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# Analysis and treatment of current unbalance abnormal situation of 750 kV double-circuit parallel transmission line

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**Abstract.** At present, the biggest problem faced by short-distance double-circuit parallel lines is the three-phase parameter asymmetry problem caused by non-transposition. This leads to three-phase current asymmetry, especially during heavy load performance is more prominent. Take a 750 kV double circuit parallel erection line in actual operation as an example, use EMTPE electromagnetic transient simulation software to simulate and analyze the current imbalance phenomenon. This paper studies the influence of phase sequence arrangement, distance between loops, distance between wires, line length, equivalent impedance, ground wire conditions and line power flow on current imbalance, and puts forward reasonable restraining measures. The simulation results show that when the line power flow is heavy, the double circuit lines are arranged in the same phase sequence and the distance between circuits is relatively short, there will be a large amplitude of zero sequence current on the line, mainly circulation current. If it is not suitable to adjust the protection measures, it can be considered to adjust the double-circuit lines to reverse phase sequence operation mode. The research results can provide reference for the engineering design of double-circuit parallel transmission lines.

**Keywords:** Current unbalance / double circuit parallel transmission lines / sequence component / influencing factors / EMTPE

## 1 Introduction

There is a shortage of resources for overhead line corridors in China. In order to save transmission line corridors and improve transmission capacity, there are a large number of high and low voltage, alternating current (abbreviated as AC) and direct current (abbreviated as DC) lines erected in parallel [1,2]. There are large electromagnetic induction and capacitive coupling phenomena between parallel transmission lines. The generated induced voltage and induced current have an impact on the resonant overvoltage, secondary arc current, zero sequence voltage (current) and current imbalance of the transmission line, it also causes DC bias, which affects the safe and stable operation of the power grid.

At present, some literatures have done some research on the asymmetry of double-circuit lines on the same tower. Wang et al. (2009) pointed out that the phase sequence arrangement and transposition mode are the main factors affecting the current unbalance of UHV transmission lines [3–5]. Adopting a compact tower and properly increasing the distance between the two circuits can effectively suppress the current unbalance. Lan et al. (2010) conducted a simulation analysis on the phenomenon of excessive current unbalance in the 220 kV line of the northern power grid in Ningxia [6]. By reasonably adjusting the phase sequence arrangement of the double-circuit lines on the same tower at the outlet of the substation, the current imbalance can be effectively improved. Zhang et al. (2009) analyzed the influencing factors of the current unbalance degree of a 1000 kV double-circuit subsection erected line with a full cycle transposition, the better transposition, phase sequence arrangement and combination scheme and the connection mode of single circuit section are obtained [7]. Ding et al. (2004) proposed a method to reduce the negative sequence component by setting the parameters of line series compensation elements and passive reactive power compensation elements at both ends of the line [8]. Yang et al. (2011) proposes to adjust the sub-tap of each phase transformer to solve the imbalance problem [9]. However, there is less analysis on the abnormal phenomenon of unbalanced current in the actual operation of extra-high voltage (hereinafter referred to as EHV) lines erected in parallel. At the same time, other factors affecting the current imbalance also need to be analyzed.

This paper is based on a 750 kV double circuit parallel erection transmission system. The abnormal phenomenon of current imbalance in EHV transmission lines is analyzed by using EMTPE electromagnetic transient software [10,11].

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The influencing factors of current imbalance in transmission lines are studied, analyze the reasons for the large unbalance factor, and propose effective solutions. The research results can provide reference for the engineering design of double circuit parallel lines, and it is of great significance to ensure the safe and stable operation of the system.

## 2 Current imbalance phenomenon

A 750 kV transmission line in Xinjiang Power Grid starts from ±800 kV Tian Shan (hereinafter referred to as TS) converter station and ends at 750 kV Yan Dun (hereinafter referred to as YD) substation (hereinafter referred to as TY I line, TY II line). The length of Line I is 66.456 km, and the length of Line II is 66.432 km. The line is not transposed, and the phase sequence arrangement along the line is shown in Figure 1.

Since two years after the line was put into operation, the current unbalance phenomenon will occur during the heavy load period, and the alarm information will appear many times in the background. After changing the zero-sequence current alarm setting, the alarm information will no longer appear. However, seven years after the normal operation of the line, the protection of the 750 kV TY II line A set of the YD station was activated, and the device abnormality warning information was issued, the zero-sequence current of the 750 kV line reaches the zero-sequence start-up value of the protection device. At this time, the power flow on TY I line and TY II line is 2470 MW and 2478 MW respectively, and the data of its start-up time are shown in Table 1, among them, $I_A$, $I_B$ and $I_C$ represent the current flowing through the three phases A, B, and C, respectively. $3I_0$ is a three-phase zero-sequence current.

The starting setting value of zero sequence current of set a protection device of the line is 0.1 A, the setting value of zero sequence section III current is 0.12 A, and the time is 3.5 s. It can be seen from Table 1 that the phase angle difference between the zero-sequence currents of the two transmission lines is 170°, which is close to the opposite phase. It can be seen that the zero-sequence current of the transmission line has an obvious circulating current component.

According to the phase sequence conversion formula (1), the measured results of the line current components on the YD side can be obtained, and the results are shown in Table 2.The zero-sequence current $I_0$ in Table 2 is the calculation result of the vector addition of the measured values of the three-phase current, which is slightly different from the measured value in numerical value.

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{1}$$

where $i_1$, $i_2$ and $i_3$—the positive, negative, and zero-sequence components of the current, respectively. $i_a$, $i_b$, and $i_c$— the current flowing through the three-phase line respectively.

$$\alpha = e^{j120^\circ}$$

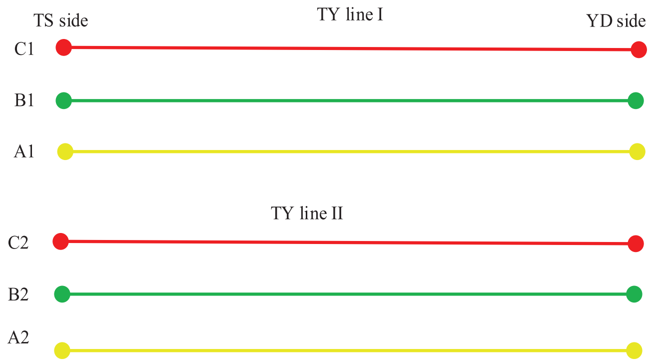


**Fig. 1.** Phase sequence arrangement of double circuit lines.

According to the provisions of "Three-phase Voltage Allowable Unbalance of Power Quality" GBT15543-2008, unbalance degree refers to the degree of three-phase unbalance in three-phase power system, which is expressed as the percentage of root mean square value of negative sequence component and positive sequence component of voltage or current [12,13]. The allowable value of normal voltage unbalance at the public connection point of power system is 2%, which shall not exceed 4% in a short time. Therefore, 2% is temporarily taken as the limit of unbalance in this paper. The unbalance calculation formula is:

$$\begin{cases} \varepsilon_{I2} = \dfrac{I_2}{I_1} \times 100\% \\ \varepsilon_{I0} = \dfrac{I_0}{I_1} \times 100\% \end{cases} \tag{2}$$

where $\varepsilon_{I2}$—the unbalance degree of negative sequence current; $\varepsilon_{I0}$—the unbalance degree of zero-sequence current; $U_1$—the positive sequence component of the current; $U_2$—the negative sequence component of the current; $U_0$—the zero-sequence component of the current.

From the measured results in Table 2 and formula (2), it can be seen that$\varepsilon_{I2}$of line I and line II are 0.76% and 0.82%, respectively; $\varepsilon_{I0}$are 3.64% and 4.34%, both exceeding the requirement of 2%.

## 3 Simulation calculation of current imbalance

### 3.1 System and transmission line overview

When studying the current imbalance problem of parallel erected lines, it is assumed that the power at the transmission end, power supply and load end parameters of the line are symmetrical. Using accurate line parameter models to simulate overhead lines, the load impedance can be calculated based on the line delivered power and power factor [14,15]. According to the requirements of the electromagnetic transient calculation program, double circuit transmission line network is simplified, and the simplified system wiring is shown in Figure 2.

The double-circuit transmission lines studied are calculated by parallel erection of two single-circuit transmission lines. The line conductor adopts $6 \times$ JL/

**Table 1.** Amplitude and phase angle of line current on YD side.

| | Line I | | Line II | |
|---|---|---|---|---|
| | Amplitude (A) | Angle (°) | Amplitude (A) | Angle (°) |
| $I_A$ | 1935.0 | 7.329 | 1810.0 | 10.363 |
| $I_B$ | 1892. 5 | –109.535 | 1892.5 | –113.327 |
| $I_C$ | 1835.0 | 126.432 | 1972.5 | 129.305 |
| $3I_0$ | 207.5 | –16.847 | 247.5 | 152.83 |

**Table 2.** The amplitude and phase angle of the sequence component of the line current on the YD side (measured result).

| | Line I | | Line II | |
|---|---|---|---|---|
| | Amplitude (A) | Angle (°) | Amplitude (A) | Angle (°) |
| $I_1$ | 1886.6 | 8.1 | 1891.0 | 8.8 |
| $I_2$ | 14.3 | 173.7 | 15.6 | –177.9 |
| $I_0$ | 68.6 | –17.0 | 82.1 | 152.4 |

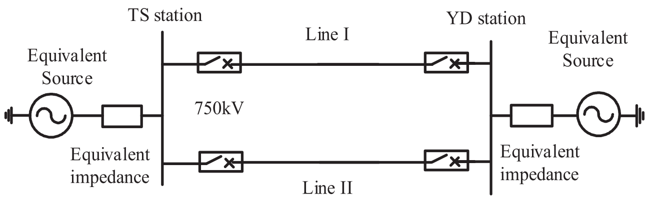


**Fig. 2.** System wiring diagram.

lha1-220/230 (aluminum alloy core aluminum stranded wire), with sub-conductor spacing of 400 mm. The model of transmission line tower is ZB1311, and the average height of conductor tower is about 21 m, and the corresponding tower structure is shown in Figure 3. The average height of the ground wire is about 29 m, of which the two ground wires of the line I are JLB20A-120 (segment grounding), the line II is JLB20A-120 (segment grounding) and 0PGW-120 (continuous grounding). The arrangement of four ground wires of two circuit lines is shown in Figure 4, and the center distance of I and II lines is considered as 100 m.

## 3.2 Calculation results

The simulation calculation results of the amplitude and phase angle of the line current on the YD side are shown in Table 3.

From the data in Tables 1–3, it can be seen that the two-phase current amplitude in the middle of the two loops is the highest (phase $A_1$ and phase $C_2$), followed by the two middle phases (phase $B_1$ and phase $B_2$), and the outermost two-phase current amplitude is the lowest (phase $C_1$ and phase $A_2$). The phase angle difference of the zero sequence current of the two circuits is 172°, which is close to the inverse phase. The measured results of the amplitude and phase angle of the current sequence component on the YD side are consistent with the calculated results, which proves the correctness of the simulation results.

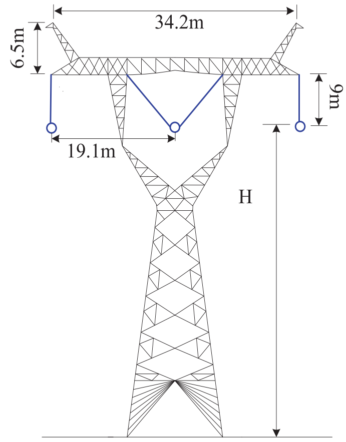


**Fig. 3.** Schematic diagram of the structure of the transmission line tower.

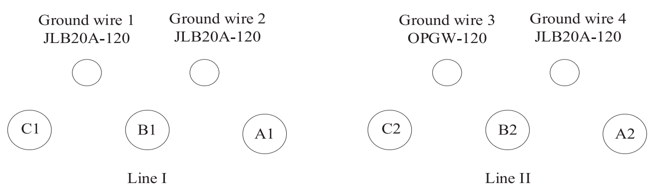


**Fig. 4.** The arrangement of conducting wires and ground wires of the research line (looking from the YD side to the TS side).

It can be seen from Table 3 and formula (1) that the $\varepsilon_{12}$ of lines I and II are 1.35% and 1.22% respectively, which are slightly deviated from the measured results $\varepsilon_{10}$ were 3.89% and 4.40%, which were in good agreement with the measured results.

**Table 3.** The amplitude and phase angle of the sequence component of the line current on the YD side (calculation results).

| | Line I | | Line II | |
|---|---|---|---|---|
| | Amplitude (A) | Angle (°) | Amplitude (A) | Angle (°) |
| $I_A$ | 1947.0 | 8.2 | 1809.2 | 11.0 |
| $I_B$ | 1911.5 | –109.5 | 1914.1 | -113.3 |
| $I_C$ | 1819.8 | 126.4 | 1961.5 | 129.5 |
| $3I_0$ | 220.5 | –16.0 | 249.6 | 156.1 |
| $I_1$ | 1888.8 | 8.3 | 1890.9 | 8.9 |
| $I_2$ | 25.4 | 126.4 | 23.1 | 142.1 |
| $I_0$ | 73.5 | –16.0 | 83.2 | 156.1 |

**Table 4.** Current unbalance degree under different phase sequence arrangement modes of the line.

| Phase sequence | Line I | | Line II | |
|---|---|---|---|---|
| | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% |
| $C_1B_1A_1$-$C_2B_2A_2$ | 1.35 | 3.89 | 1.22 | 4.40 |
| $A_1B_1C_1$-$C_2B_2A_2$ | 1.85 | 0.95 | 1.40 | 0.22 |
| $B_1A_1C_1$-$C_2B_2A_2$ | 9.04 | 1.18 | 9.11 | 0.52 |
| $C_1A_1B_1$-$C_2B_2A_2$ | 8.90 | 3.80 | 9.00 | 4.33 |
| $B_1C_1A_1$-$C_2B_2A_2$ | 9.04 | 4.56 | 8.80 | 4.39 |
| $A_1C_1B_1$-$C_2B_2A_2$ | 8.98 | 4.32 | 8.94 | 4.23 |

**Table 5.** Influence of distance between circuits on current unbalance.

| Phase sequence | Interphase spacing (m) | Line I | | Line II | |
|---|---|---|---|---|---|
| | | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% |
| Same phase sequence | 80 | 1.27 | 5.45 | 1.14 | 5.91 |
| | 100 | 1.35 | 3.89 | 1.35 | 4.40 |
| Reverse phase sequence | 80 | 1.67 | 0.70 | 1.50 | 0.12 |
| | 100 | 1.85 | 0.95 | 1.40 | 0.22 |

## 4 Analysis of influencing factors of line unbalanced current

### 4.1 Phase sequence arrangement mode

According to different arrangement modes of line phase sequence, the corresponding calculation results are shown in Table 4. During calculation, the current value of each phase sequence is 1890 A.

It can be seen from Table 4 that when the arrangement modes of phase sequence $A_1B_1C_1$-$C_2B_2A_2$ and $B_1A_1C_1$-$C_2B_2A_2$ is adopted, the zero-sequence current of the two-circuit line is small. Only from the perspective of zero-sequence current balance, the phase sequence $A_1B_1C_1$-$C_2B_2A_2$ and $B_1A_1C_1$-$C_2B_2A_2$ arrangements are roughly equivalent. However, the negative sequence unbalance degree is higher when the phase sequence $B_1A_1C_1$-$C_2B_2A_2$ arrangement is used. Considering the overall situation, the $A_1B_1C_1$-$C_2B_2A_2$ sequence (reverse phase order) is better.

### 4.2 Distance between return circuit

When other conditions remain unchanged and the center distance between circuits is reduced from 100 m to 80 m, the calculation results under the same phase sequence and reverse phase sequence arrangement are shown in Table 5.

It can be seen from Table 5 that when the two circuits are arranged in the same phase sequence, the zero-sequence circulating current increases with the decrease of the distance between the circuits; when the two circuits are arranged in the opposite phase sequence, the influence of the zero-sequence circulating current can be ignored.

**Table 6.** Influence of distance between conductors on current unbalance.

| Phase sequence | Wire spacing (m) | Line I | | Line II | |
|---|---|---|---|---|---|
| | | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% |
| Same phase sequence | 19.1 | 1.35 | 3.89 | 1.22 | 4.40 |
| | 19.6 | 1.35 | 3.96 | 1.20 | 4.59 |
| Reverse phase sequence | 19.1 | 1.85 | 0.95 | 1.40 | 0.22 |
| | 19.6 | 1.63 | 0.64 | 1.41 | 0.27 |

**Table 7.** Influence of line length and equivalent impedance on current unbalance.

| Phase sequence | length of line (p.u.) | Equivalent impedance (p.u.) | Line I | | Line II | |
|---|---|---|---|---|---|---|
| | | | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% |
| Same phase sequence | 1.0 | 1.0 | 1.35 | 3.89 | 1.22 | 4.40 |
| | 1.5 | 1.0 | 1.86 | 3.72 | 1.76 | 4.49 |
| | 1.0 | 1.5 | 0.97 | 3.85 | 0.89 | 4.35 |
| | 1.5 | 1.5 | 1.37 | 3.75 | 1.28 | 4.49 |
| Reverse phase sequence | 1.0 | 1.0 | 1.85 | 0.95 | 1.40 | 0.22 |
| | 1.5 | 1.0 | 2.21 | 0.64 | 2.08 | 0.21 |
| | 1.0 | 1.5 | 1.18 | 0.27 | 1.01 | 0.17 |
| | 1.5 | 1.5 | 1.64 | 0.29 | 1.51 | 0.23 |

### 4.3 Effect of distance between wires

When the center distance between the two circuits remains unchanged and the distance between the two adjacent phases is changed, the calculation results under the same phase sequence and reverse phase sequence arrangement are shown in Table 6.

It can be seen from the calculation results in Table 6 that under the premise that the phase sequence arrangement of the transmission line remains unchanged, the distance between the conductors has no significant effect on the zero-sequence current of the line.

### 4.4 Influence of line length and equivalent impedance

When other conditions remain unchanged, only the line length or the equivalent impedance of the system are changed, the calculation results under the same phase sequence and reverse phase sequence of the line are shown in Table 7. Among them, the line length and equivalent impedance take the original line length and equivalent impedance as the datum respectively, and express by the p.u.. Equivalent impedance includes equivalent self impedance and mutual impedance at both ends of the line.

It can be seen from Table 7 that when the two circuits are arranged in reverse phase sequence, the change of the line length and the system equivalent impedance has a greater impact on the zero-sequence circulating current.

### 4.5 Influence of ground wire erection

For most sections of the line, ground wire 1, ground wire 2 and ground wire 4 use JLB20A-120 (segment grounding), and ground wire 3 uses OPGW-120 (continuous grounding). Regarding the type of ground wire and its grounding method, three situations are considered in the text: (1) 0PGW-120 (continuous grounding), referred to as "OP". (2) JLB20A-120 (segmented grounding), referred to as "J1". (3) JLB20A-120 (continuous grounding), referred to as "J0". Considering different ground wire combinations, the calculation results under the same phase sequence and reverse phase sequence arrangement are shown in Table 8.

From the calculation results in Table 8, it can be seen that the type of ground wire and its grounding method have a certain influence on the zero-sequence current. If the continuous grounding method is adopted, the influence on the zero-sequence current of the line can be ignored. The calculation results show that when JLB20A-120 adopts different grounding methods, it has obvious influence on the zero-sequence current of the line. When the reverse phase sequence arrangement is used, if the model of the four ground wires and their grounding methods are the same, there is basically no zero-sequence and negative-sequence circulating currents.

### 4.6 Line power flow

The single-circuit power flow of this line can reach 3000 MW, and the calculation results under the same phase sequence and reverse phase sequence are shown in Table 9.

It can be seen from the calculation results in Table 9 that when the transmission line is arranged in the same phase sequence, when the power flow of the single-circuit line is 3000 MW, the current of the line I is 2432 A, the positive sequence current is 2347.0 A, the zero-sequence

**Table 8.** The influence of the ground wires on the current imbalance.

| Phase sequence | Ground wire 1 | Ground wire 2 | Ground wire 3 | Ground wire 4 | Line I | | Line II | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $\varepsilon_{I2}$ | $\varepsilon_{I0}$ | $\varepsilon_{I2}$ | $\varepsilon_{I0}$ |
| Same phase sequence | J1 | J1 | OP | J0 | 1.35 | 3.89 | 1.22 | 4.40 |
| | J0 | J0 | OP | J0 | 1.28 | 3.53 | 1.24 | 3.87 |
| | OP | J0 | OP | J0 | 1.24 | 3.19 | 1.31 | 4.28 |
| | OP | OP | OP | OP | 1.23 | 3.40 | 1.24 | 3.74 |
| | J0 | J0 | J0 | J0 | 1.23 | 3.50 | 1.26 | 3.79 |
| | J1 | J1 | J1 | J1 | 1.27 | 3.90 | 1.32 | 4.07 |
| Reverse phase sequence | J1 | J1 | OP | J0 | 1.85 | 0.95 | 1.40 | 0.22 |
| | J0 | J0 | OP | J0 | 1.52 | 0.47 | 1.46 | 0.39 |
| | OP | J0 | OP | J0 | 1.53 | 1.38 | 1.52 | 0.38 |
| | OP | OP | OP | OP | 1.46 | 0.41 | 1.46 | 0.41 |
| | J0 | J0 | J0 | J0 | 1.48 | 0.41 | 1.48 | 0.41 |
| | J1 | J1 | J1 | J1 | 1.55 | 0.68 | 1.55 | 0.68 |

**Table 9.** Influence of line power flow on current unbalance.

| Phase sequence | Line power flow (MW) | Line I | | Line II | |
|---|---|---|---|---|---|
| | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% | $\varepsilon_{I2}$/% | $\varepsilon_{I0}$/% | |
| Same phase sequence | 2450 | 1.35 | 3.89 | 1.22 | 4.40 |
| | 3000 | 1.34 | 3.85 | 1.23 | 4.39 |
| Reverse phase sequence | 2450 | 1.85 | 0.95 | 1.40 | 0.22 |
| | 3000 | 1.57 | 0.64 | 1.46 | 0.22 |

current is 90.3 A, and the zero sequence current is 3.85% of the positive sequence current. The positive sequence current of line II is 2349.4 A, the zero sequence current is 103.1 A, and the zero sequence current is 4.39% of the positive sequence current. In this way, the 3I0 of this line can reach 309.3 A.

## 5 Conclusion

- The current imbalance occurs in EHV transmission lines, and the simulation analysis is carried out on the actual transmission lines without any measures. The large zero sequence current is the main cause of current imbalance. At the same time, the measured results of the line current sequence component are consistent with the regular characteristics of the calculation results, which proves the correctness of the simulation model.
- The phase sequence arrangement, distance between circuits, line length, equivalent impedance, ground wire erection and line power flow can all affect the unbalance degree of line current. Among them, the influence of phase sequence arrangement and line power flow is the greatest.
- The unbalance degree of the current varies greatly when the phase sequence arrangement of the line is changed. The unbalance degree of reverse phase sequence arrangement is the smallest, which can avoid current unbalance to the greatest extent and improve the reliability of grid power supply.

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