

Analysis of Safety Protection Measures for Maintenance Work of 500 kV Double-Circuit Transmission Lines on Same Tower

Qi Yang¹, Dehua Zou¹, Jianjun Zhang¹, Hui Li¹, Jianping Chen¹ and Jinliang Li¹

¹Live Working Center of State Grid Corporation of Hunan, Changsha 410100, China

Wuhu_yangqi@qq.com

Abstract. Four transmission lines on the same tower are widely used because of their obvious economic and social benefits. But it also has high power supply reliability, so the choice of reasonable maintenance mode is particularly important. In this paper, we deduced the maintenance influence of the energized line to non-energized line, calculated and analyzed protection measures of non-energized singular line of 500kV double-circuit transmission line on the same tower with ATP software, and calculated field intensity distribution of typical operating position of the energized double-circuit transmission line with the finite element software. The calculation shows that when using the outage maintenance method, hanging both ground current and personal security line can reduce the current flowing through the operator's body effectively. When using the live maintenance method, the field intensity of operator body strengths up to 383.69kV/m, The operator needs to wear shielding cloth with at least 43.08 dB shielding efficiency, in order to meet the security requirements.

1. Introduction

Multi-circuit transmission lines on the same tower can not only increase transmission capacity per unit area, but reduce comprehensive cost and requirement of line corridor, which have remarkable economic and social benefits, and are thus widely used [1]. However, a part of important multi-circuit transmission lines are very difficult to maintain with a full outage mode, it appears particularly important to select a reasonable maintenance mode.

When a part of lines are maintained with power-off, electromagnetic coupling and electrostatic coupling between outage lines and operating lines causes induced voltage and current, which may affect the operator. References [2-3] carried out simulation calculation and actual measurement analysis on induced voltage and current of the multi-circuit transmission lines on the same tower at difference voltage levels and obtained the relation between induced parameters with parameters such as voltage level, load, line length and conductor arrangement of the operating lines. Reference [4] calculated the induced current and voltage of the outage line under different levels of voltage respectively, and selected a reasonable grounding switch accordingly.

When performing live working on defective transmission lines, the operator needs to take whether the filed intensity on body surface of typical operation positions meets requirement into account. References [5] determined live working modes of different types of compact double-circuit transmission lines on the same tower respectively through tests. References [6] calculated and



determined safety protection measures of live working of different types of four-circuit transmission lines on the same tower.

However, compared with ordinary double-circuit transmission lines on the same tower, 500kV vertical compact double-circuit transmission lines on the same tower is more compact, and has greater safety risk on maintenance work, so carry out research is extremely urgent.

The author firstly analyzed an influence mechanism of non-outage lines on maintenance of outage lines and presented a reasonable maintenance mode for non-outage lines, then analyzed the risk and of typical operation positions and field intensity on body surface of the operator during live maintenance, and finally presented a reasonable live maintenance mode.

2. Calculation model

A section of 500kV double-circuit transmission lines on the same tower, including a total of six forms of pole towers, a total of 13 base, including 5SCZ1, 5SCZ2 double loop straight-line tower 9, 5SCJ1, 5SCJ2, 5SCJ3, 5SCJ4 double-loop tension turret 4 base. The average span of 304m, the average strain length of 0.99km section, the number of towers per kilometer 3.28 base, the maximum span of 534m.

As the same tower double-circuit transmission line tower is mainly used for compact tower model 5SCZ2, this paper takes 5SCZ2 for study, as shown in Figure 1. Compact line section wire with $6 \times \text{JL} / \text{G1A-300/40}$ ACSR, sub-conductor hexagonal layout, split pitch of 375mm, the other metal fittings are designed with reference to the 5E7 module design of SGCC General Design [7].

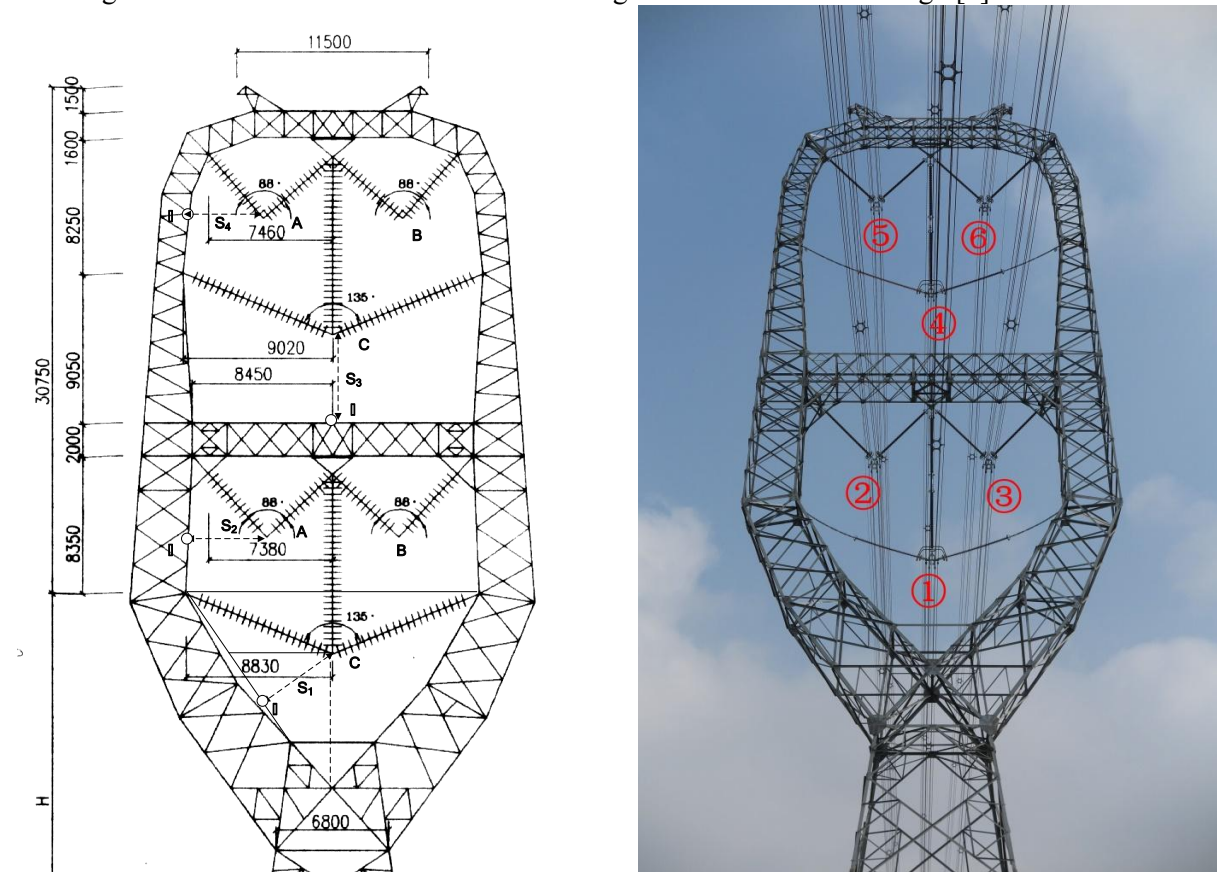


Figure 1. 500kV vertical compact tower structure diagram

2.1. Influence of non-outage lines on maintenance of outage lines

For arbitrary k circuit line and j circuit line, the mutual capacitance matrix and mutual inductance matrix of the two lines are respectively:

$$\begin{aligned}
C_{kj} &= \begin{bmatrix} C_{kaja} & C_{kajb} & C_{kajc} \\ C_{kbja} & C_{kbjb} & C_{kbjc} \\ C_{kcja} & C_{kcjb} & C_{kcjc} \end{bmatrix} \\
L_{kj} &= \begin{bmatrix} L_{kaja} & L_{kajb} & L_{kajc} \\ L_{kbja} & L_{kbjb} & L_{kbjc} \\ L_{kcja} & L_{kcjb} & L_{kcjc} \end{bmatrix}
\end{aligned} \tag{1}$$

When $k=j$, C_{kaja} and L_{kaja} represent self-capacitance and self-inductance of phase a in k circuit, C_{kajb} and L_{kajb} represent mutual capacitance and mutual inductance of phase a and phase b in k circuit, and other parameters are explained with reference to corresponding subscripts or superscripts. When $k \neq j$, C_{kaja} and L_{kaja} represent mutual capacitance and mutual inductance of phase a in k circuit and phase a in j circuit, and other parameters are explained with reference to corresponding subscripts or superscripts.

That $U_k = [U_{ka}, U_{kb}, U_{kc}]^T$ and $I_k = [I_{ka}, I_{kb}, I_{kc}]^T$, then the matrixes of the current and voltage are that $U = [U_1, U_2]^T$ and $I = [I_1, I_2]^T$.

When two ends of the power-off line are grounded, the power-off line is dominated by electromagnetic induction voltage $j\omega LI = \Delta U = 0$. Induction current of the twice circuit power-off line is that. namely $\Delta U_2 = 0$, it can be obtained that

$$I_2 = -L_{22}^{-1} L_{12} I_1 \tag{2}$$

The above deduction can be extended to outage states of multiple lines, and then values of induction voltage and voltage under the condition that two ends of the outage line are suspended, one end of the outage line is grounded and two ends of the outage line are grounded respectively.

2.2. Influence of non-outage lines on maintenance of outage lines

Electric field measuring points are selected according to tower structure, line position and basic law of distribution of space electric field. When the operator climbs to a certain height, measurements are carried out at position of the tower body with equal height to the line and suspension pints of of upper phase, middle phase and lower phase insulator strings, as shown in Fig. 1. As shown in Fig. 1 above, the measuring points 1, 2, 3, 4, 5, 6 are located at the wire.

3. Analysis of protection measures for maintenance work

3.1. Protection measures for outage maintenance

According to the typical structure of towers, models of a power source, transmission lines and a load are connected, and a power transmission system including a transformer substation, transmission lines and loads is established through ATP-EMTP.

When two ends of one circuit of the double-circuit transmission lines on the same tower are grounded for maintenance and the other circuit line operate normally, induction current on the outage line is as shown in Fig. 2.

It can be seen from Fig.2 that with growing of length, induction current on the outage line increases gradually. Take power-off maintenance of 500kV I circuit line for example, when the line is 20km long, induction current of the line is 46.89A, thus safety of the operator can't be guaranteed only by grounding knife-switches at two ends of the outage line, and safety protection measures need to be taken. According to Fig.2, the induction current is the largest when the 500kV II circuit line is

powered off, thus the maintenance mode of the other outage lines can be developed based on the maintenance mode of the 500kV II circuit line.

When the grounding knife-switches at two ends of line are closed and the 500 kV II circuit line is powered off for maintenance, define a maintenance mode 1 in which temporary ground wires are suspended on the towers on two sides of the operator, and define a maintenance mode 2 where a safety protection line is suspended at the position of the operator based on maintenance mode 1.

When the distance between the two temporary ground wires is 5km, simulation of current flowing through human body is carried out when the distance between the ground wires is 0.5, 1, 2, 3, 4 and 5km respectively, then current flowing through human body under the maintenance mode 1 and maintenance mode 2 is as shown in Fig. 3. According to the simulation, under the two maintenance modes, with growing of distance between the temporary ground wires, current flowing through the body of the operator increases, but the rate of increase is low.

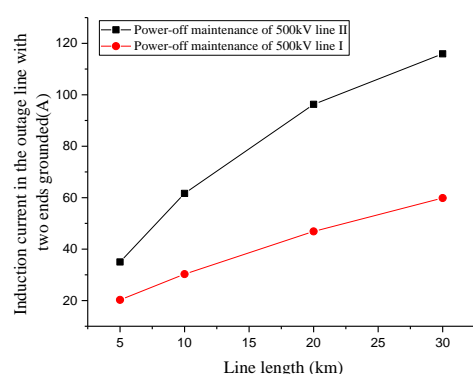


Figure 2. Induction current in the outage line with two ends grounded

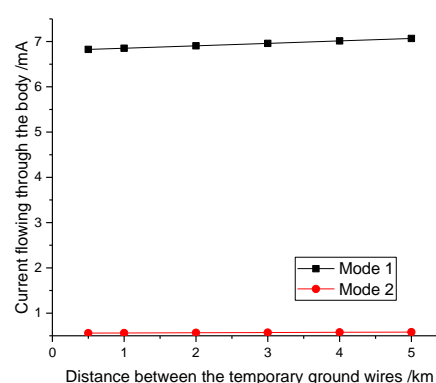


Figure 3. The current flows through the worker with different maintenance modes

Under the maintenance mode 1, current flowing through the body of the operator exceeds human body induction current (1 mA as stipulated in regulation) during operation of the operation, its maximum value reaches 6.27A and its minimum value is up to 5.63A, thus maintenance under the maintenance mode 1 has great potential safety hazards, and operations can't be smoothly completed. Under the maintenance mode 2, the resistance of the temporary ground wires is greatly lower than that of human body, the induction current on the maintaining line flows to the ground mainly through the temporary ground wires, and current flowing through the body of the operator is only 1.15-1.24 μ A, which is far below the minimum induction current of human body, therefore the operator can complete various maintenance operations on the line safely under the maintenance mode 2.

3.2. Protection measures for live maintenance

The electric field intensity of each measurement point is calculated through the finite element calculation software, and distribution results of electric fields around human body of each measurement point are obtained through simulation, as shown in Fig.4.

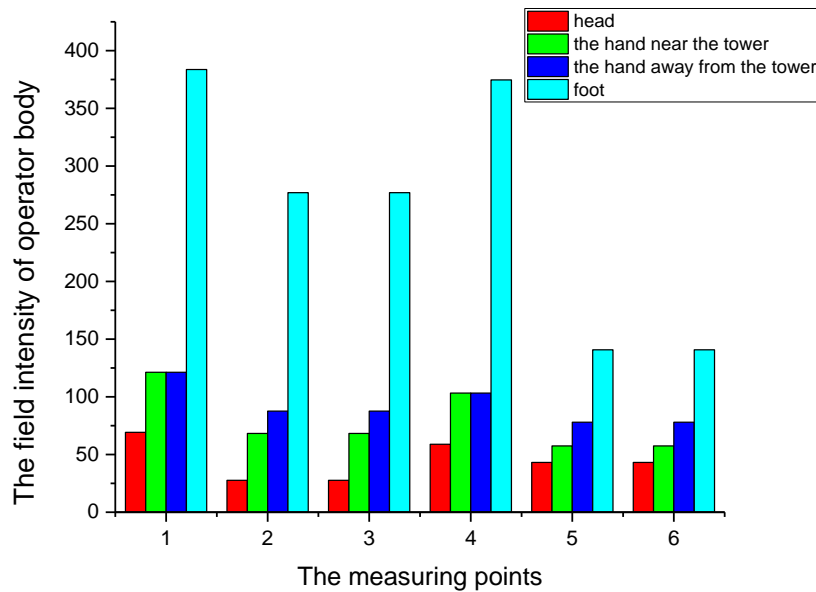


Figure 4. the field intensity distribution of operators in equal potential points (kV/m)

When the operator is located on the line for working, the maximum field intensity on surface of human body lies on feet, in the meanwhile, the head of the operator forms a high electric field area with the end of the cross arm, and field intensity of fingers of the left hand and the right hand is high. In all the equipotential positions, the field intensity of foot and hand was large, the maximum field intensity of foot was at position 2, reaching 383.69 kV / m; the maximum field intensity of hand was at position 1, reaching 121.33 KV / m, in which case we need to take protective measures.

Shielding effectiveness is an index for measuring performances of shielding clothes, which is a decibel value of voltage ratio on a receiving pile before and after shielding:

$$SE = 20 \lg \frac{E_0}{E_i} \quad (3)$$

In this formula, E_0 is field intensity outside the shielding clothes, kV/m, and E_i is field intensity outside the shielding clothes, kV/m.

On the 500kV double-circuit transmission lines on the same tower, the maximum field intensity of human body constantly lies on feet when the operator is not wearing the shielding clothes, which can reach the maximum value of 383.69kV/m. According to GB/T 6568-2008 Screen Clothes for Live Working [8], after the operators wear the shielding clothes, field intensity on the surface of body inside the shielding clothes shall not be higher than 15kV/m and field intensity of exposed part shall not be higher than 240k/V. The shielding cloth of 40dB with the theoretical field intensity of less than 4 kV / m inside can meet the requirements of live maintenance operation.

4. Conclusion

1) The author deduced influence of four-circuit transmission lines on the same tower on maintenance of non-outage lines, and obtained induction current in the outage line with two ends grounded. This deduction can be extended to outage of multiple lines.

2) Using ATP-EMTP software to analyze the induced current in the non-energized 500kV double-circuit transmission lines on the same tower, and the analysis is that the mode of suspending

“temporary ground wires and personal safety wire” can effectively reduce current flowing through body of the operator, and safety risk is decreased accordingly.

3) In the live maintenance mode, the field intensity of the operator’s body is 383.69 kV / m when the operator is in the equipotential working position. The shielding cloth of 40dB with the theoretical field intensity of less than 4 kV / m inside can meet the requirements of live maintenance operation.

References

- [1] Electric Power Research Institute. AC to DC Power transmission line conversion, USA. 2009.
- [2] Ma Aiqin, Xu Dongjie, Wang Haibo, et al. Induced Voltage and Induced Charge of 0.38 kV lines Operated Parallel Under 500 kV AC Double-circuit Transmission Lines on Same Tower[J]. High Voltage Engineering, 2015, 41(1): 306-312.
- [3] Wu Jinwen, Zhang Longwei, Cao Baojiang, et al. Analysis on the Electromagnetic Coupling Components of UHV AC Double-Circuit on the Same Tower Transmission Lines[J]. Electric Power, 2014, 47(6):1-5,7.
- [4] Li Xinwang, Lu Qifu, Wang Jingyi, et al. Research on Switching Induced Voltage and Current by Earthing Switch in 500/220 kV Four-circuit on One Tower[J]. High Voltage Apparatus, 2013, 49(9):63-68.
- [5] Din Yujian, Song Gang, Chen Jiamiao, et al. Experimental Research on Live Working Carried on Double Circuit Vertically Arranged 500 kV Compact Transmission Lines on the Same Tower[J]. Power System Technology, 2013, 37(11):3281-3287.
- [6] Su Ziming, Peng Yong, Liu Kai, et al. Simulation Analysis of Electric Field Protection for Live-Working on 1 000 kV and 500 kV AC Four-Circuit Transmission Lines on One Tower[J]. Electric Power, 2014, 47 (2):78-84.
- [7] Liu Zhenya, SGCC Transmission and Transformation Project Universal Design[M]. Beijing, China: China Electric Power Press, 2011:60-61.
- [8] DL/T 966-2005. Technical guide for live working in 500kV AC compact transmission line [S].2005.