

Analysis of Induced Voltage of Parallel UHV Double-circuit AC Transmission Lines

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Abstract. With the vigorous development of power transmission technology in China, parallel AC and DC transmission lines in the same corridor is also expanding. The inductive electricity between the lines is harmful to the system, and much attention should be paid to it. In this paper, the principle of line induced voltage is described, and the EMTP electromagnetic transient analysis software is used to calculate the induced voltage of the 1000 kV transmission line to the new transmission line. The influence of the distance between the transmission lines, the parallel length and the height of the transmission line on the induced voltage is analyzed. The waveform of the induced voltage is simulated, and the simulation results agree well with the theoretical analysis.

1. Introduction

With the increasing scale of the HV and UHV transmission lines in China, it is inevitable that the transmission lines run parallel or cross across the transmission lines to save the line corridor and the urban space. For the newly built parallel lines, the voltage will be induced, which will threaten the stable operation of the system as well as the safety of the working staff.

The domestic research on induction coupling is focused on the coupling problem between two transmission lines in the same tower. References [1-4] analyzed the induced voltage and current of UHV transmission lines. The numerical calculation and analysis of induced voltage and current under different line lengths, transmission currents and phase sequence arrangements were taken into account. References [5-7] took into account the induced voltage and current at double circuit transmission lines at different voltage levels.

The principle of induction coupling between transmission lines is analyzed in this paper, and then the induced voltage of the 1000 kV UHV AC line on the new line is calculated in EMTP. The influence of the distance, the parallel length and the line height on the induced voltage of the new line is analyzed. And the simulation results are consistent with the theory analysis.



2. Basic Principle and Characteristics of Induced Voltage Coupling

2.1. Coupling Principle of Induced Voltage between Lines

Capacitance C and mutual inductance M exist between adjacent transmission lines. When a polar conductor is energized, an induced voltage will be generated on adjacent conductors through the coupling of capacitance and mutual inductance between the lines. The equivalent circuit of the coupling effect is shown in Fig. 1.

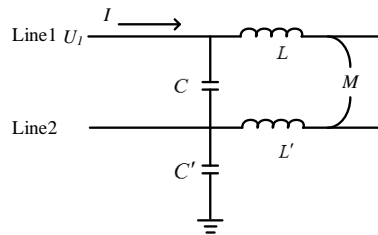


Figure 1. Equivalent circuit of transmission line coupling

The induced voltage on the inductive line mainly includes the electrostatic induction component and the electromagnetic induction component. The electrostatic induction component is generated by coupling capacitance C while the electromagnetic induction component is mainly caused by mutual inductance M .

According to the principle of capacitor divider, the electrostatic induction voltage on line 2 is:

$$U_2' = \frac{1/(j\omega C')}{1/(j\omega C) + 1/(j\omega C')} U_1 = \frac{C}{C + C'} U_1 \quad (1)$$

According to the principle of electromagnetic induction, the current of line 1 will generate a longitudinal induction electromotive force on line 2 through mutual inductance M :

$$U_2'' = E_{12} = j\omega MI \quad (2)$$

Where, ω is the angular frequency of the AC transmission system.

Hence, the total induced voltage U_2 on line 2 is the sum of the two voltages:

$$U_2 = U_2' + U_2'' \quad (3)$$

As can be seen from the equations above, only the induced voltage on the line near the AC transmission line is U_2'' .

2.2. Characteristics of Induced Voltage in Different Grounding Modes of New Lines

When the nearby AC lines are energized, the induced voltage level of the new lines is distinctly different under different grounding modes.

2.2.1. Two ends of line ungrounded. When two ends of the new line are not grounded, the open circuit voltage U_2 will exist at both ends. The open circuit voltage is a combination of induced voltages of both capacitive coupling and mutual induction coupling between lines, and the voltage of both ends is approximately equal and the amplitude is relatively high.

2.2.2. Single end grounding. When the new line is grounded at one end, there is a longitudinal induced electromotive force on the newly built line due to the mutual induction coupling. The

amplitude of induced voltage is related to several factors, i.e. the mutual inductance between lines, the frequency of the system and the operating current of the AC line. Due to capacitive coupling, the normally operating line will also supply power to the new line through the capacitance C . At this time, only the open circuit voltage U_2 is generated at one end of the new line, but its amplitude is lower than that with two ends open, and the amplitude of the induced voltage of the opening end to the grounding end has a linear descent relationship.

2.2.3. Two ends grounding. When the new line is grounded at both ends, the stable electromotive force will still be induced on the newly built line due to the mutual coupling inductance. At this time, the induced voltage U_2 is lower than the open circuit voltage when the two ends is not grounded and the single end is not grounded. it should be noted that there is an electromagnetic induction current flowing through the new line.

3. Simulation Model

3.1. Model and Parameters of Transmission Line and Tower

Based on the EMTP, it is necessary to obtain the parameters of the transmission line and the parameters of the tower when calculating the induced voltage of the ± 1100 kV Changji-Guquan UHV DC transmission line under construction, which is in parallel with the 1000 kV Anhui-to-East UHV AC transmission line. Among them, 1000 kV Anhui-to-East UHV AC transmission line used double circuit lines on the same tower, with the line splitting number of eight. The ± 1100 kV Changji-Guquan UHV DC transmission line with a splitting number of eight is the DC transmission project with the highest voltage level and the farthest transmission distance in the world. The length of stringing construction is 10 km. The wire parameters are listed in Table I.

Tangent tower is selected as the tower structure of 1000 kV AC transmission lines and ± 1100 kV new transmission lines. The average line spacing is 500 m, and the soil resistivity is $20 \Omega \cdot \text{m}$. The length of the hanging string is 12 m. The parallel situation of the two lines is shown in Fig. 2, where d represents the distance between the center line of the AC tower and the newly built nearest line. And P1 represents nearest polar conductor of the newly built line.

Table 1. Transmission Line Parameters

Parameters	AC line	DC line
model	JL/GIA-630/45	JL1/G3A-1250/70
Wire diameter (mm)	33.6	47.35
DC resistance(Ω/km)	0.0459	0.02291
Splitting number	8	8
Split spacing (mm)	400	550

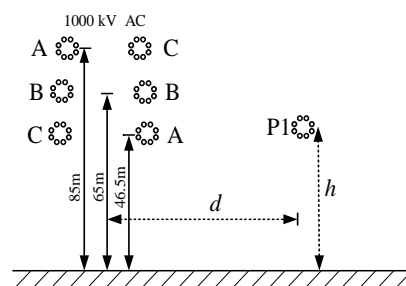


Figure 2. Location of UHV AC and new line

3.2. Simulation Model

In this paper, the LCC model in EMTP is used to build the circuit and simulate the induced voltage, as is shown in Fig. 3. The two circuits above represent two AC transmission lines, and the below one represents the polar conductor of the new line, where P11 and P12 are the two ends of the P1 polar of the new line.

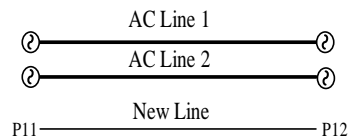


Figure 3. Simulation model of UHV AC and new line

4. Calculation and Analysis of Induced Voltage

4.1. Induced Voltage in Different Grounding Modes of New Lines

When the total length of the construction line is 10 km, $d=70$ m, and $h=50$ m, the induced voltage in different grounding modes of new lines are calculated, as listed in Table II. For the case of the two ends ungrounded, the induced voltage is 5.97 kV, which is much larger than the single end grounding or double ends grounding of the line. whereas, the two ends of the line being grounded, the induced voltage drops to 0 V. So grounding is an effective measure to reduce the induced voltage. When the two ends are grounded, the induced voltages at both ends of the first and the end are consistent. When single end is grounded, the ungrounded voltage is 154.86 V and the grounding voltage is 0 V. When the two ends are ungrounding, the induced voltages at both ends are 0 V.

Table 2. Induced Voltage of New Lines

Grounding mode	P11	P12
Two ends ungrounded	5.97 kV	5.96 kV
Single end grounding	154.86 V	0 V
Two ends grounding	0 V	0 V

The above grounding methods do not consider the resistance. The calculation results listed in Table II is consistent with theoretical analysis presented above.

4.2. Analysis of Influential Factors on Induced Voltage between Lines

4.2.1. Distance between lines. The distance between transmission lines is one of the important factors that affect the induced voltage. In the case that both ends of the line ungrounded and the distance d varies from 45 m to 100 m, the induced voltage is calculated and listed in Table III, assuming that the transmission lines height and the parallel length are constant. The induced voltage rapidly decreases with the increase of the distance d . It should be noted that the drop speed of the voltage become gentle when the distance between the lines increases to a certain extent.

Table 3. Induced Voltage Calculation Results of Distance Change When Two Ends Are Ungrounded

Distance between lines (m)	Induction voltage (kV)
45	27.73
50	20.18
60	10.73
70	5.97
80	4.18
90	3.98

4.2.2. Parallel length. In this part, assuming other parameters stay unchanged, while the parallel length varies from 500 m to 10 km. The calculated induced voltage of the ungrounded conductor are listed in Table IV. When the line is ungrounded, the induced voltage tends unchanged with the increase of the parallel length.

Table 4. Induced Voltage Calculation Results of Parallel Length Change When Two Ends Are Ungrounded

Parallel length(km)	Induction voltage (kV)
0.5	5.97
5	5.97
10	5.97

However, when the new line is grounded in the single end mode, the induced voltage calculation results are different, as listed in Table V. It can be clearly seen that the induced voltage increases with the parallel distance and changes substantially linearly.

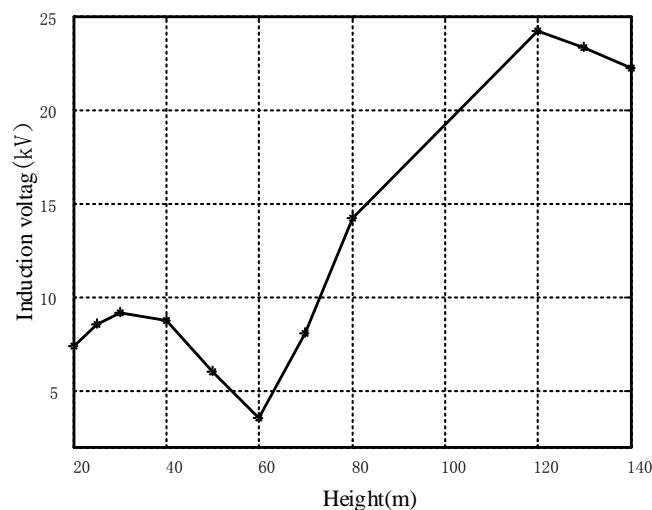
Table 5. Induced Voltage Calculation Results of Single End Grounding

Parallel length(km)	Induction voltage (V)
0.5	7.35
1	10.43
2	29.63
3	44.69
4	59.89
5	75.31
10	154.86

4.2.3. Line height. When the height of the ungrounded line varies, the calculation results of the induced voltage are listed in Table VI. The induced voltage on the ungrounded line increases from 20 m to 140 m, and the induced voltage increases slightly as the height increases at first. After a while, the induced voltage begins to decrease. The induced voltage decreases to the minimum value and then it begins to increases with height. Finally, the induced voltage is reduced after moving away from the AC transmission line. The trend chart is depicted in Fig. 4, which demonstrates a trend like the shape M.

Table 6. Induced Voltage Calculation Results of Height Change When Two Ends Are Ungrounded

Line height (m)	Induced voltage (kV)
20	7.40
25	8.53
30	9.17
40	8.73
50	5.99
60	3.54
70	8.03
80	14.21
120	24.23
130	23.33
140	22.22

**Figure 4.** Induced voltage variation with height change when Two ends are ungrounding

5. Conclusion

This paper describes the basic principle of induced voltage coupling in the new transmission line of the parallel UHV AC transmission line of the same corridor, and the simulations are carried out to calculate the influential factors of the induced voltage in EMTP. Some conclusions are drawn according to the calculation results:

- 1) The induced voltages of the line coupling under different grounding modes are different, and the results of the calculations are consistent with the theoretical analysis results.
- 2) The induced voltage on the ungrounded conductor is inversely proportional to the distance between the lines. The parallel length of the line has little effect on the induced voltage of the ungrounded conductor, but the induced voltage at the open end of the single end grounding conductor is proportional to the parallel length.
- 3) The induced voltage of ungrounded conductor changes in M shape with height, and the value of induced voltage is minimum when it is close to the height of the AC intermediate phase line

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