Analysis of Induced Voltage and Influencing Factors of Transmission Lines with Different Voltage Levels and Different Towers in Parallel on the Same Corridor

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Abstract. In view of the strong coupling between the parallel transmission lines of different voltage levels and different towers running in the common corridor, in order to study the electrical imbalance between the 750kV transmission line and the 330kV transmission line erected in the common corridor, the simulation analysis of the common corridor transmission and distribution Causes and influencing factors of induced voltage in electric lines. The system equivalent model is established by using ATP-EMTP. The results show that the 750kV transmission line has obvious electrostatic induction voltage to the 330kV transmission line parallel to the corridor, and the electromagnetic induction voltage between them is not obvious. The influence of 750kV transmission lines on 330kV distribution lines is related to the transmission power. The greater the line power, the more severe the three-phase voltage imbalance of 330kV distribution lines, and vice versa.

Keywords: Electrical imbalance, induced voltage, simulation calculation, shared corridor parallel

1. Introduction
With the national interconnection of large regional power grids, coupled with the increasing shortage of land resources, there are common corridor sections between UHV transmission lines, transmission lines and distribution lines in Hexi, Gansu. Due to the distance between the transmission lines and the transmission and distribution lines between the parallel sections, there is a certain electromagnetic coupling between the lines and between the phases, and the commutation method between the phase sequences of the UHV transmission lines makes the electromagnetic coupling relationship more complicated. The transmission power of the line will change due to the power flow of the system and the power load. These are the main factors that increase the electrical imbalance between the transmission lines of different voltage levels and different towers operating in the shared corridor.

According to the different states of the transmission line, one line will have 4 different induction parameters for the other line: electrostatic induction voltage, electromagnetic induction voltage, and electrostatic induction current, electromagnetic induction current, especially the high voltage line induction voltage will be as high as several Ten kilovolts. Therefore, it is of great practical
significance to study the induced voltage and induced current on transmission lines with different voltage levels and different towers operating in a shared corridor.

2. Model and theoretical calculation of transmission and distribution lines
The transmission and distribution line model is shown in Figure 1. The lines are 750kV transmission lines and 330kV distribution lines operating in parallel in a shared corridor. For transmission and distribution lines operating with different voltage levels and towers, the self-capacitance and mutual capacitance $C$ of each phase have been erected. Capacitance and matrix of self-inductance and mutual inductance $L$.

$$
C = \begin{bmatrix}
    C_{aa} & C_{ab} & C_{ac} & C_{aa} & C_{ab} & C_{ac} \\
    C_{ba} & C_{bb} & C_{bc} & C_{ba} & C_{bb} & C_{bc} \\
    C_{ca} & C_{cb} & C_{cc} & C_{ca} & C_{cb} & C_{cc} \\
    C_{aa} & C_{Ab} & C_{Ac} & C_{AA} & C_{Ab} & C_{AC} \\
    C_{Ba} & C_{Bb} & C_{Bc} & C_{BA} & C_{Bb} & C_{BC} \\
    C_{Ca} & C_{Cb} & C_{Cc} & C_{CA} & C_{Cb} & C_{CC}
\end{bmatrix}
$$

(1)

$$
L = \begin{bmatrix}
    L_{aa} & L_{ab} & L_{ac} & L_{aa} & L_{ab} & L_{ac} \\
    L_{ba} & L_{bb} & L_{bc} & L_{ba} & L_{bb} & L_{bc} \\
    L_{ca} & L_{cb} & L_{cc} & L_{ca} & L_{cb} & L_{cc} \\
    L_{ba} & L_{AI} & L_{IA} & L_{Ab} & L_{IA} & L_{AC} \\
    L_{Ba} & L_{Bi} & L_{BI} & L_{BA} & L_{Bi} & L_{BC} \\
    L_{Ca} & L_{Ci} & L_{CI} & L_{CA} & L_{Ci} & L_{CC}
\end{bmatrix}
$$

(2)

In the above formula, A, B, C, a, b, and c respectively represent the phases of transmission line I and transmission line II.

Suppose $U_{abc} = [U_a U_b U_c]^T$ and $I_{abc} = [I_a I_b I_c]^T$ is known, solve $U_{ABC} = [U_A U_B U_C]^T$ and $I_{ABC} = [I_A I_B I_C]^T$.

The following is a theoretical analysis for one of the two transmission lines under different conditions of power outage operation:

1) The two ends of an induced transmission line are suspended, and the induced voltage will appear when the induced voltage is generated when capacitive coupling, so there is:

$$
\begin{bmatrix}
    C_1 C_m \\
    C_m C_2
\end{bmatrix}
\begin{bmatrix}
    U_{abc} \\
    U_{ABC}
\end{bmatrix} = \begin{bmatrix}
    Q_{abc} \\
    0
\end{bmatrix}
$$

(3)

The above formula $Q_{abc}$ is the matrix of induced charges, which can be obtained

$$
C_1 U_{abc} + C_m U_{ABC} = Q_{abc}
$$

$$
C_m U_{abc} + C_2 U_{ABC} = 0
$$

(4)

Then

$$
U_{ABC} = -C_2^{-1} C_m U_{abc}
$$

(5)
2) One end of the erection transmission is suspended, $\Delta U_{ABC}$ which is the voltage difference between the two ends of the line. At this time, it is inductive coupling.

$$j\omega \begin{bmatrix} L_1 & L_m \\ L_m & L_2 \end{bmatrix} \begin{bmatrix} I_{abc} \\ 0 \end{bmatrix} = \begin{bmatrix} \Delta U_{abc} \\ \Delta U_{ABC} \end{bmatrix}$$

(6)

From the above formula:

$$j\omega L_1 I_{abc} = \Delta U_{abc}$$

$$j\omega L_m I_{abc} = \Delta U_{ABC}$$

(7)

It can be concluded that the voltage at the open terminal is

$$U_{ABC} = j\omega L_m I_{abc}$$

(8)

3) When the two ends of the induced transmission line are grounded, the induced current flows through the inductive transmission line at this time, it can be obtained:

$$j\omega \begin{bmatrix} L_1 & L_m \\ L_m & L_2 \end{bmatrix} \begin{bmatrix} I_{abc} \\ I_{ABC} \end{bmatrix} = \begin{bmatrix} \Delta U_{abc} \\ \Delta U_{ABC} \end{bmatrix}$$

(9)

Because both sides of the line are grounded, we get:

$$I_{ABC} = -L_2 L_m I_{abc}$$

Figure 1. Model of tower

3. Simulation analysis of unbalanced causes

3.1. Electrical parameters of transmission lines

The parameters of the two transmission lines with different voltage levels and different towers are shown in Table 1. The wire adopts 6-split mode, the split spacing is 400mm.

| Wire model | Ground wire model | DC Resistance (Ω/km) | Wire diameter (mm) |
|------------|-------------------|----------------------|--------------------|
| JL/G1A-400/45 | OPGW-17-150-2 | 0.0723                | 27.6               |
| LGJ-35      | No                | 0.8230                | 8.16               |

Table 1. Line electrical parameters
3.2. Simulation results of electromagnetic field
The ATP-EMTP software was used to simulate and analyze the electrostatic induction voltage and electromagnetic induction voltage of the two transmission lines at different transmission powers of 300MW and 900MW, as shown in Table 2, Table 3, Table 4, and Table 5. The table shows that the difference is different. The electrostatic induction voltage between towers of different voltage levels is very large, while the electromagnetic induction voltage is not obvious. For transmission lines running in parallel in a shared corridor where the system operating parameters and the spatial locations of the two lines have been determined, the electrical imbalance between each other has a great influence.

| Table 2. Static induction voltage of two lines with power of 300MW | Unit: kV, ° |
|----------------------|----------------------|
| Voltage amplitude    | Voltage amplitude    |
| A 11.19              | A 11.18             |
| B 15.75              | B 15.75             |
| C 10.65              | C 10.65             |
| Voltage phase angle  | Voltage phase angle  |
| A 23.47              | A 23.48             |
| B 21.76              | B 21.77             |
| C 22.05              | C 22.07             |

| Table 3. Static induced voltage of two lines with a power of 900MW | Unit: kV, ° |
|----------------------|----------------------|
| Voltage amplitude    | Voltage amplitude    |
| A 11.14              | A 11.14             |
| B 15.71              | B 15.70             |
| C 10.61              | C 10.60             |
| Voltage phase angle  | Voltage phase angle  |
| A 27.93              | A 27.94             |
| B 25.97              | B 25.99             |
| C 26.57              | C 26.58             |

| Table 4. Electromagnetic induction voltage of two lines with a power of 300MW | Unit: kV, ° |
|----------------------|----------------------|
| Voltage amplitude    | Voltage amplitude    |
| A 0.31               | A 0.31              |
| B 0.37               | B 0.37              |
| C 0.30               | C 0.30              |
| Voltage phase angle  | Voltage phase angle  |
| A 159.23             | A 159.15            |
| B 155.20             | B 155.14            |
| C 157.98             | C 157.91            |

| Table 5. Electromagnetic induction voltage of two lines with a power of 900MW | Unit: kV, ° |
|----------------------|----------------------|
| Voltage amplitude    | Voltage amplitude    |
| A 0.74               | A 0.73              |
| B 0.86               | B 0.86              |
| C 0.73               | C 0.73              |
| Voltage phase angle  | Voltage phase angle  |
| A 143.14             | A 143.16            |
| B 140.11             | B 140.12            |
| C 141.73             | C 141.75            |

3.3. Electric field simulation analysis
Comsol software is used to analyze the electric field of the induction line and the induced line. The first case is that when both the induction line and the induced line are charged with voltage, the electric field distribution is shown in Figure 2-4.
The second case is when the induction line is charged with voltage and the induced line is not charged with no voltage, the electric field distribution is shown in Figure 5-7.

Figure 2. Ca Sectional electric field

Figure 3. Cb Sectional electric field

Figure 4. Bb Sectional electric field

Figure 5. Ca Sectional electric field
4. Conclusion

1) This paper simulates and analyzes the electrical imbalance characteristics between the transmission lines of different voltage levels and different towers running in parallel in the shared corridor. It is found that the distance, number, and parallelism of the shared corridor in parallel operation under certain system parameters and transposition methods. The transmission power of the section has a greater impact on the electrical imbalance between the transmission lines in the shared corridor.

2) The electrostatic induction voltage increases significantly as the length of the transmission line increases, and is proportional to the relationship. The electromagnetic induction voltage has little relationship with the length of the transmission line. Electromagnetic induction and transmission power increase proportionally, while the influence between electrostatic induction voltage and transmission power is not significant.

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