Electrical Power and Energy Systems 85 (2017) 67–76

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Research on the electric unbalance degree of multiple transmission lines non-parallelly erected entirely in one common corridor

Jun Zhu [a,*], Guangning Wu [b], Chaoqun Shi [b], Degang Gan [a], Yongxing Cao [a], Chi Wu [a]

[a] Power Research Institute, State Grid Sichuan Electric Power Company, Chengdu 610072, China
[b] School of Electrical Engineering, Southwest Jiaotong University, Chengdu 610031, China

ARTICLE INFO

Article history:
Received 14 January 2016
Accepted 14 August 2016

Keywords:
Common corridor
Electric unbalance degree
Double-circuit UHV AC transmission line
Parallel section
Extension section

ABSTRACT

When multiple transmission lines are not entirely parallel erected in one common corridor, the electric unbalance degree of double-circuit ultra-high voltage (UHV) AC transmission line can be affected by several factors, such as severe electromagnetic coupling between lines in parallel section, various phase sequence arrangements and transposing modes of the lines, active power of the lines changing constantly. This paper presents a detailed analysis on the electric unbalance degree of double-circuit UHV AC line in common corridor, with particular attention to the effects of the parallel section's length, number and the active power of the lines. The causes and factors of unbalanced currents of double-circuit UHV AC line were taken into account by phase-sequence conversion of current and voltage, and the above effects were proved by an actual example. The main factors were studied by simulating in PSCAD/EMTDC. The results show that the parallel section's length, number and the active power of lines have considerable influences on the electric unbalance degree of double-circuit UHV AC line in common corridor. Finally, some suggestions have been proposed to provide as a construction reference to confine the level of electric unbalance degree of double-circuit UHV AC line which is not entirely parallel erected with other lines in common corridor.

1. Introduction

At present, China has basically completed UHV grid, which connects major regional power grids, large coal bases, large hydropower bases, large renewable energy bases and main load centers [1,2]. Therefore, the cross-regional and inter-provincial interconnection of power grids has been realized, and the optimal allocation and rational utilization of energy resources has been promoted [3]. Along with overall acceleration of industrialization, informationization and urbanization construction in China, it is inevitable choice to continue to promote the construction of UHV smart grid for ensuring power supply and the economic development.

In China, due to the shortage of construction territory, more and more transmission lines have been sharing a common corridor. This has many advantages, such as to improve the transmitting capacity of corridor in per unit width, to reduce the investment of power engineering construction and to save the available land resource [4–6]. However, in real cases, not all of the lines in common corridor are in parallel with each other from the beginning to the end, but they have parallel section of a certain length in some areas, such as mountain district and concentration areas of power load. For example, multiple extra-high voltage (EHV)/UHV DC lines are sharing a common corridor for delivering electricity from west to east in the southwest China, and in some place, they are in close proximity and parallel with other HVAC transmission lines [6,7]; in South China and East China, some HVAC and HVDC lines of differing voltages are sharing a common corridor [8,9]. In the parallel section, on the one hand, the effect of electromagnetic coupling among the lines is strengthened due to the distance between the lines reduced [10,11]. On the other hand, the spacing between the phase conductors is unequal because the line on each tower has its own phase sequence arrangement [11]. So, these will bring about the asymmetry of mutual impedances and capacitances between the lines. And more importantly, for double-circuit UHV AC transmission line which needs the main concern in common corridor, there are many kinds of transposing modes to choice, and the active power of each line changes frequently with load flow. These situations do not exist when double-circuit UHV AC line is built alone. Therefore, above all, it is necessary to study on the electric unbalance degree of double-circuit UHV AC line, which is partially parallel with other lines in common corridor.

* Corresponding author.
E-mail address: zhujun253@163.com (J. Zhu).

http://dx.doi.org/10.1016/j.ijepes.2016.08.005

Over the last several decades, several papers have been presented to study unbalanced currents and voltages of double-circuit lines on the same tower, but they mainly aim at the parallel lines in total length. The calculation model of electric unbalance degree has been established, based on electromagnetic transient simulation software ATP/EMTP and numerical calculation software MATLAB. The effects of many factors, such as transposing mode and phase sequence arrangement, on the asymmetry of coupling parameters and unbalance degree have been analyzed. The harms of unbalanced currents and voltages to power system equipment have been evaluated. And then, some suppressing measures and engineering suggestions have been given.

However, very little work has been done so far, to study the electric unbalance degree of transmission lines which are not totally parallel in common corridor. So, it is not clear about the effects of parallel section and active power of the lines in the parallel section on the unbalance degree of double-circuit UHV AC line. To summarize, it is necessary to do research on this in detail. Thus, this paper presents a detailed analysis of the electric unbalance degree of double-circuit UHV AC line which erects partially parallel with other lines in common corridor. Firstly, the causes and factors of unbalanced currents of double-circuit UHV AC line were proved. Various kinds of change rules of unbalance degree were studied by simulating in PSCAD/EMTDC. Finally, some necessary suggestions about how to configure double-circuit UHV AC line which is not totally parallel with other lines in common corridor were given by further analysis on the calculation results.

2. Electric unbalance degree of double-circuit UHV AC line in common corridor

In China, there are some transmission lines in different voltage levels to be built in parallel sharing the same common corridor with double-circuit UHV AC line, because the length of UHV AC line usually reaches to hundreds or thousands of kilometers. And more, in the parallel section, conductor spatial arrangements, phase sequences and transposing modes of transmission lines are complicated. So, first of all, the following limits on transmission system are done in this paper:

- Transmission lines: double-circuit UHV AC line and 500 kV AC line are sharing a common corridor.
- Conductor spatial arrangements: double-circuit UHV AC line is vertical arrangement and 500 kV AC line is single circuit and horizontal arrangement [12,13].
- Phase sequences: UHV AC line can be in one of the typical phase sequences, that is, super-bundle (SB) arrangement, low-reactance (LR) arrangement [14,15] and another different arrangements (except SB arrangement and LR arrangement). Moreover, in the parallel section, the lines also need to consider different kinds of phase sequence combinations.
- Transposing modes: UHV AC line can be in one of the below transposing modes, that is, un-transposed, non-complete transposed and complete transposed. And in the parallel section, the lines are un-transposed.

2.1. Sequence components of transmission lines in common corridor

Fig. 1 is schematic diagram of multi-circuit lines which are sharing a common corridor. The dashed boxes in Fig. 1 indicate parallel sections, in which the lines on different towers are in close proximity. Each circuit of double-circuit UHV AC line is marked as 1000 kV I and 1000 kV II, and its length is l. The parallel sections are marked as $P_1, P_2, \ldots, P_n$, respectively, and the length is $l_{P1}, l_{P2} \ldots l_{Pn}$. Other than the parallel section, there are several areas in which UHV AC line is built alone, marked as $1, 2, \ldots, n$, and the length is $l_1, l_2, \ldots, l_n$. And what is important is that there is only a one-circuit line erected close to UHV AC line in every parallel section, and marked as line #S1, line #S2…line #Sn, respectively.

Firstly, to analyze sequence components of transmission lines in common corridor. As known, a conductor has self-impedance, and there are mutual impedances between two or multiple lines [16–18]. Therefore, as shown in Fig. 1, the impedances of multiple transmission lines are defined in the following, and their computation formulas have been given in [19]. $\boldsymbol{Z_I}$ and $\boldsymbol{Z_{II}}$ are, respectively, the self-impedance matrixes of 1000 kV I and 1000 kV II in per-unit-length. $\boldsymbol{Z_M}$ and $Z_{\mathbf{M}}^{\mathbf{T}}$ are the mutual impedance matrixes between 1000 kV I and 1000 kV II in per-unit-length. $\boldsymbol{Z_{I\text{-}Sn}}$ and $Z_{\mathbf{I-Sn}}^{\mathbf{T}}$ are the mutual impedance matrixes between 1000 kV I and line #Sn in per-unit-length. $\boldsymbol{Z_{II\text{-}Sn}}$ and $Z_{\mathbf{II-Sn}}^{\mathbf{T}}$ are the mutual impedance matrixes between 1000 kV II and line #Sn in per-unit-length.

Then, the following relation, on the current and potential difference at two ends of the section P_n, is obtained:

$$\begin{pmatrix} \dot{U}_{\mathbf{I-Pn}} \\ \dot{U}_{\mathbf{II-Pn}} \\ \dot{U}_{\mathbf{Sn}} \end{pmatrix} = l_{\mathrm{Pn}} \begin{pmatrix} Z_{\mathbf{I}} & Z_{\mathbf{M}} & Z_{\mathbf{I-Sn}} \\ Z_{\mathbf{M}}^{\mathbf{T}} & Z_{\mathbf{II}} & Z_{\mathbf{II-Sn}} \\ Z_{\mathbf{I-Sn}}^{\mathbf{T}} & Z_{\mathbf{II-Sn}}^{\mathbf{T}} & Z_{\mathbf{Sn}} \end{pmatrix} \begin{pmatrix} \dot{I}_{\mathbf{I}} \\ \dot{I}_{\mathbf{II}} \\ \dot{I}_{\mathbf{Sn}} \end{pmatrix} \tag{1}$$

where $\dot{U}_{\mathbf{I-Pn}}$ and $\dot{U}_{\mathbf{II-Pn}}$ are, respectively, the matrixes of potential differences of 1000 kV I and 1000 kV II in the section P_n. $\dot{I}_{\mathbf{I}}$ and $\dot{I}_{\mathbf{II}}$ are, respectively, the current matrixes of 1000 kV I and 1000 kV II. $\dot{U}_{\mathbf{Sn}}$ is the matrix of potential difference and $\dot{I}_{\mathbf{Sn}}$ is the current matrix of line #Sn.

In order to analyze the electric unbalance degree of double-circuit UHV AC line, after some transformation, Eq. (1) can be written to the following:

$$\begin{pmatrix} \dot{U}_{\mathbf{I-Pn}} \\ \dot{U}_{\mathbf{II-Pn}} \end{pmatrix} = l_{\mathrm{Pn}} \begin{pmatrix} Z_{\mathbf{I}} + \frac{1}{2} Z_{\mathbf{I-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{I}}^{-1} & Z_{\mathbf{M}} + \frac{1}{2} Z_{\mathbf{I-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{II}}^{-1} \\ Z_{\mathbf{M}}^{\mathbf{T}} + \frac{1}{2} Z_{\mathbf{II-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{I}}^{-1} & Z_{\mathbf{II}} + \frac{1}{2} Z_{\mathbf{II-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{II}}^{-1} \end{pmatrix} \begin{pmatrix} \dot{I}_{\mathbf{I}} \\ \dot{I}_{\mathbf{II}} \end{pmatrix} \tag{2}$$

Based on the symmetrical component method, the solution of positive, negative and zero sequence current components on each circuit of double-circuit UHV AC line can be expressed as

$$\dot{\mathbf{U}}_{\mathbf{S-Pn}} = l_{\mathrm{Pn}} \mathbf{Z}_{\mathbf{S-Pn}} \dot{\mathbf{I}}_{\mathbf{S}} \tag{3}$$

where $\dot{\mathbf{U}}_{\mathbf{S-Pn}} = (\dot{U}_{1\mathrm{I-Pn}} \quad \dot{U}_{2\mathrm{I-Pn}} \quad \dot{U}_{0\mathrm{I-Pn}} \quad \dot{U}_{1\mathrm{II-Pn}} \quad \dot{U}_{2\mathrm{II-Pn}} \quad \dot{U}_{0\mathrm{II-Pn}})$,

$$\mathbf{Z}_{\mathbf{S-Pn}} = S \begin{pmatrix} Z_{\mathbf{I}} + \frac{1}{2} Z_{\mathbf{I-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{I}}^{-1} & Z_{\mathbf{M}} + \frac{1}{2} Z_{\mathbf{I-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{II}}^{-1} \\ Z_{\mathbf{M}}^{\mathbf{T}} + \frac{1}{2} Z_{\mathbf{II-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{I}}^{-1} & Z_{\mathbf{II}} + \frac{1}{2} Z_{\mathbf{II-Sn}} \dot{I}_{\mathbf{Sn}} \dot{I}_{\mathbf{II}}^{-1} \end{pmatrix} S^{-1},$$

$$\dot{\mathbf{I}}_{\mathbf{S}} = (\dot{I}_{1\mathrm{I}} \quad \dot{I}_{2\mathrm{I}} \quad \dot{I}_{0\mathrm{I}} \quad \dot{I}_{1\mathrm{II}} \quad \dot{I}_{2\mathrm{II}} \quad \dot{I}_{0\mathrm{II}}).$$

$\dot{U}_{1\mathrm{I-Pn}}$, $\dot{U}_{2\mathrm{I-Pn}}$ and $\dot{U}_{0\mathrm{I-Pn}}$ are, respectively, the positive, negative and zero sequence component of potential difference of 1000 kV I at two ends of the section P_n. $\dot{I}_{1\mathrm{I}}$, $\dot{I}_{2\mathrm{I}}$ and $\dot{I}_{0\mathrm{I}}$ are the positive, negative and zero sequence current component of 1000 kV I. $\dot{U}_{1\mathrm{II-Pn}}$, $\dot{U}_{2\mathrm{II-Pn}}$ and $\dot{U}_{0\mathrm{II-Pn}}$ are the positive, negative and zero component of potential difference of 1000 kV II at two ends of the section P_n. $\dot{I}_{1\mathrm{II}}$, $\dot{I}_{2\mathrm{II}}$ and $\dot{I}_{0\mathrm{II}}$ are the positive, negative and zero current component of 1000 kV II. $\boldsymbol{S}$ is the transformation matrix.

By Eq. (3), it can be seen that in the parallel section, the electromagnetic coupling among multiple lines which are on different towers, affects the positive, negative and zero component of mutual impedance of double-circuit UHV AC line. This would enhance the mutual impedance between the above lines. As a result, this would make the electric unbalance degree of double-