*Applied Mechanics and Materials*
*ISSN: 1662-7482, Vol. 740, pp 379-385*
*doi:10.4028/www.scientific.net/AMM.740.379*

*Submitted: 2014-11-26*
*Accepted: 2014-12-02*
*Online: 2015-03-09*

# The Research of Multi-wave Impedance Model Based on Different Tower Structures

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**Keywords:** lightning overvoltage; tower; muti-wave impedance model; power system

**Abstract.** This paper mainly discusses the tower models in lightning overvoltage calculation, especially analysis the lossless and lossy models. Build the muti-wave impedance model of the most commonly used towers, which are portal tower, glass tower, cat head tower and strain tower in accordance with the reality. The simulation shows that muti-wave impedance model has a higher lightning overvoltage than simple model under the same condition. This is because the simple model ignores the influence of resistance and inductance, so the more accurate the model is, the more effective the protection will be.

## 0 Introduction

There are four tower models widely used in lightning overvoltage calculation: lumped inductance model, single wave impedance model, lossless multi-wave impedance model and lossy multi-wave impedance model. In the early calculation, there are only lumped inductance model and single wave impedance model. But Lumped inductance model ignores the spread of wave on tower, and single wave impedance model can't reflect the change of the waves reflected back from the bottom of the tower and ignore the influence of the cross arm. So these models can not satisfy the demand of the lightning overvoltage calculation now. The different part of the tower equal to different equivalent impedance is the method to build models. Consider whether the wave decay in the tower, it can be classified as lossless multi-wave impedance model and lossy multi-wave impedance model.

With the development of technology and the application of relevant new materials, the voltage of transmission line and the height of the transmission tower is becoming increasingly higher, which means the tower is easier to be affected by the lightning overvoltage and the spread of the wave in the tower is more complicated. It is probable to get a big error if the calculation model is too simple. Although muti-wave impedance model had been raised for a long time, in many articles, there is usually just a simple explanation. But the model which is used in actual lightning overvoltage calculation is simple as well, there are not multi-wave impedance models related to different structures of the towers. Consider this point, this paper use ATP-EMTP to build muti-wave impedance models of different tower structures and complete the simulation.

## 1 The method to build muti-wave impedance model

The wave impedance of different height on a vertical conductor is different, so for the tower, the wave impedance is different at different height as well. In fact, when the wave propagates through the tower, the capacity per length C0 and inductance per length L0 are changeable, so the wave impedance is changeable on the tower.

### 1.1 Lossless multi-wave impedance model

The tower can be separated into main member, diagonal member and cross arm, which can be simulated by lossless transmission line model. The wave impedance of different parts is different, in this way the distortion of lightning surge wave can be simulated. Figure 1 and figure 2 are the diagram of the tower and the relevant multi-wave impedance calculation model. In figure 1, $h_k$,$r_{TK}$,$R_{TK}$,$R_B$ and $r_B$ are the length of the corresponding parts. In figure 2, $Z_{TK}$, $Z_{LK}$ and $Z_{AK}$ are the wave impedance of the main member, diagonal member and cross arm.(k=1, 2, 3, 4)

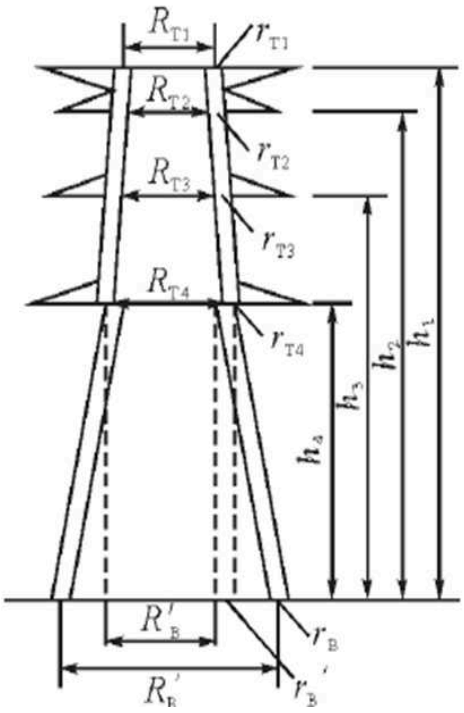



Fig.1 Structure of the tower

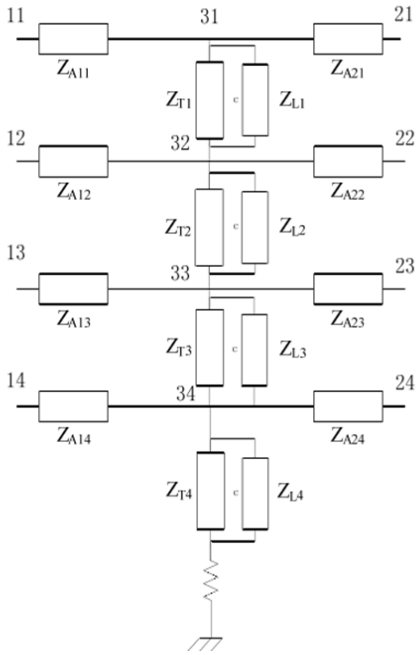



Fig.2 Multi-wave impedance model

After the research of some scholars, the calculation method of the multi-wave impedance of different parts is proposed [1]:

(1)Main member.

$$Z_{\mathrm{Tk}} = 60(\ln\frac{2\sqrt{2}h_k}{r_{\mathrm{ek}}} - 2)\ \Omega\ (\mathrm{k} = 1,2,3,4) \tag{1}$$

In formula (1):

$$r_{\mathrm{ek}} = \sqrt[8]{2}[\sqrt[3]{\mathrm{r_{Tk}}(\mathrm{r_{B'}})^2}]^{1/4}[\sqrt[3]{\mathrm{R_{Tk}}(\mathrm{R_{B'}})^2}]^{3/4}\ (k = 1,2,3) \tag{2}$$

$$r_{\mathrm{ek}} = \sqrt[8]{2}[\sqrt[3]{\mathrm{r_{Tk}}(\mathrm{r_B})^2}]^{1/4}[\sqrt[3]{\mathrm{R_{Tk}}(\mathrm{R_B})^2}]^{3/4}\ (k = 4) \tag{3}$$

(2)diagonal member.

The experiment suggested that, because of the existence of diagonal member, the wave impedance decreases about 10%. Its length is 1.5 times longer than the corresponding main member. The wave impedance can be calculated in accordance to the following formula.

$$\mathrm{Z_{Lk}} = 9\mathrm{Z_{Tk}}\Omega\ (\mathrm{k} = 1,2,3,4) \tag{4}$$

(3)Cross arm.

The wave impedance of the cross arm can be calculated as horizontal conductor.

$$Z_{Ak} = 60\ln\frac{2h_k}{r_{Ak}}(k = 1,2,3,4) \tag{5}$$

In this formula, $\mathbf{r_{AK}}$ is equivalent radius, one quarter of the connecting length of main member and cross arm.

Actually, the spread of the voltage wave is lossy, this leads to the fact that the lossless model can't reflect the real circumstance, so some researchers proposed the method to build lossy impedance model [2].

1.2 Lossly multi-wave impedance model

It can also be called four segments model [2], using lossless lines and parallel R-L circuit connected in series to simulate the tower. As is shown in figure 3, the lumped resistor is used to realize the decrease of the shock wave, and parallel R-L circuit is used to realize a big decrease in high frequency while in low frequency the decrease is smaller.

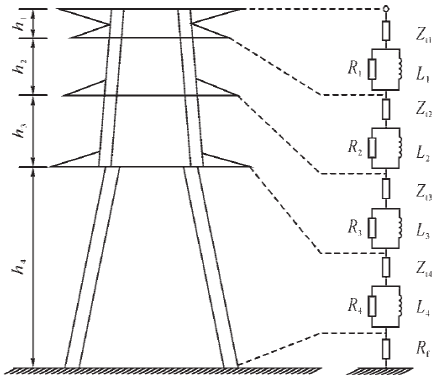


Fig.3 Lossy multi-wave impedance model

The parameters of this model are based on direct experimental measurement. According to the experiment of Msaru Ishii, supposing that the wave impedance of the upper and lower parts of the tower are different ($Z_{T1}$=220Ω, ZT2=150Ω), the upper wave impedance $Z_{t1}$= $Z_{t2}$= $Z_{t3}$= $Z_{T1}$, the lower wave impedance $Z_{t4}$= $Z_{T2}$. View the attenuation coefficient of the upper and lower parts as equal, $\gamma_1$=$\gamma_2$=0.8.The damping coefficient α=1. Take the corresponding length as $h_1$, h2, h3 and $h_4$ Take L/R=2t, in the formula t=H/ν, t is the transit time and its unit is μs. H is the height of the tower; the unit is m.ν is propagation velocity with the unit m/μs. Calculate the values of R and L.

$$R_i = \frac{-2Z_{T1}\ln\sqrt{\gamma_1}}{h_1 + h_2 + h_3}\cdot h_i (i = 1,2,3) \tag{6}$$

$$R_4 = -2Z_{T2}\ln\sqrt{\gamma_2} \tag{7}$$

$$L_i = \alpha\tau R_i = \alpha\left(\frac{2H}{\upsilon_t}\right)R_i \left(i = 1,2,3,4\right) \tag{8}$$

$$H = h_1 + h_2 + h_3 + h_4 \tag{9}$$

The model can reflect the decrease of the voltage impulse wave, but it can't reflect the influence of the cross arm. Consider that the length of the cross arm is much smaller than the height of the tower, its resistance can be ignored, so formula (5) in lossless model can be used here to build a complete model.

## 2 Simulation and Analysis

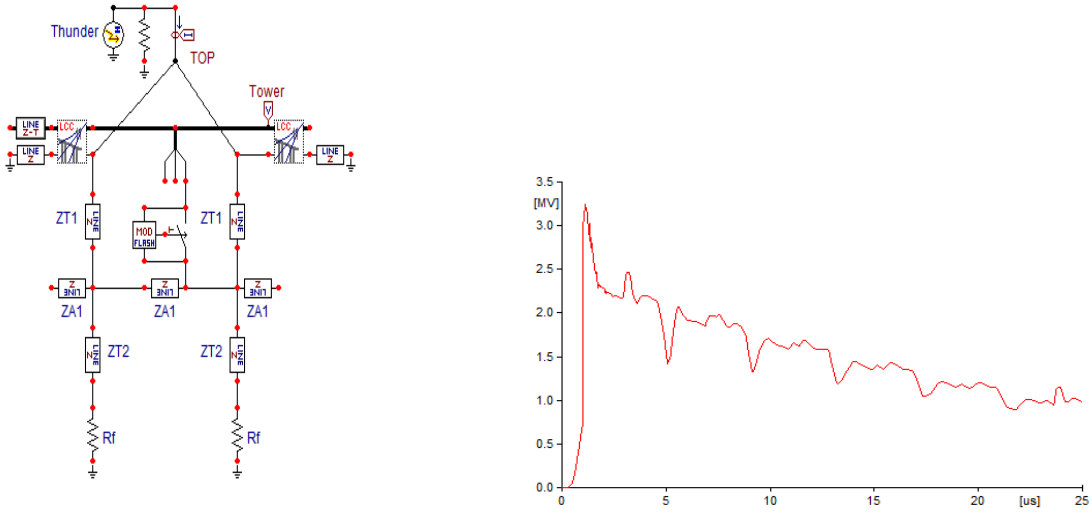
According to the structure of the towers, glass tower, cat head tower, portal tower and strain tower are commonly used in power system. Build the models of these towers and do the simulation [6].

Suppose there is a lightning overvoltage surge wave in the tower, compare the values of the voltage of the towers with the same height. According to the relevant paper [4] [5], the tip time of the lightning current wave can be 2.5μs; the stroke duration can be 50μs; the amplitude can be 220kA; the wave impedance of the lightning channel can be 400Ω; the grounding resistance can be 20Ω. Connect a long transmission line with the same characteristic at the end of the line to avoid the influence of the lightning wave reflect back to the lightning strike point. Use JMarti model to simulate the overhead line. Set the soil resistivity as 100Ω/m, the length is 300m, in this model the number of the phase PH.no., the inside diameter Rin , the outside diameter Rout, the DC resistance of the conductor Resis, the Horizontal distance Horiz, the height of the wire Vtower, the height of the transmission line in the middle Vmid, the bundle spacing Separ, the protect angle of the shield line Alpha, the Splitting root number NB can be set as table 1.

Tab.1 The parameters of the overhead line

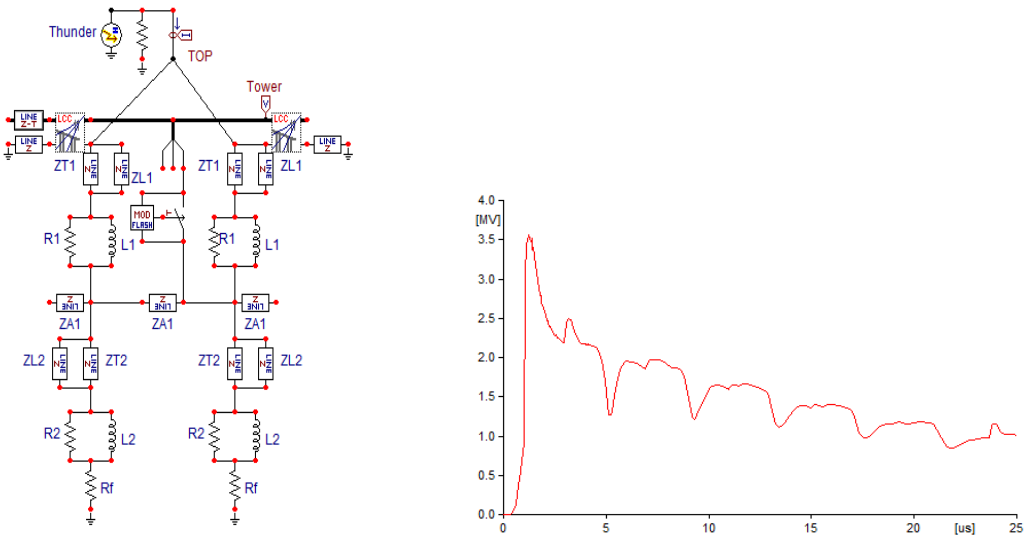
| Ph.no. | Rin | Rout | Resis | Horiz | Vtower | Vmid | Separ | Alpha | NB |
|---|---|---|---|---|---|---|---|---|---|
| | cm | cm | Ω/km | m | m | m | cm | deg | |
| 1 | 0 | 1.125 | 0.114 | 4.8 | 40.5 | 32.6 | 40 | 0 | 2 |
| 2 | 0 | 1.125 | 0.114 | 4.8 | 40.5 | 32.6 | 40 | 0 | 2 |
| 3 | 0 | 1.125 | 0.114 | 4.8 | 40.5 | 32.6 | 40 | 0 | 2 |
| 4 | 0.5 | 0.8 | 0.304 | 0.8 | 42 | 35 | 0 | 0 | 0 |

In many papers, the models of the towers in lightning overvoltage calculation are always simple, for example, in the calcution of portal tower, compare the results of different models which are shown in figure 4 and figure 5.




(a) The circuit of simple calculation model (b)The result of the simple calculation model

Fig.4 The circuit and result of simple calculation model for portal tower




(a)The circuit of lossy multi-wave impedance calculation model

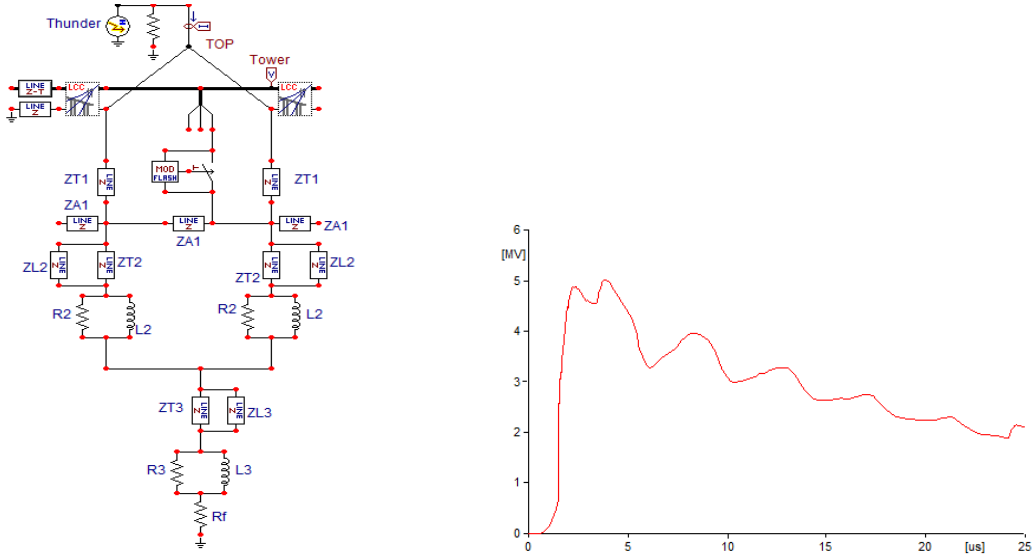
(b)The result of lossy multi-wave impedance calculation model

Fig.5 The circuit and result of lossy multi-wave impedance calculation model for portal tower

In the calculation model, set $Z_{T1}$=102.13Ω, $Z_{T2}$=86.86Ω, $Z_{A1}$=269.24Ω, $Z_{L1}$= 919.17Ω, $Z_{L2}$= 781.74Ω, $R_1$= 22.79Ω, $R_2$= 19.38Ω, $L_1$= 0.008mH, $L_2$=0.007mH. Compare the results, it is obvious that the wave in lossy multi-wave impedance calculation model is more gently, and the amplitude is increased form 3.26MV to 3.56MV. This is because the simple model ignores the influence of the resistance and inductance. In fact, with the increase of the height of the tower, the inductance increases as well. And multi-wave impedance model is seperated the tower into main member, diagonal member and cross arm, then build the models with the different parts. It is closer to the actual situation, and the result is more reliable.

According to this way, the models of other towers can be built, figure 6 to figure 8 is the calculation models and results.

For glass tower, set $Z_{T1}$=102.13Ω, $Z_{T2}$=95.06Ω, $Z_{T3}$=66.86Ω, $Z_{A1}$=269.24Ω, $Z_{L2}$= 855.54Ω, $Z_{L3}$=601.74Ω, $R_2$=15.91Ω, $R_3$=14.92Ω, $L_2$=0.0058mH, $L_3$=0.0055mH.

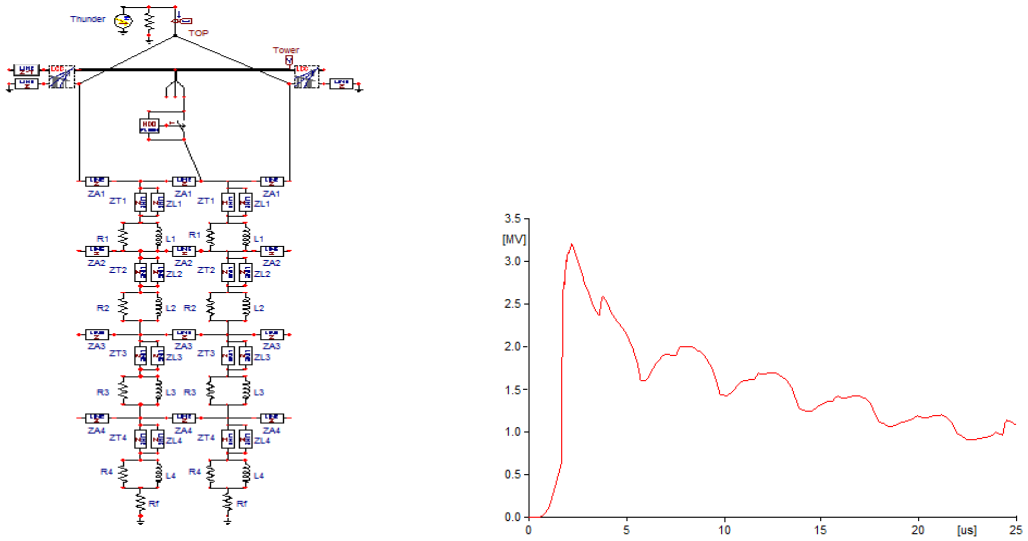



(a) The circuit of the calculation model

(b)The result of the calculation model

Fig.6 The circuit and result of simple calculation model for glass tower

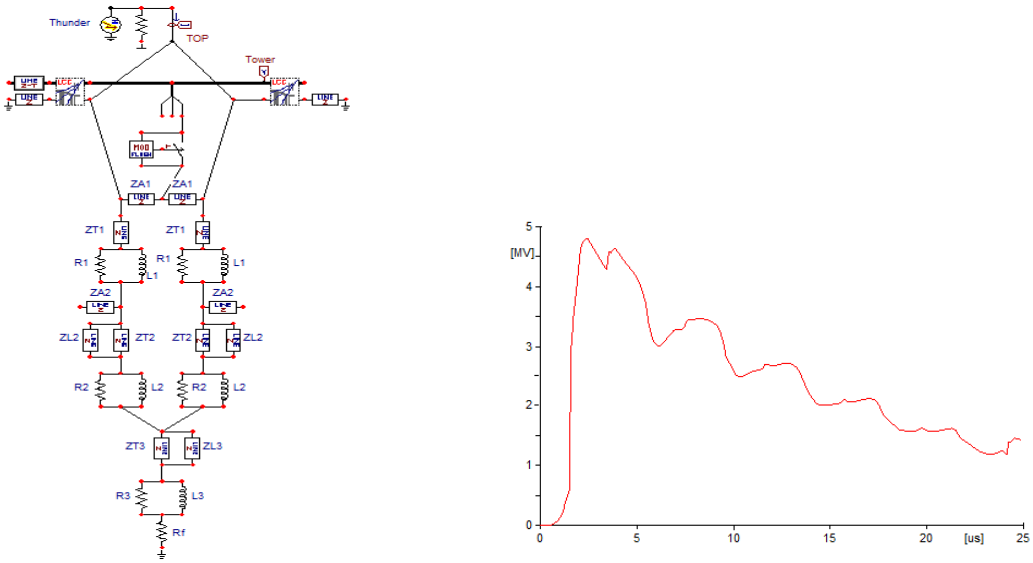
For strain tower, set $Z_{T1}$=95.2Ω, $Z_{T2}$=88.4Ω, $Z_{T3}$=76.4Ω, $Z_{T4}$=59.2Ω, $Z_{A1}$=305.4Ω, $Z_{A2}$=282.3Ω, $Z_{A3}$=256Ω, $Z_{A4}$=248.7Ω, $Z_{L1}$=856.5Ω, $Z_{L2}$=795.3Ω, $Z_{L3}$=687.3Ω, $Z_{L4}$=532.4Ω, $R_1$=5.3Ω, $R_2$=7.54Ω, $R_3$=12.08Ω, $R_4$=12.25Ω, $L_1$=0.0019mH, $L_2$=0.00277mH, $L_3$=0.0044mH, $L_4$=0.0045mH.




(a) The circuit of the calculation model (b)The result of the calculation model

Fig.7 The circuit and result of simple calculation model for strain tower

For cat head tower, set $Z_{T1}$=102.13Ω, $Z_{T2}$=95.06Ω, $Z_{T3}$=52.53Ω, $Z_{A1}$=276.31Ω, $Z_{A2}$=269.2Ω, $Z_{L2}$=855.56Ω, $Z_{L3}$=562.79Ω, $R_1$=7.6Ω, $R_2$=14.14Ω, $R_3$=11.72Ω, $L_1$=0.00279mH, $L_2$=0.00519mH, $L_3$=0.0043mH.




(a) The circuit of the calculation model (b)The result of the calculation model

Fig.8 The circuit and result of simple calculation model for cat head tower

## 3 Conclusion

By analyzing of the tower structures and the spread of the wave, the lossy multi-wave impedance model can be built .The model mainly includes the equivalent impedance, resistance and inductance of the main member, diagonal member and cross arm. The simulation models and results show that it is needful to build multi-wave impedance model of towers with different structures. In the same condition, the overvoltage of multi-wave impedance model is higher than simple model,

this is because the simple model ignroes the influence of the resistance and inductance. So the more accurate the model is, the more effective the protection will be.

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