is reduced from about 40 Ω to 24Ω.

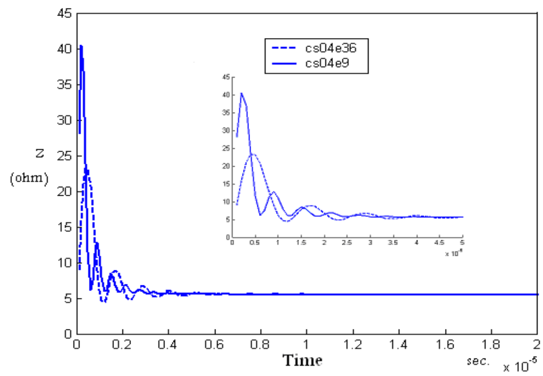

Fig.(6-b) Transient impedance for CS04, ε =9 and 36

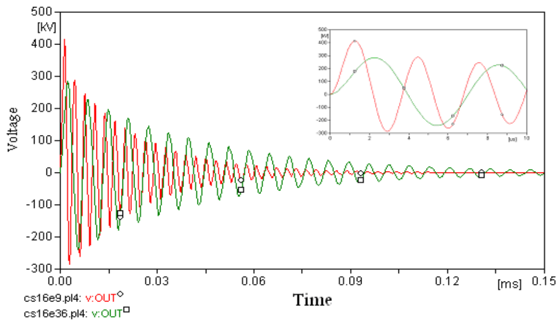

Fig.(7-a) Voltage wave form for CS16, ε =9 and 36

Figures (7-a) and (8-a) show small phase shift in the transient voltage response for CS16 grid (about 0.5 µsec.).

From figure (7-b) and (8-b) it is noticed that the peal value of the transient impedance is reduced from about 52Ω to 30Ω in CS16 and from about 60Ω to 33Ω inCS64

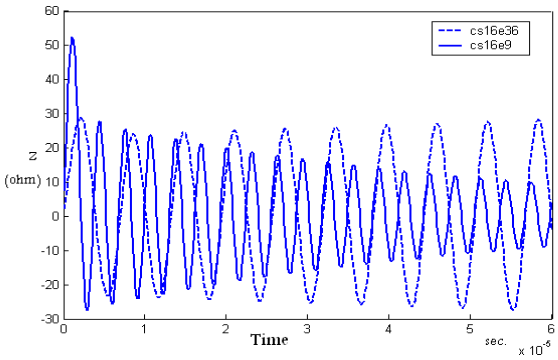

Fig.(7-b) Transient impedance for CS16, ε =9 and 36

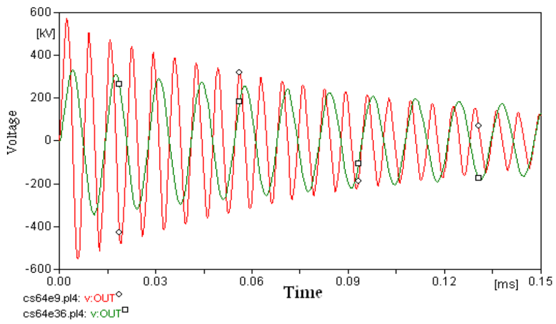

Fig.(8-a) Voltage wave form for CS64, ε =9 and 36

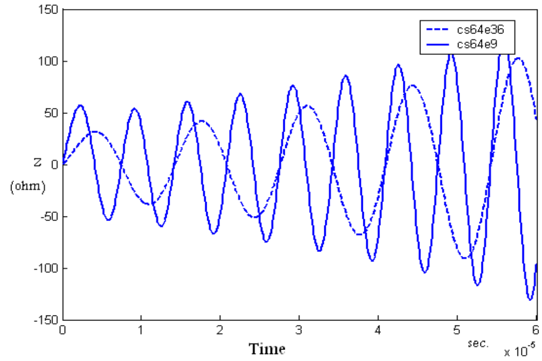

Fig.(8-b) Transient impedance for CS64, ε =9 and 36

3.2 The Influence of the Conductors' Diameter

The horizontal grounding grid conductor is taken 7mm and 20mm, the grid is buried at 0.6m depth in the soil with ε =50 and ρ=100 Ω.*M* .Figures (9-a,b), (10-a,b), (11-a,b) and (12-a,b) show the transient impedances and voltages for the tested grids. Table 6 shows the values of Lumped RLC circuit for each grid configuration for r =7mm.

Table (6) RLC values for r =7mm

	R (Ω)	L_1 (H)	C (F)	L_2 (H)
CS01	6.499	2.491e-05	6.802e-09	5.767e-06
CS04	5.665	2.491e-05	7.803e-09	5.767e-06
CS16	1.071	1.460e-04	4.125e-08	3.420e-05
CS64	0.496	3.105e-04	8.896e-08	7.302e-05

Table 7 shows the values of Lumped RLC circuit for each grid configuration for r =20mm.

Table (7) RLC values for r=20mm

	R (Ω)	L_1 (H)	C (F)	L_2 (H)
CS01	6.499	2.211e-05	6.802e-09	5.067e-06
CS04	5.665	2.211e-05	7.803e-09	5.067e-06
CS16	1.071	1.320e-04	4.125e-08	3.070e-05
CS64	0.496	2.825e-04	8.896e-08	6.602e-05

From figure (9-a) it is noticed that changing the radius of the conductors reduce the peak value of the transient voltages from 118kv to 100kv for CS01, for CS04 from 116kv to 99kv as shown in figure (10a), for CS16 from 250kv to 246kv as shown in figure (11-a) and for CS46 from 292kv to 287kv as shown in figure (12-a).

From figures (10-b), (11-b) and (12-b) it is noticed that increasing the conductor's diameter from 7mm to 20mm reduces the peak value of the transient impedance from 23Ω to 21Ω for CS01 , from 21Ω to 19Ω for CS04 and from 26Ω to 24.5Ω for CS16.

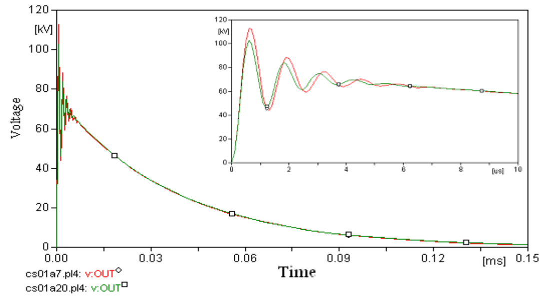

Fig.(9-a) Voltage wave form for CS01,a=7 and 20mm

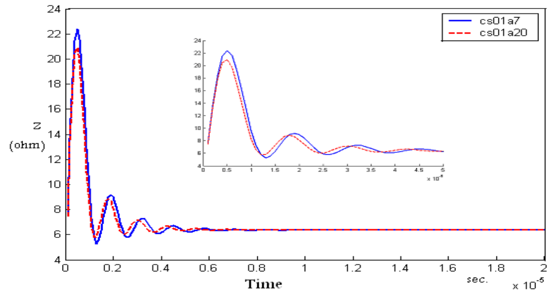

Fig.(9-b) Transient impedance for CS01, a=7 and 20mm

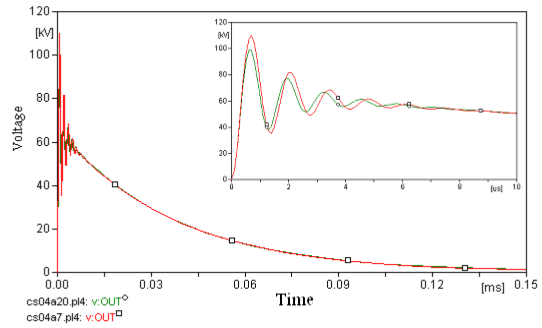

Fig.(10-a) Voltage wave form for CS04,a=7 and 20mm

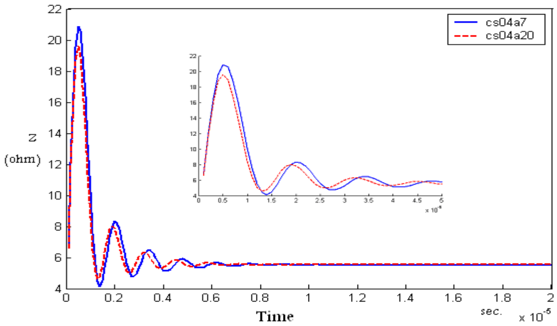

Fig.(10-b) Transient impedance for CS04, a=7 and 20mm

As shown in figure (10-a) when the conductor radius changes from 7mm to 20mm the maximum voltage magnitude for CS04 grid reduced from about 114kV to 98kV.

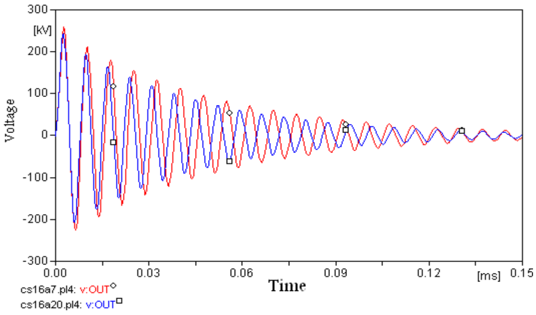

Fig.(11-a) Voltage wave form for CS16,a=7 and 20mm

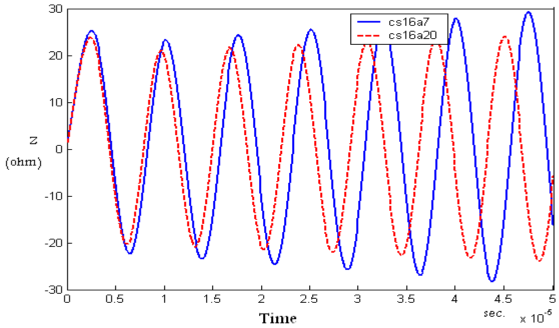

Fig.(11-b) Transient impedance for CS16, a=7 and 20mm

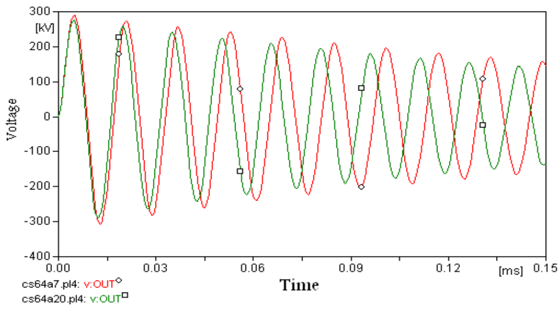

Fig.(12-a) Voltage wave form for CS64,a=7 and 20mm

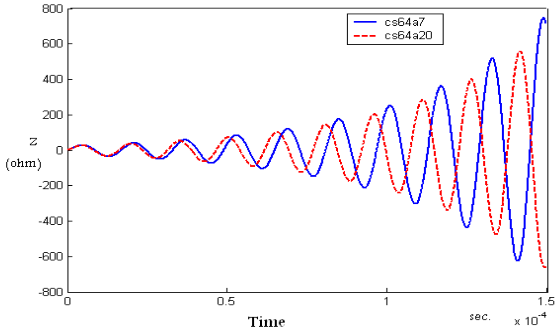

Fig.(12-b) Transient impedance for CS64, a=7 and 20mm

CONCLUSIONS

(1) Lightning performance of large grids dimension are complicated and its transient voltage and impedance response may contain oscillation.
(2) As the soil resistivity increases the impedance of the ground system increases and the oscillation of the transient voltage and impedance reduced.
(3) The impedance of large grid dimension is more affected by the capacitance and inductance of the grid rather than the resistive part so it's transient impedance and voltages are large at the beginning of the lightning impulse.

REFERENCES

[1] Thottappillil R., "Electromagnetic pulse environment of cloud-to ground lightning for EMC studies", IEEE transactions on EMC, Vol. 44, No. 1, Feb. 2002, p.203-213.

[2] C. Mazzetti and G. M. Veca, "Impulse behavior of grounding electrodes", IEEE Trans. Power Apparatus and Systems, Vol. PAS-102, No. 9, pp. 3148-3156, 1983.

[3] R.Verma and D.Mukhedkar, "Fundamental Considrations and Impulse Impedance of Ground Grids", IEEE Transaction on Power Apparatus and Systems, Vol. Pas-100,March 1981,pp.2053-2059.

[4] F.Menter and L.Gercev, "EMTP-Based Model of Grounding System Analysis" IEEE Transactions on Power Delivery, Vol.9,OCT, 1994, pp.1838-1849.

[5] ATP rule book, Can/Am EMTP User Group, 1995.

[6] J.G.Sverak, "Simplified analysis of electrical gradients above a ground grid," IEEE Trans. Vol.PAS-103,No.1,Jan.1984,pp.7-25

[7] L. D. Grcev and M. Heimbach, "Frequency dependent and transient characteristics of substation grounding system," IEEE Trans. Power Delivery, vol. 12, pp. 172–178, Jan. 1997.

[8] Yaqing Liu, Mihael Zitnik, and Rajeev Thottappillil, "An Improved Transmission-Line Model of Grounding System " IEEE Trans. on electromagnetic compatibility, vol. 43, no. 3, August 2001