# Lightning Transient Study of a Hybrid Overhead and Underground High-Voltage System

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**June 26, 2007**

# Outline

- Introduction
- Insulation Coordination
- Modeling of the Hybrid Transmission System
- Simulations & Results
- Conclusions

# Introduction

- Transmission systems are often exposed to severe weather conditions, especially due to the lightning.


Fig. 1: Lightning events

# Introduction (cont'd)

- In general, the probability and parameters of lightning stroke are main factors for investigating lightning transients.

Fig. 2: Overhead transmission lines

Fig. 3: Underground cable systems

# Introduction (cont'd)

Fig. 4: Cable breakdown

Fig. 5: GIS fault

- In this paper, the authors try to make some transient analysis and computer simulations, then the results are used to evaluate whether there is a lightning overvoltage problem in the system or not.

# Insulation Coordination

- Insulation coordination is important for correlating electric equipment insulation strength with protective device characteristics so that the equipment obtains an acceptable risk of failure and against expected overvoltage.

- The selection of equipment insulation strength and the voltage level provided by protective devices usually depends on engineering judgments and cost.

# Insulation Coordination (cont'd)

- BIL is defined as the peak value of the standard lightning impulse waveform. Equipment conforming to these BILs must be capable of withstanding repeated applications of the standard waveform of positive or negative polarity without insulation failure.

Table 1: BIL for 345kV system

| Items | BIL(kV): 1.2x50us |
|---|---|
| Cable System (IEC Std. 62067) | 1175 |
| Termination (IEEE Std. 48) | 1300 |
| Joint (IEEE Std. 404) | 1300 |

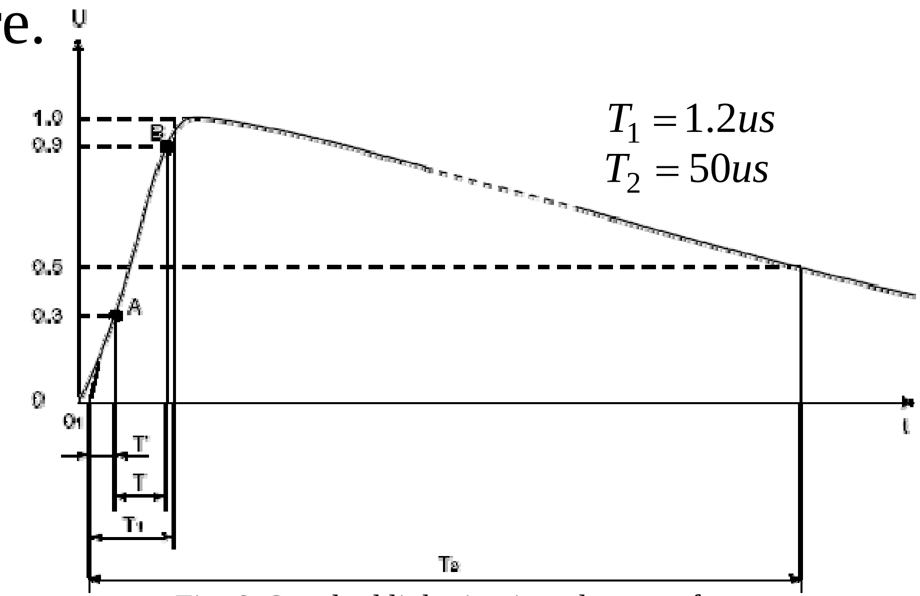

Fig. 6: Standard lightning impulse waveform


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# Insulation Coordination (cont'd)

- Protective ratio (PR) is definded in (1), which is used to measure the degree of equipment coordination.

$$PR = \frac{insulation\ withstand\ level}{voltage\ at\ protected\ equipment} \qquad (1)$$

- Protective margin (PM) is defined as the difference between the equipment breakdown voltage and the protective device ceiling voltage.

$$PM = (PR - 1) \times 100\% \qquad (2)$$


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# Modeling of the Hybrid Transmission System

- One of the most important tasks in power system transient analysis is the selection of the model by which the physical system can be accurately represented.

- Distributed parameter models take into account the distributed nature of the component parameters and they are based on" *Traveling Wave Theory*" .

# Modeling of the Hybrid Transmission System (cont'd)

- Considering a single-phase two-wire lossless transmission line. Figure 7 shows a line section with an infinitesimal length.

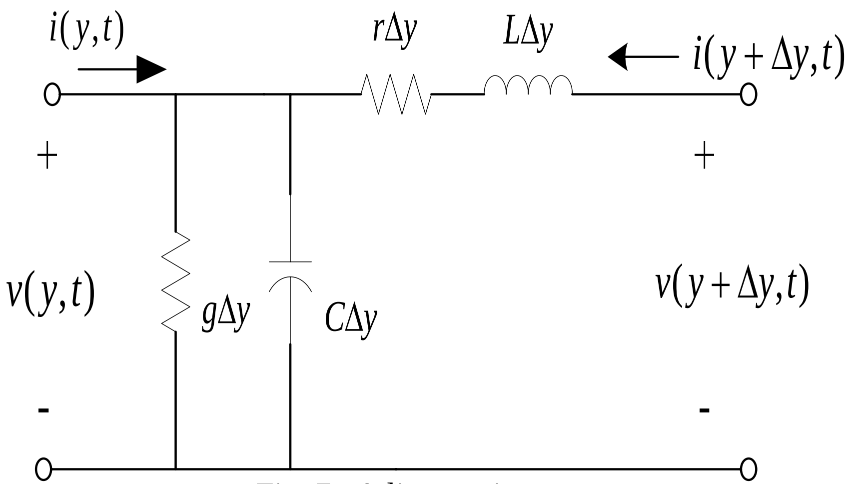

Fig. 7: A line section

$$\frac{\partial v(y,t)}{\partial y} = L\frac{\partial i(y,t)}{\partial t} + ri(y,t)$$
$$\frac{\partial i(y,t)}{\partial y} = C\frac{\partial v(y,t)}{\partial t} + gv(y,t) \quad (3)$$

# Modeling of the Hybrid Transmission System (cont'd)

- For convenience, the shunt conductance and series resistance can be omitted. In addition, the parameters $L$ and $C$ are assumed to be constants and are independent of the frequency.

$$\begin{aligned} \frac{\partial v(y,t)}{\partial y} &= L\,\frac{\partial i(y,t)}{\partial t} \\ \frac{\partial i(y,t)}{\partial y} &= C\,\frac{\partial v(y,t)}{\partial t} \end{aligned} \qquad (4)$$


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# Modeling of the Hybrid Transmission System (cont'd)

- According to the traveling wave theory analysis, a general solution set of (4) is given below

$$v(y,t) = v_1(t - \frac{y}{c}) + v_2(t + \frac{y}{c})$$
$$i(y,t) = \frac{v_1}{Z_c}(t - \frac{y}{c}) + \frac{v_2}{Z_c}(t + \frac{y}{c}) \qquad (5)$$

where $v_1$ and $v_2$ are constants; $Z_c$ is the characteristic impedance of the line which is defined as $Z_c = \sqrt{L/C}$; $c$ is the propagation velocity of a traveling wave and is defined as $c = 1/\sqrt{LC}$.

# Modeling of the Hybrid Transmission System (cont'd)

- A hybrid overhead and underground 345 kV high-voltage system that supplies a high-tech industrial park is under investigation.

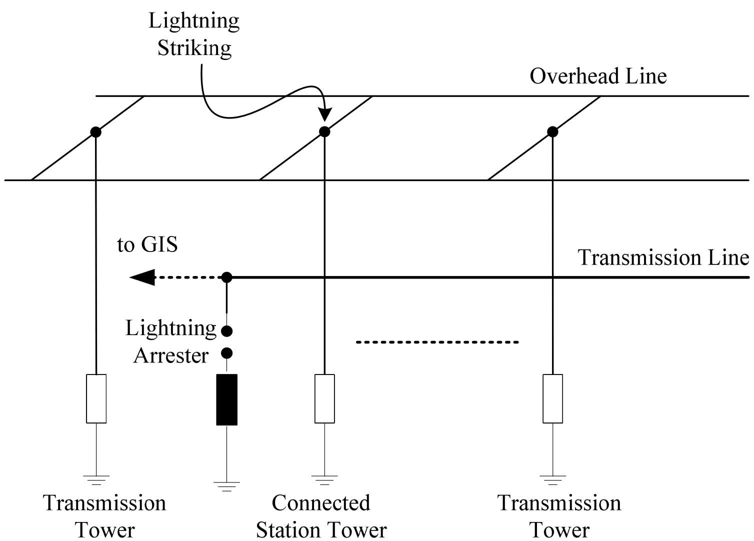

Fig. 8: Overhead transmission line of the substation.

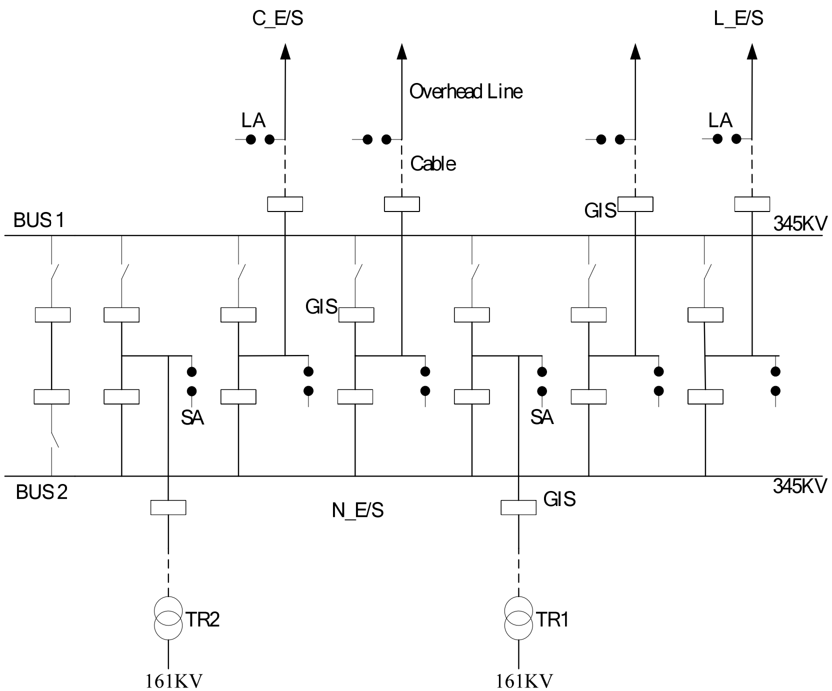

Fig. 9: Configuration of the substation.

# Modeling of the Hybrid Transmission System (cont'd)

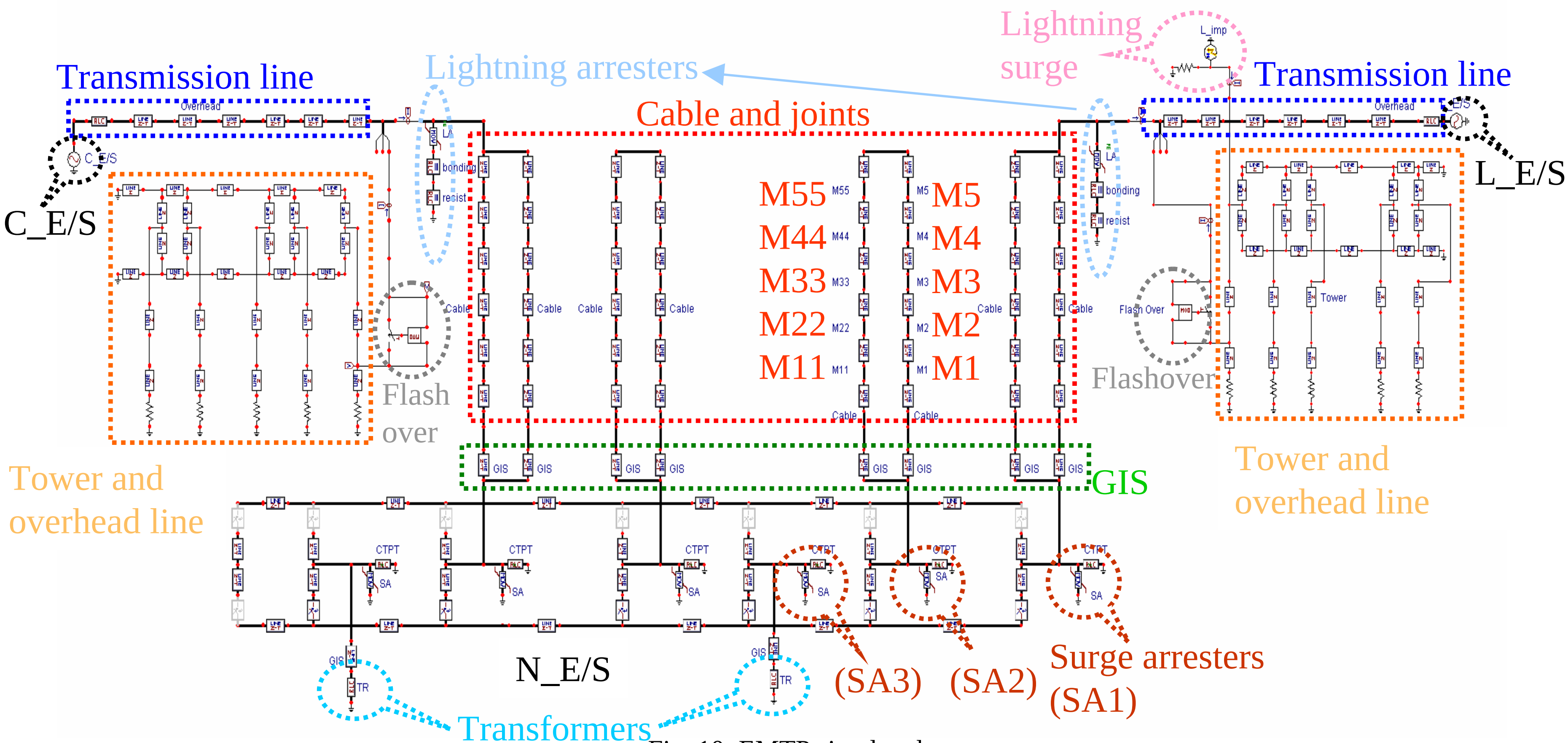


Fig. 10: EMTP simulated system



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# Simulations & Results

Table 2: Case study

| | Simulation Parameters |
|---|---|
| Case 1 | Lightning current $150kA\,(0.1 \times 40us)$, lightning channel impedance $400\Omega$, MOV grounding resistance $10\Omega$, MOV bounding wire $40m$, transmission tower foot impedance $7\Omega$, connected station tower foot impedance $3\Omega$ |
| Case 2 | Lightning current $150kA(1.8 \times 30us)$, lightning channel impedance $400\Omega$, MOV grounding resistance $10\Omega$, MOV bounding wire $40m$, transmission tower foot impedance $7\Omega$, connected station tower foot impedance $3\Omega$ |

Table 3: BIL for the simulated system

| Items | BIL(kV): |
|---|---|
| Cable Joint | 1300 |
| GIS | 1175 |
| Transformer | 1050 |

# Simulations & Results (cont'd)

- Transient currents of the lightning and surge arresters

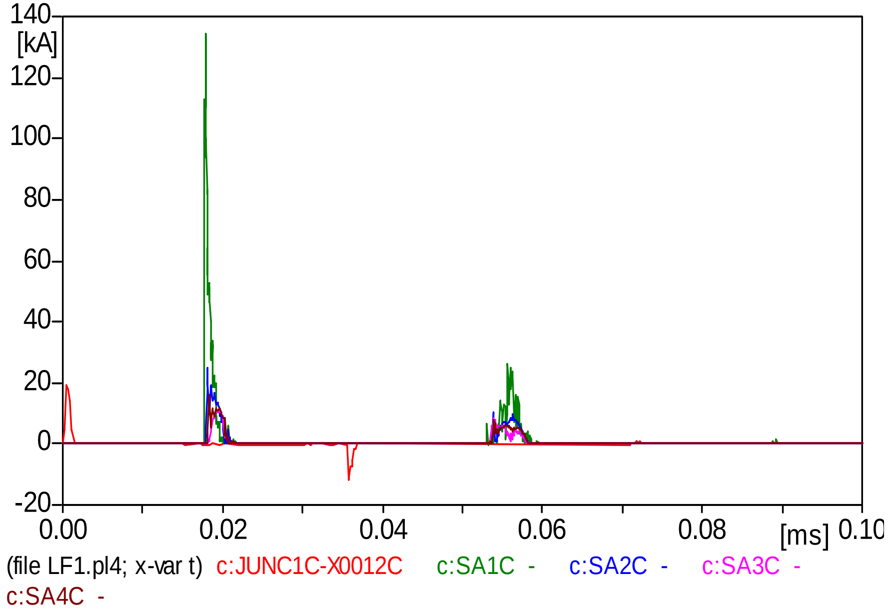


Fig. 11: Case 1

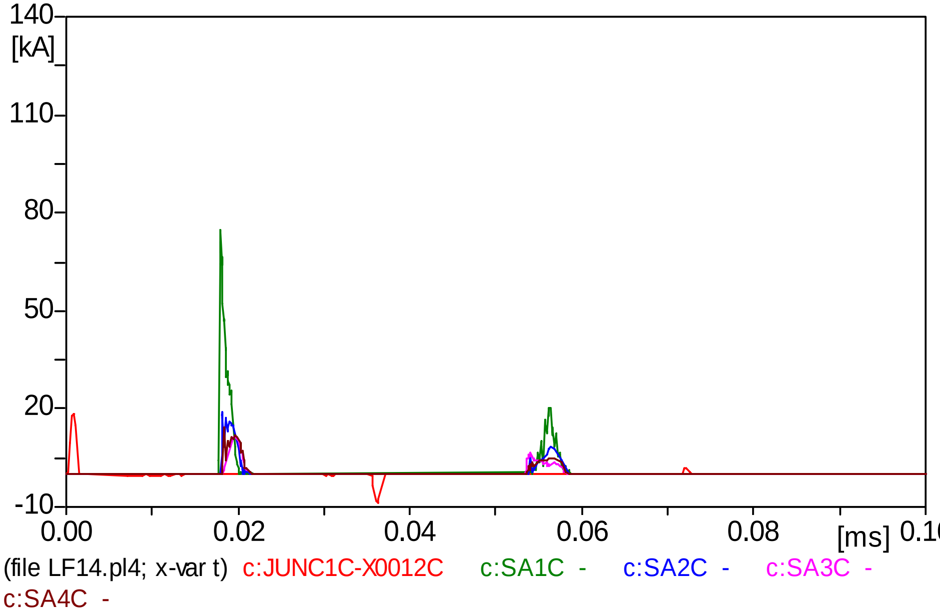


Fig. 12: Case 2




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# Simulations & Results (cont'd)

- Energy of the lightning and surge arresters

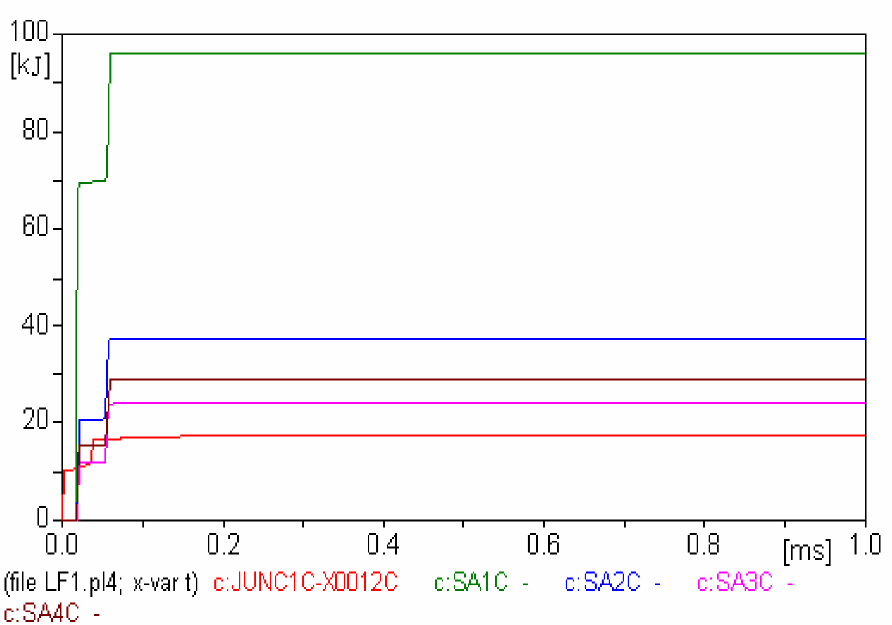


Fig. 13: Case 1

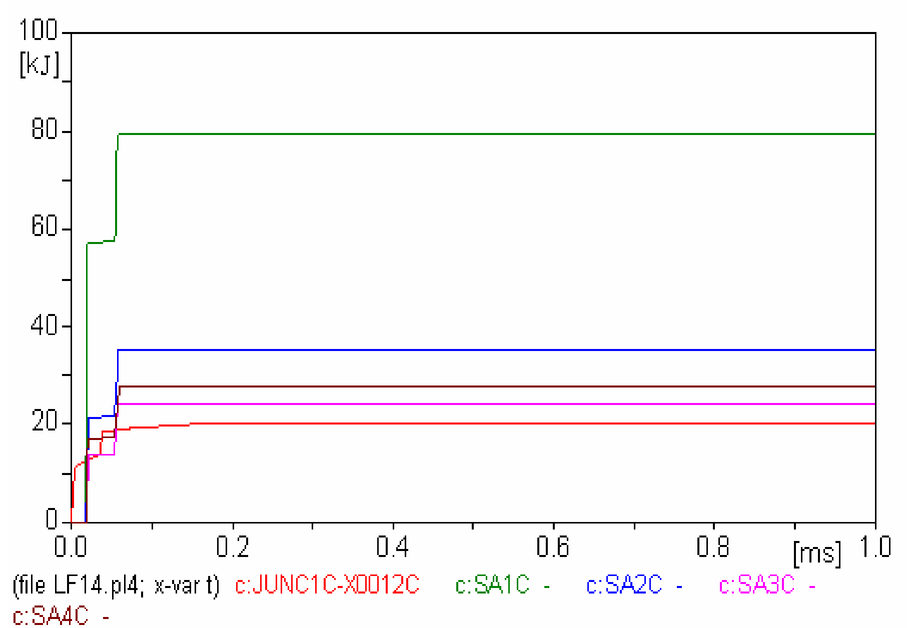


Fig. 14: Case 2



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# Simulations & Results (cont'd)

- Transient voltages at cable joints M5~M1

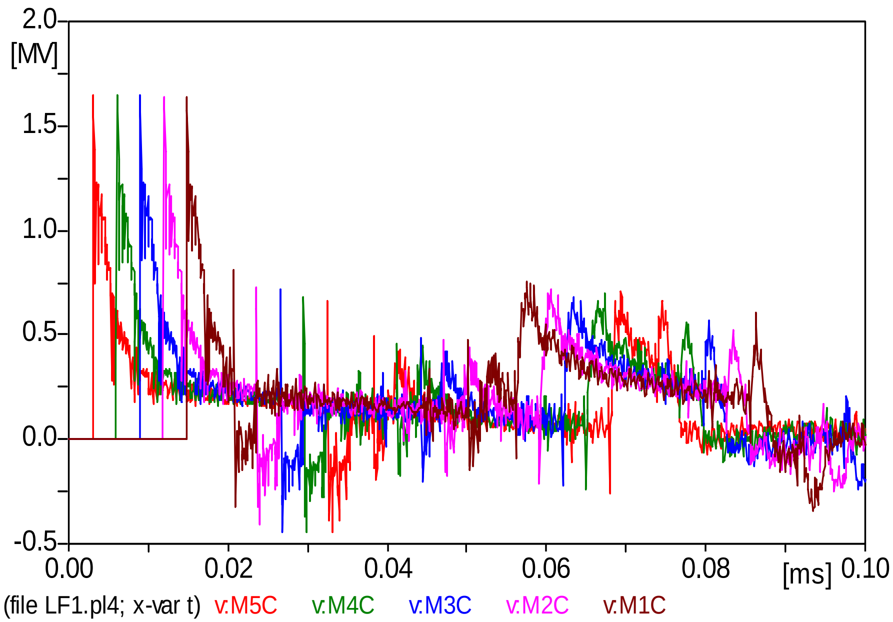


Fig. 15: Case 1

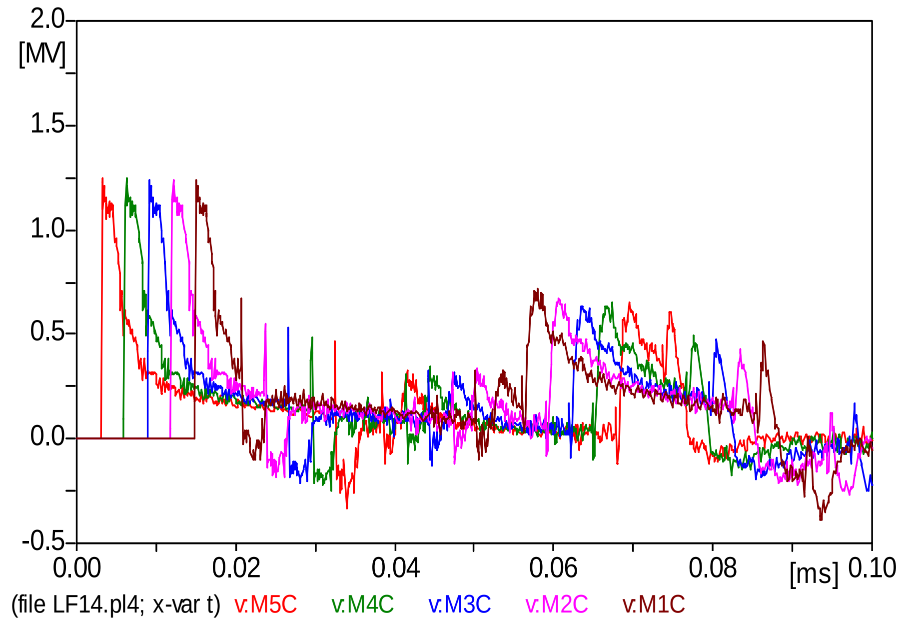


Fig. 16: Case 2

# Simulations & Results (cont'd)

Table 4: Statistics of case1

| Case 1 | | $V_{max}$ (kV) | $PR$ | $PM$ |
|---|---|---|---|---|
| Cables | $M_{55}$ | 984.28 | 1.32 | 32% |
| | $M_5$ | 1642.2 | 0.792 | < 1% |
| GIS | | 691.31 | 1.7 | 70% |
| Tr. | | 926.1 | 1.34 | 34% |
| Tower | | 1353.4 | | |
| Arresters | LA | 1643.7 | | |
| | SA | 1012.4 | | |

Table 5: Statistics of case 2

| Case 2 | | $V_{max}$ (kV) | $PR$ | $PM$ |
|---|---|---|---|---|
| Cables | $M_{55}$ | 975.82 | 1.33 | 33% |
| | $M_5$ | 1245.4 | 1.04 | 4% |
| GIS | | 693 | 1.69 | 69% |
| Tr. | | 892.2 | 1.17 | 17% |
| Tower | | 1186 | | |
| Arresters | LA | 1247.8 | | |
| | SA | 920.78 | | |

# Conclusions

- This paper presents a transient study of lightning overvoltage in a 345 kV hybrid transmission system. An effective transient simulation of lightning overvoltage is demonstrated by the use of distributed parameters to model the transmission system.

- Considering the system insulation coordination several indices are used to evaluate the capability of withstanding transient overvoltage of each equipment.

# Conclusions (cont'd)

- Simulation results indicate only useing the worst-case to do simulation the transient overvoltage will unusual occur. If the lightning impulse is in a reasonable range, the transient overvoltage will not be produced.

- It can firstly to conclude that the current transmission system in the industrial park does not produce the serious destruction of transient overvoltage that caused by lightning stroke.

# ***Thank You!***

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