Power System Transient Analysis in the Frequency Domain: A MoM-AOM Approach

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Outline

- Introduction
- Frequency dependency of grounding systems
- Frequency domain treatment of nonlinearly loaded antennas, ionized soil and lightning arrester
- Conclusions

Why Frequency Domain Method?

We are in favor of using a frequency domain approach:

- To consider the effect of multilayer soil grounding systems
- To consider the effect of soil conductivity
- To consider the frequency dependence of the grounding system and the other power system apparatus

Obstacles of Frequency Domain Approach

How to consider nonlinear loads?

Despite the well suitability of the time domain methods in treating the nonlinear loads, frequency domain techniques are not well suited to treat the nonlinear loads.

The Main Obstacle

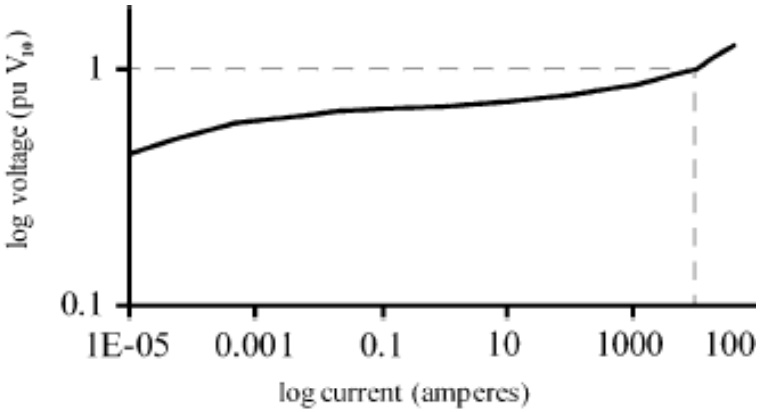
Frequency domain + Nonlinear load+ Transient regime

Nonlinearities

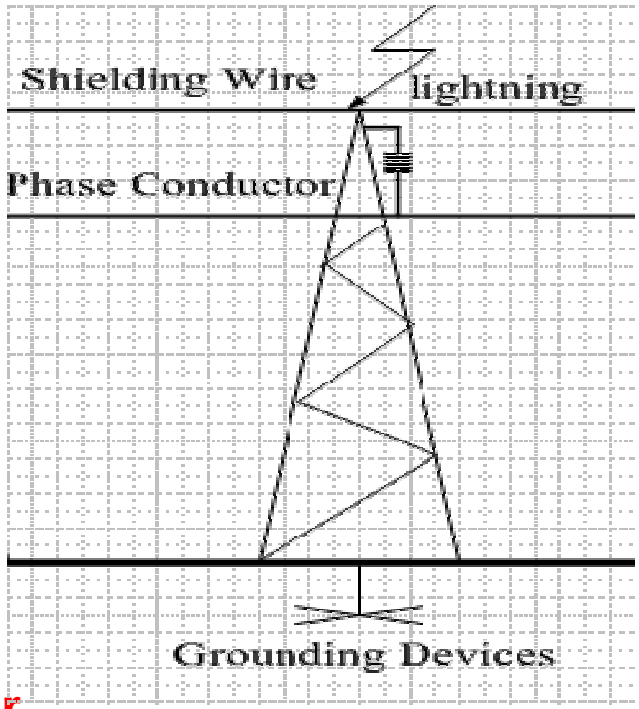
➢Lightning arresters

Lightning arresters are considered as strong nonlinear loads and connected to grounding systems

$$i = p\left(\frac{v}{Vref}\right)^q$$



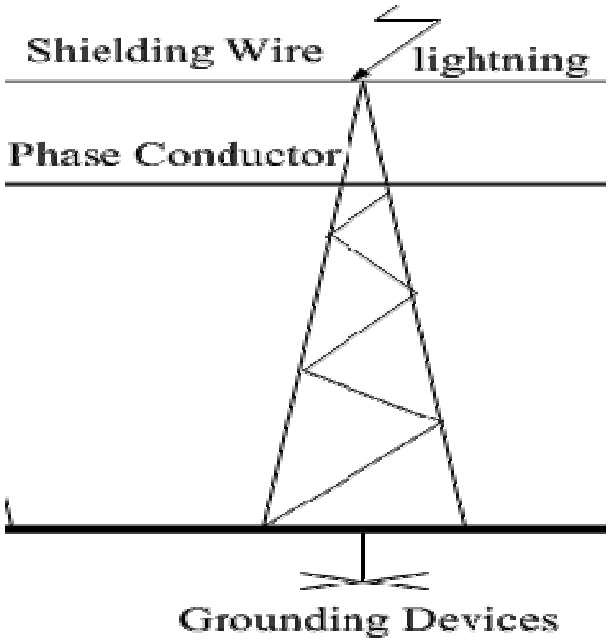
A typical *i-v* characteristics of an arrester

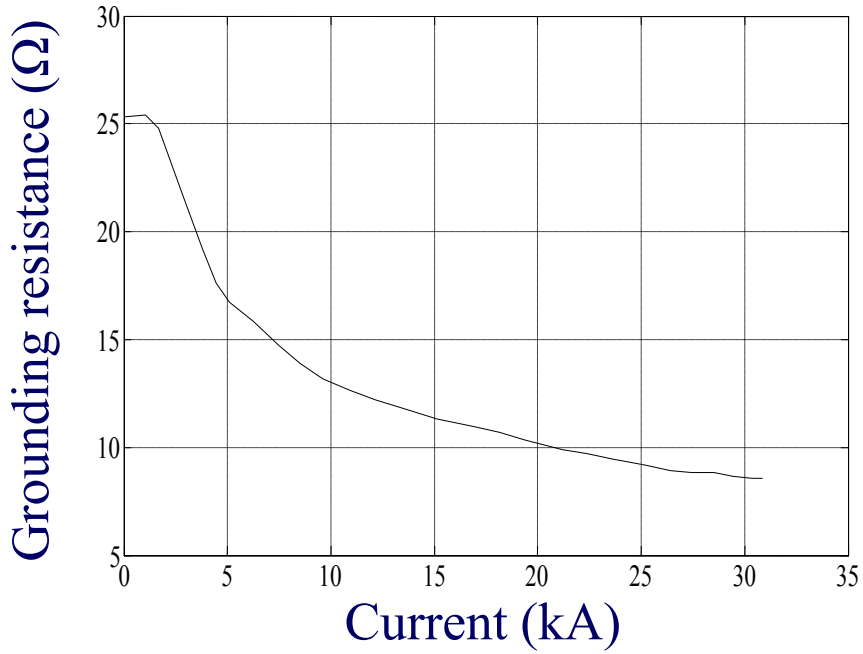


Nonlinearities

➢Soil ionization

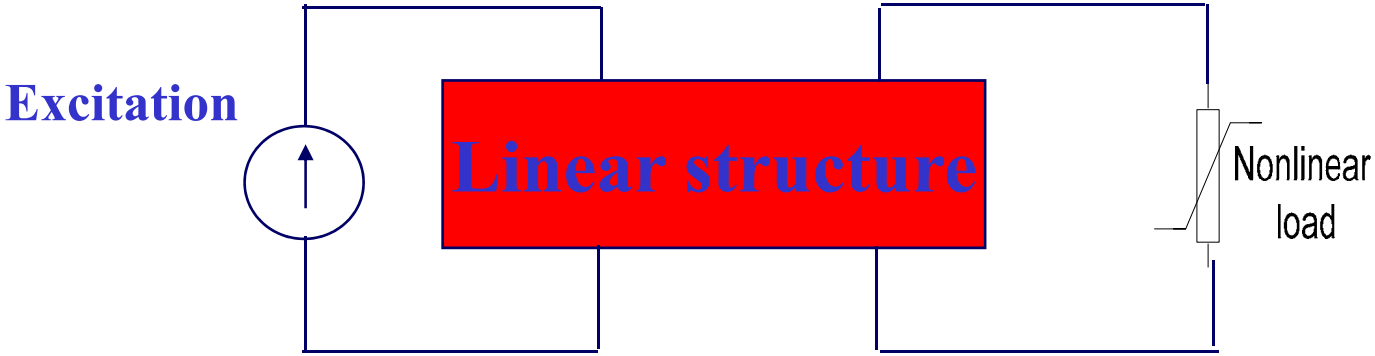
Subjected to a high amplitude current injection into the grounding system, Soil may be ionized and acts like a nonlinear resistance.



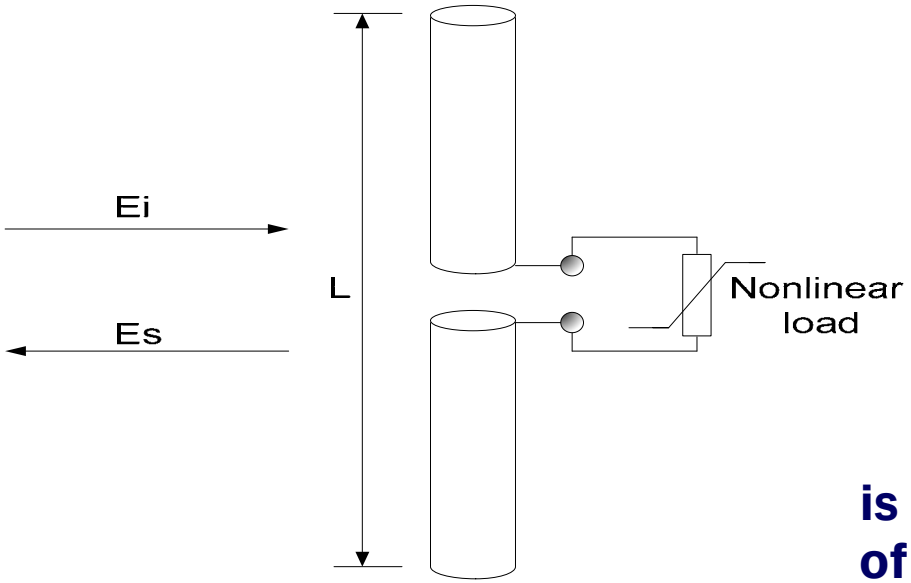


Proposed Method (MoM-AOM)

General Model

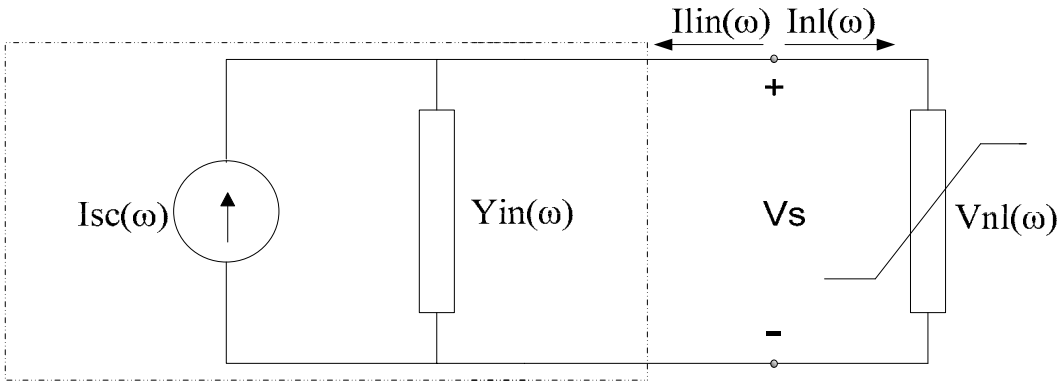


Basic Model of the Problem



$: Yin(\omega)$

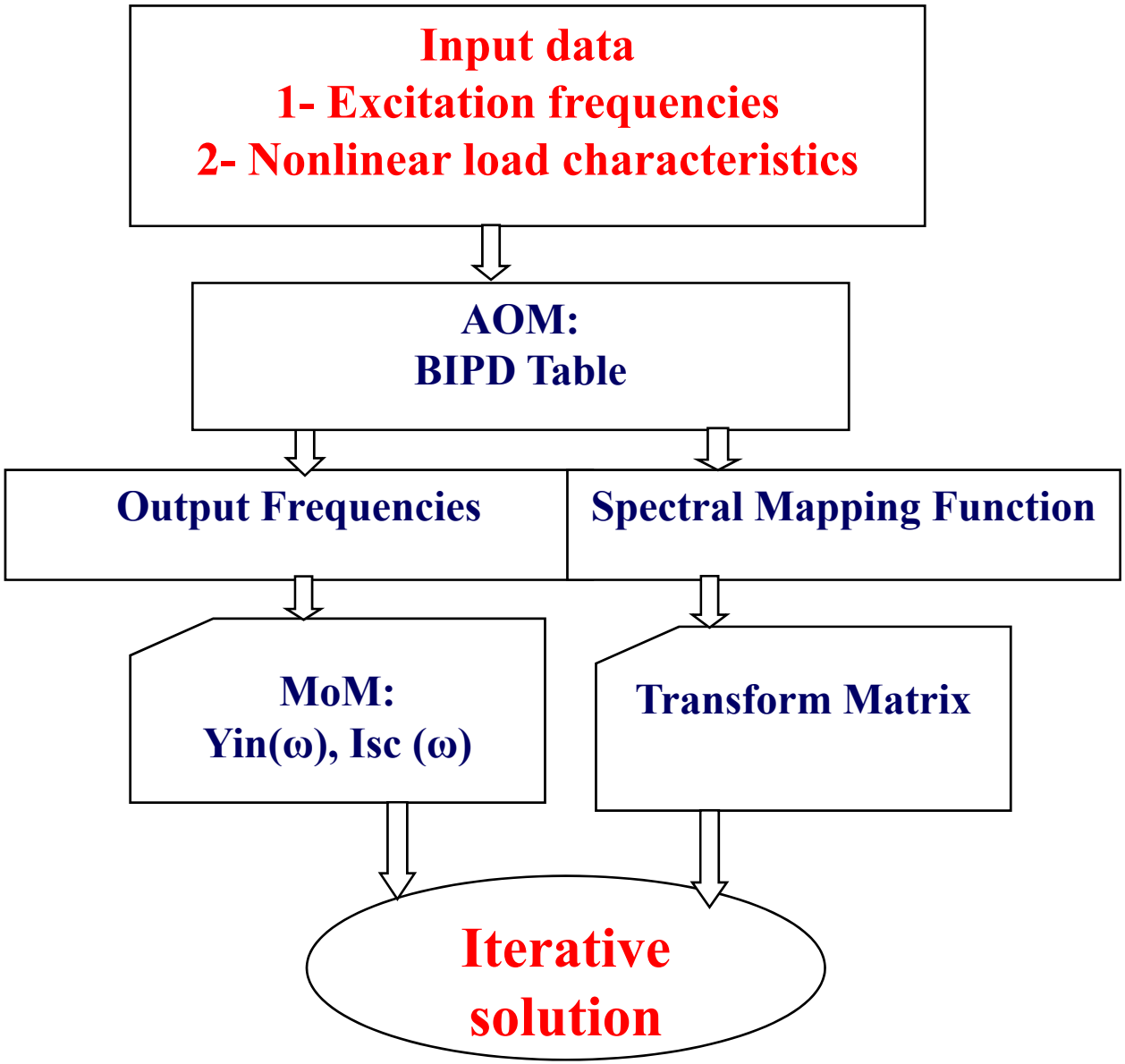
is the input admittance matrix of the antenna



$: Isc(\omega)$

short-circuit current at the antenna input

Solution Procedure

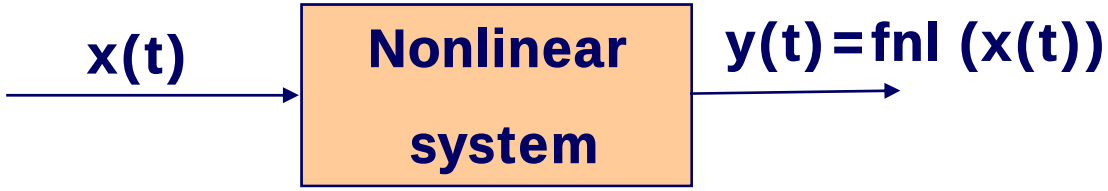


Arithmetic Operator Method

$$[x(t)]^n \overset{F}{\Rightarrow} \underbrace{X(f) * X(f) * \cdots * X(f)}_{n \text{ times}}.$$

X(f) can be represented in a discreet vector form

The convolution operation can be recast in matrix form.



$$y(t) = [x(t)]^2 \Longrightarrow Y(f) = X(f) * X(f) \equiv Y = T_x X$$

Arithmetic Operator Method

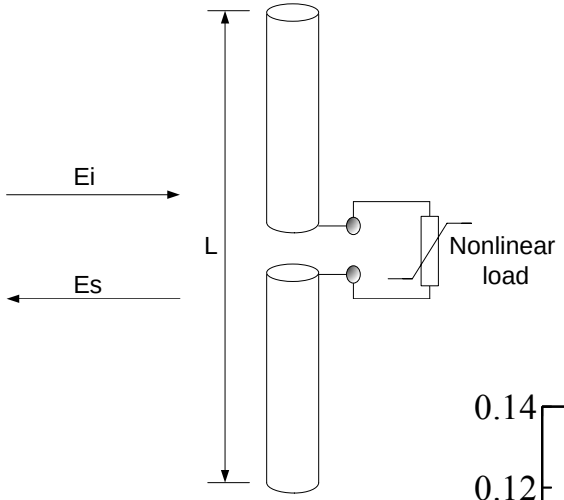
$$y(t) = a_0 + a_1 x(t) + a_2 [x(t)]^2 + \cdots + a_N [x(t)]^N$$
$$= \sum_{n=0}^{N} a_n [x(t)]^n,$$

AOM →

$$Y = a_0 e_{DC} + a_1 X + a_2 T_x X + \cdots + a_N T_x^{N-1} X$$
$$= a_0 e_{DC} + \sum_{n=1}^{N} a_n T_x^{n-1} X$$

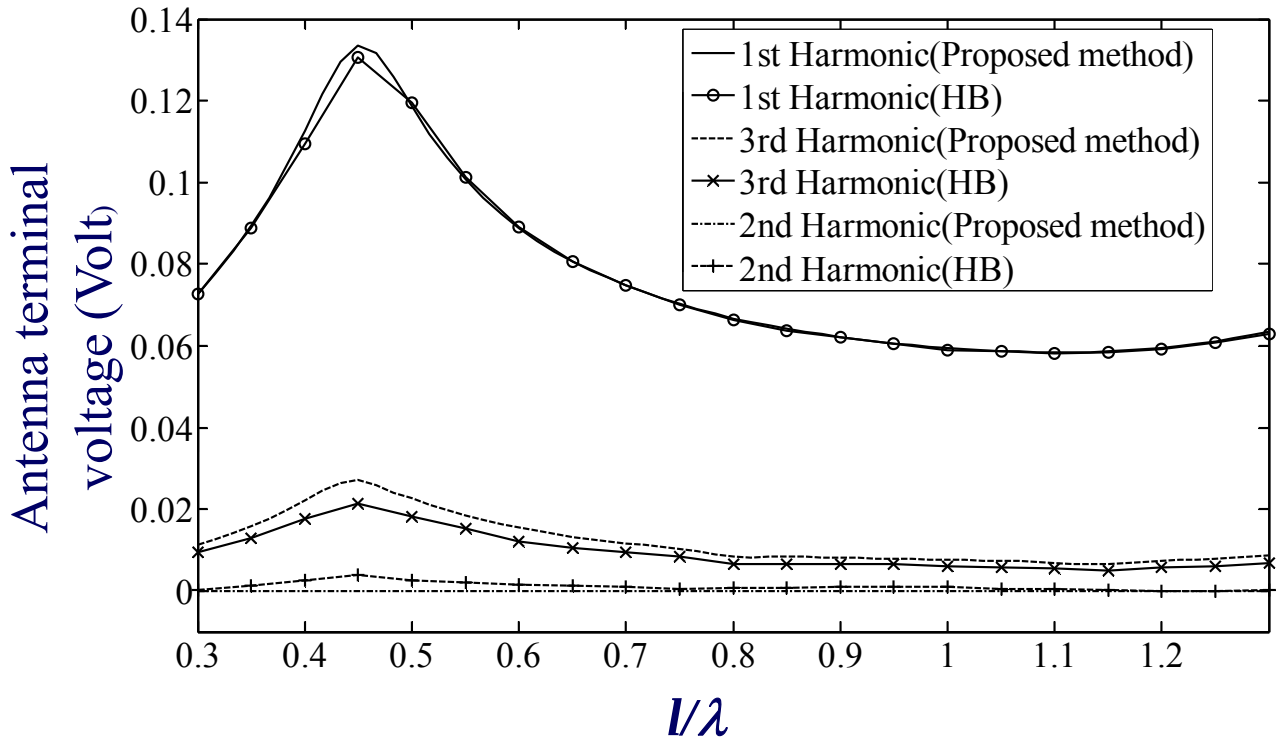
Examples

Nonlinearly Loaded Antenna (Single Frequency)

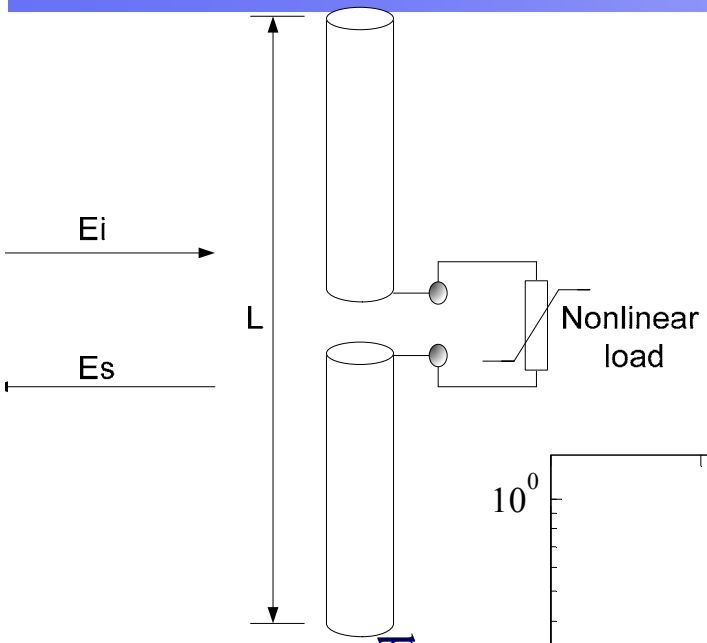


E_i = 1V/m, L/a=74.2

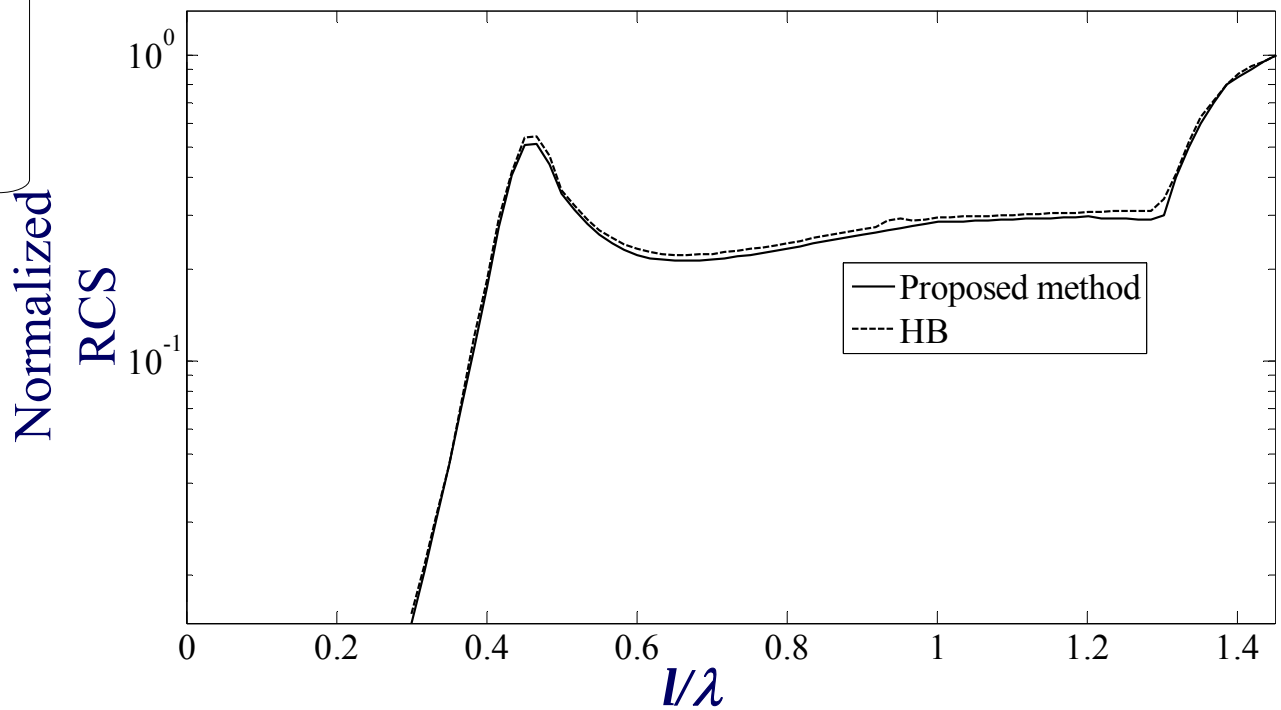
$$i=\frac{1}{75}v+4v^3$$



Nonlinearly Loaded Antenna (Single Frequency)

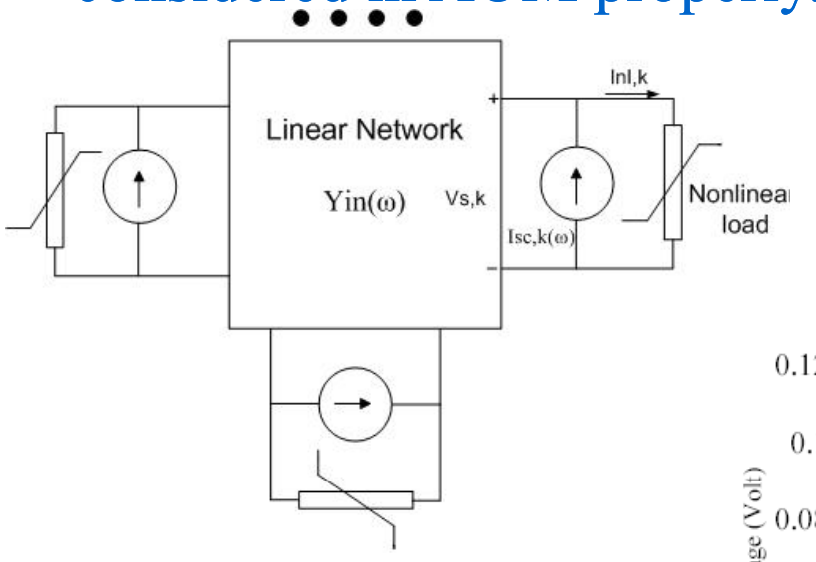


$$i=\frac{1}{75}v+4v^3$$

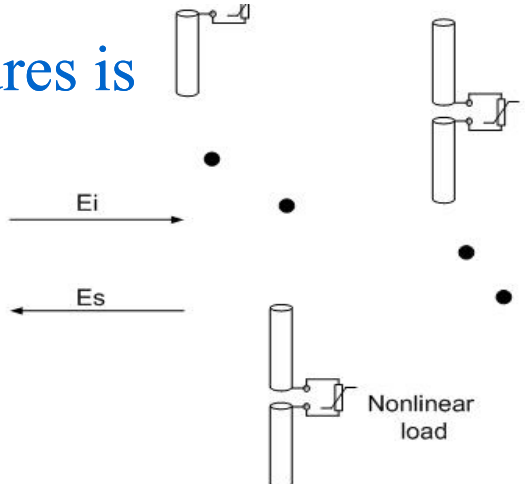


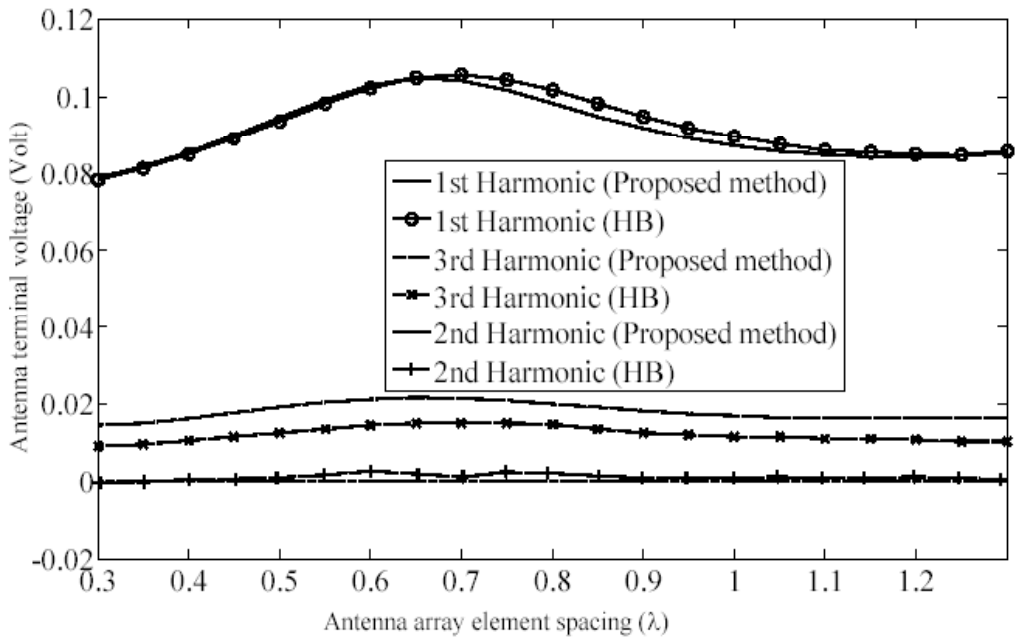
Nonlinearly Loaded Antenna Array (Single Frequency)

Coupling effects between the wire structures is considered in AOM properly.

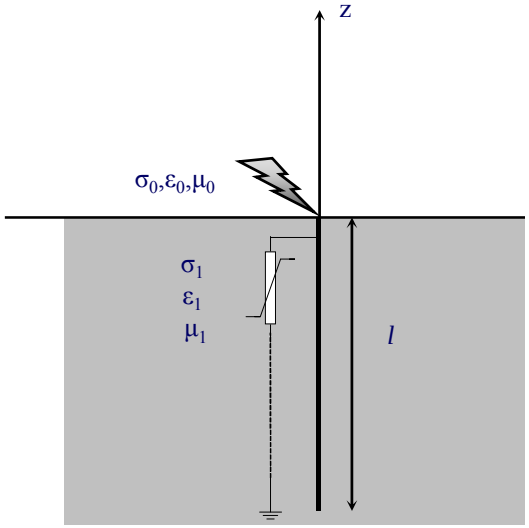


The Mutiport Equivalent Circuit of the Antenna Array

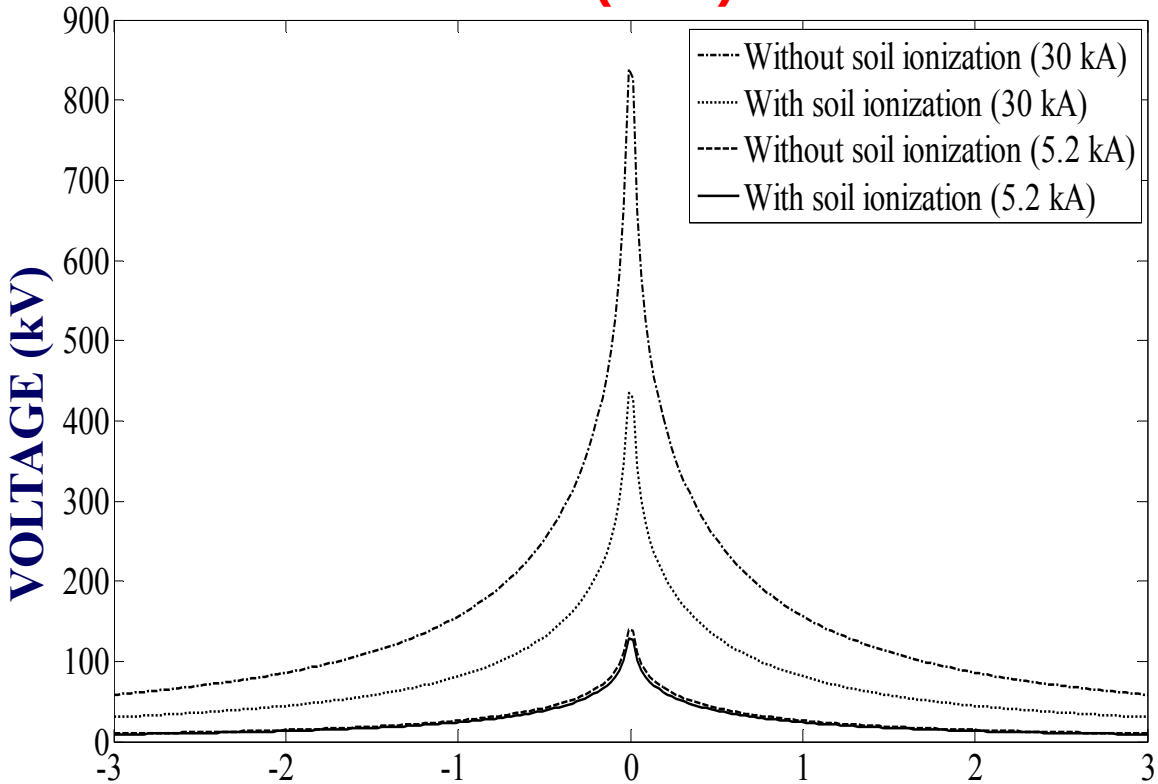




Soil Ionization

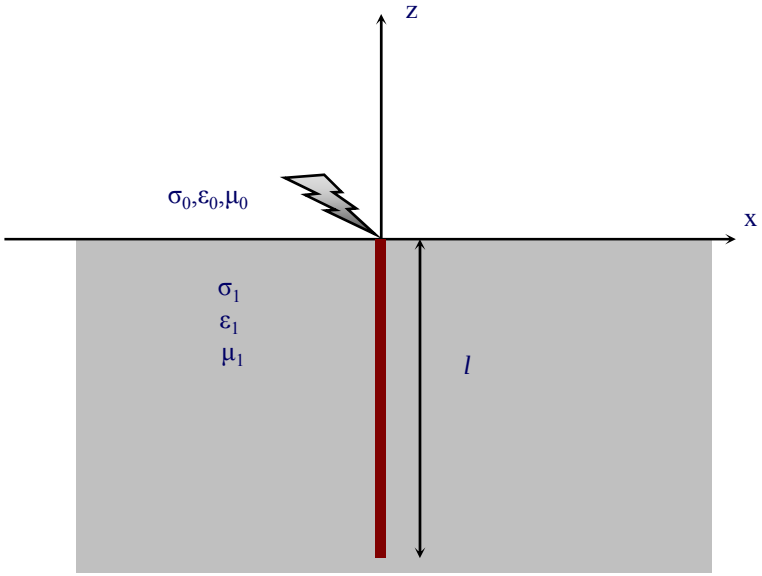


Ground Potential Rise (GPR)

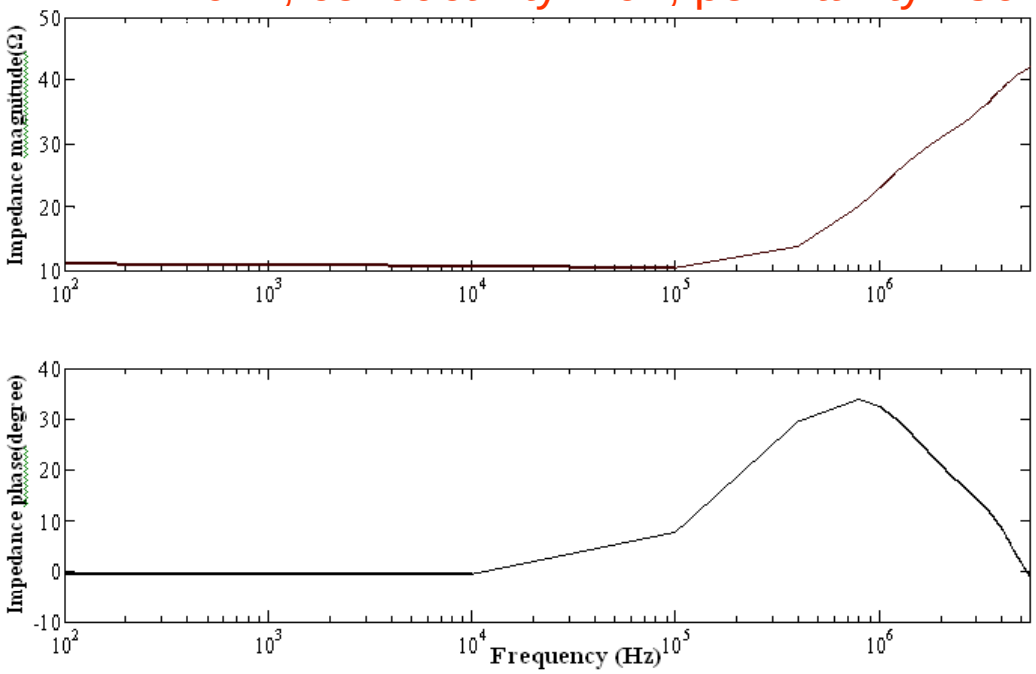


Frequency dependency of grounding systems

- The grounding system has a frequency dependent behavior which is of great importance for transient analysis.



L=10 m, conductivity= .01, permittivity= 36



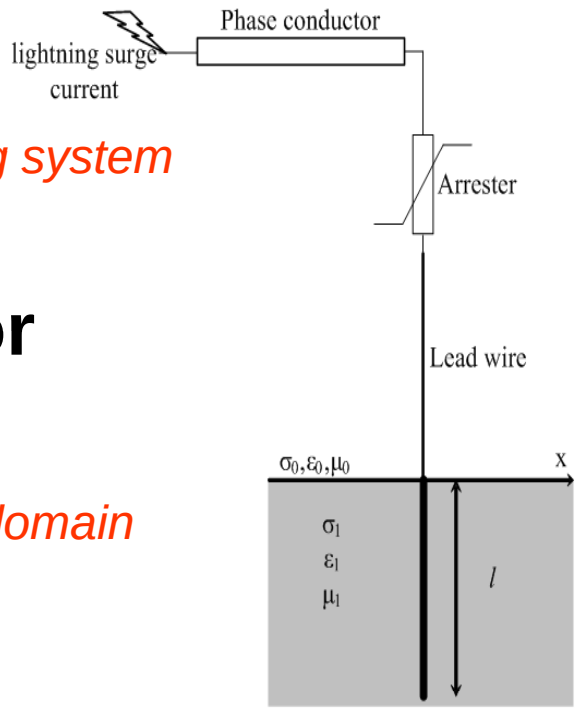
Lightning Arresters

- **We take the advantage of the MoM solution of the electrical field integral equations (EFIE) to,**

Obtain the ***input impedance*** *of the grounding system*

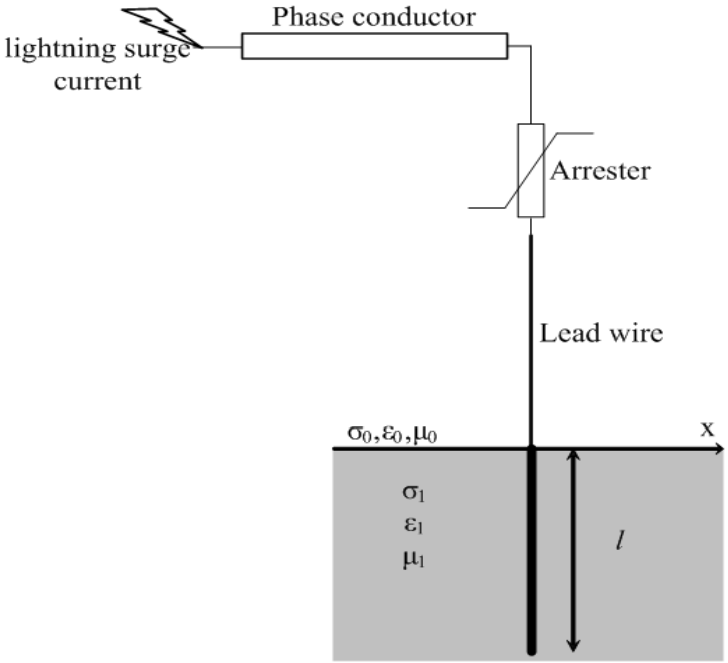
- **We use Arithmetic Operator Method (AOM) to,**

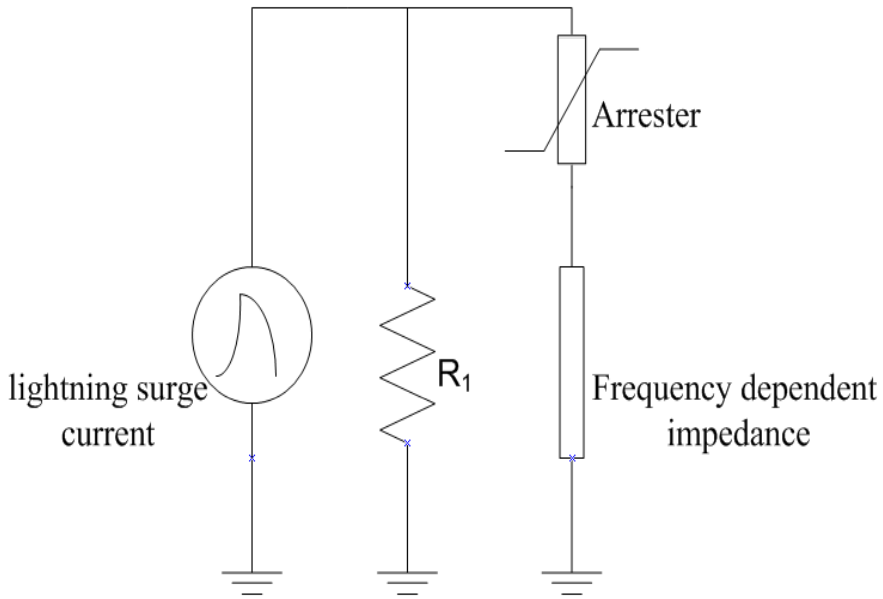
treat the arrester ***nonlinearity*** *in frequency domain*



Lightning Arresters

An equivalent nonlinear circuit is extracted for the problem and treated by use of AOM.

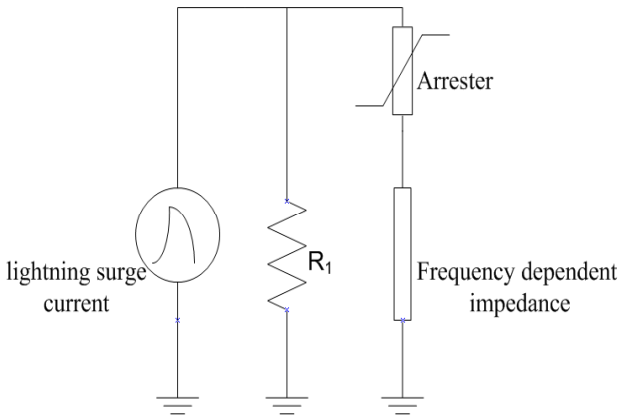




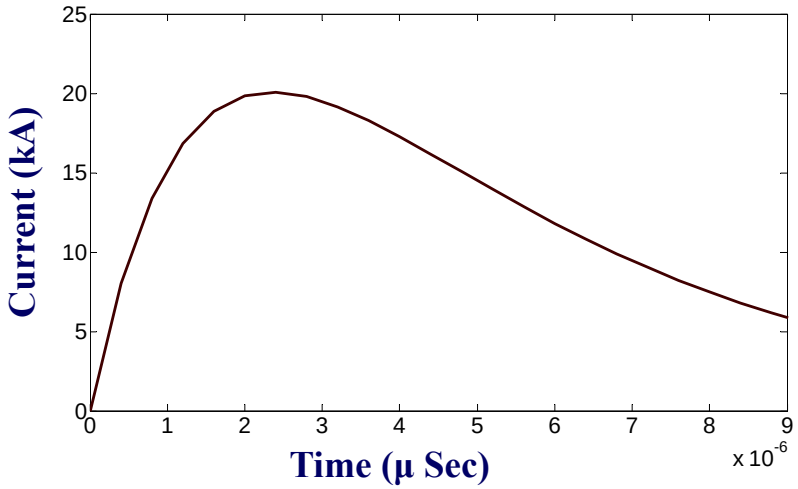
Example

Grounding system Parameters:

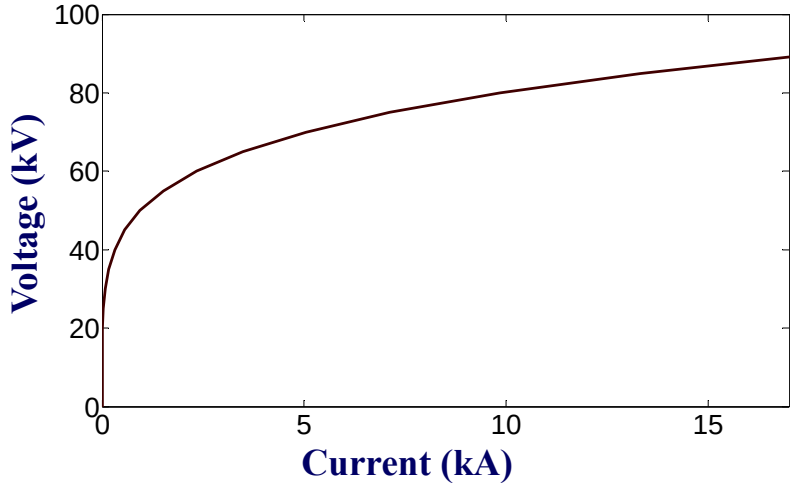
L=24 m, resistivity=100 and permittivity= 36.



Lightning current

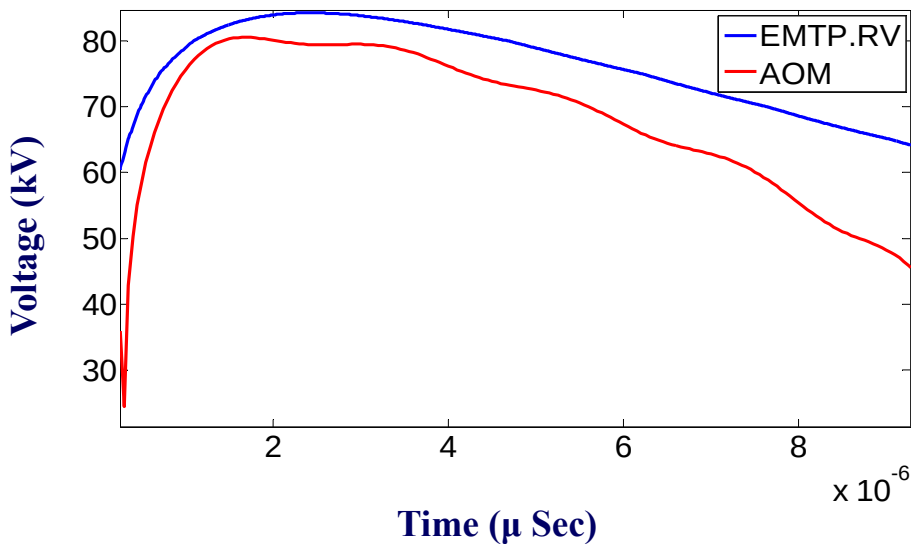


Arrester characteristics

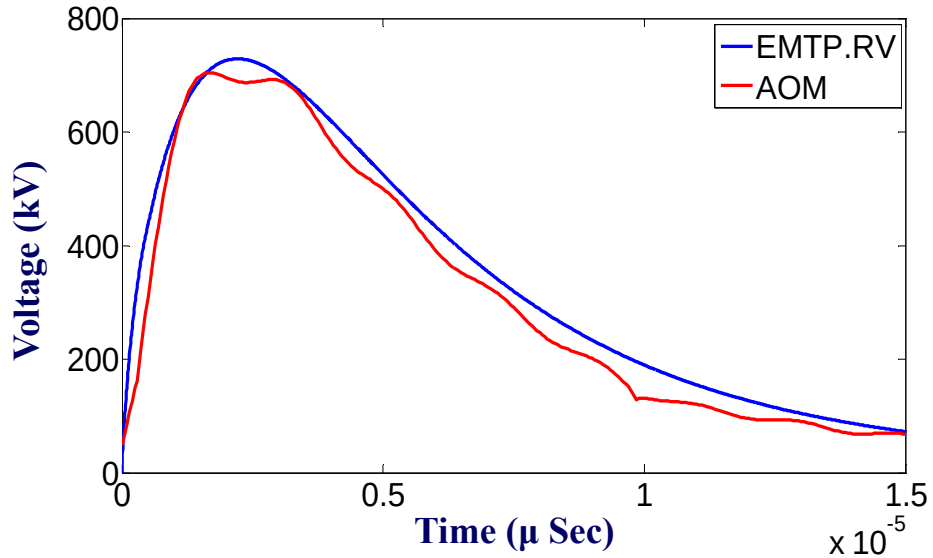


Results

Arrester residual voltage



System over-voltage



Conclusion

- The nonlinear characteristics of the ionized soil and arrester is treated in frequency-domain.

- As opposed to the time-domain methods, frequency dependency of the grounding system is well included in the analysis.

Thanks