

Research for the Calculation of the Potential Transfer Energy on $\pm 800\text{kV}$ DC Transmission Lines

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Abstract. It would be hard to be repaired in the case of a power outage if the $\pm 800\text{kV}$ ultra high voltage DC (UHVDC) transmission line was put into operation, so live working is the guarantee for its security and stability. It's necessary to calculate potential transfer energy to ensure the safety of the live working personnel. The transfer energy can be calculated by establishing the equivalent model of the process of potential transfer. Potential differences and capacitance parameters can be calculated by the finite element method, thereby transfer energy in different transfer distances can be worked out. The results show that the transfer energy increases with the increase of the transfer distance and the transfer energy reaches to 1.0 J when the distance is 0.5 m. So the potential transfer rod is necessary for the security of the live working personnel on $\pm 800\text{kV}$ DC transmission lines.

1. Introduction

Once the ultra high voltage DC (UHVDC) transmission lines were put into operation, it is hard to repair at outage. The live working is the forceful guarantee for the security and stability of operation of the UHVDC transmission lines [1]. The potential shift is necessary in live working, it means the worker uses conductive gloves or other special tools to connect himself with the wire, which can make him to get the same potential with the wire [2]. Because of the high voltage and strong field in the live working area, the electric arc, transferring current and transient energy would generate during the moment of the potential shift [3-5]. If the safety prevention measures are not enough or the operations are not proper in the process the safety accident would occur. The current through the worker is the pulse current with high frequency. Because of its complex change, the energy of the spark discharge is used to measure the severity that the pulse current act on the worker [4-6]. Therefore the research and calculation of the transfer energy on UHVDC transmission lines are necessary.

Take the calculation of the potential transfer energy on $\pm 800\text{kV}$ DC transmission lines, and the hanging basket method is used as the way of entering the electric field. The partial capacitances and potential differences can be obtained by the finite element method. Then the transfer energy under different transfer distances can be obtained based on the established equivalent calculation model, which provides reference for the confirm of the potential transfer way and distance on the following live work on the UHV transmission lines.

2. The calculation method of the energy transfer

The equivalent circuit diagram of potential shift is shown as Fig.1, it is used to simulate the process of the worker entering the equipotential field of the $\pm 800\text{kV}$ DC transmission lines by the hanging basket.



The U_1 presents the voltage of the line needed to be hooked, the U_2 presents the voltage of the other line, the L presents the inductance of the screening clothes and potential rod, C_{12} presents the capacitance between the worker and the line needed to be hooked, C_{13} presents the capacitance between the worker and the other line, C_{11} presents the capacitance between the worker and the ground. The worker and the basket is defined as the conductor 1, the line needed to be hooked is defined as the conductor 2, the other line is defined as the conductor 3, the tower, the ground wire and the ground are defined as the conductor 4.

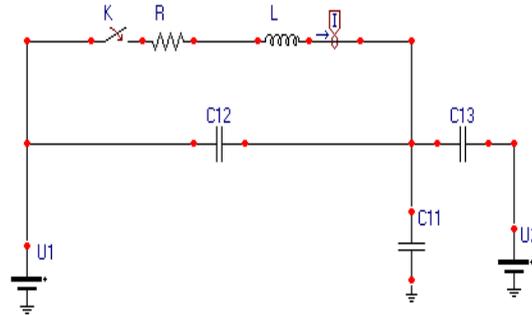


Figure 1. Equivalent circuit diagram of potential shift

The moment that the operator contacting the wire is simulated as the switch K closed in Fig.1. The energy stored in C_{12} is released through the operator's body, it is calculated by the equation (1), the U_{12} is the potential between the operator and the wire needed to be hanged and it can be calculated by the finite method. Because of the small value and short discharge time of the three capacitors, the potential of every wire is constant in the process of the operator hanging himself on the certain wire.

$$W = \frac{1}{2} C_{12} U_{12}^2 \quad (1)$$

3. The calculation of the capacitances

The capacitance of C_{ij} ($i \neq j, i, j=1,2,3$) and C_{ii} ($i=1,2,3$) in the equivalent circuit shown in Fig.1 is calculated according to the total electrostatic energy stored in electrostatic system multiple conductor, which is shown as the equation (2).

$$W = \frac{1}{2} \int_V \mathbf{E} \cdot \mathbf{D} dV = \sum_{i=1}^n \frac{1}{2} u_i q_i \quad (2)$$

The C_{ij} ($i \neq j, i, j=1,2,3$) presents the capacitance between the conductor i and the conductor j , the C_{ii} ($i=1,2,3$) presents the capacitance between the conductor i and the ground. In the equation (2), the \mathbf{E} presents the electric field intensity, the \mathbf{D} presents the electric flux density, the u_i presents the voltage between the conductor i and the ground, the q_i presents the charge stored in the conductor i and it can be expressed as the equation (3).

$$q_i = C_{i1}u_1 + C_{i2}u_2 + \dots + C_{ii}u_i + \dots + C_{in}u_n \quad (3)$$

Plug the equation (3) into the equation (2), we can get the equation (4).

$$W = \frac{1}{2} \sum_{i=1}^n \left(C_{ii}u_i^2 + \sum_{j=1, j \neq i}^n C_{ij}u_i u_j \right) \quad (4)$$

The processes of capacitance calculation follows:

Step 1) The calculation of the principal diagonal elements C_{ii} : the voltage of the i th conductor is assigned to be unit voltage and the voltage of the others is set to be zero potential, the three-dimensional electrostatic field can be calculated by the finite element method. The energy W_{ii} can be calculated based on the equation (2), and then the C_{ii} ($i=1,2,3$) can be calculated based on the equation (4).

Step 2) The calculation of the off-diagonal elements C_{ij} : the voltage of the i th and the j th conductor is assigned to be unit voltage and the voltage of the others is set to be zero potential, the three-

dimensional electrostatic field can be calculated by the finite element method. The energy W_{ij} can be calculated based on the equation (2), and then and then the C_{ij} ($i \neq j, i=1,2,\dots,n-1, j=i+1\dots n$) can be calculated based on the equation (4). And the capacitances can be calculated and shown in Tab.1 according to the above formulas when the potential transfer distance is 0.3m.

Table 1. Calculated capacitance values

Type	Capacitance/pF
C_{11}	13.10
C_{22}	737.20
C_{33}	722.50
C_{12}	44.56
C_{13}	0.53
C_{23}	64.65

The curve of the C_{12} variable against the time is available through the calculation and it is shown in Fig.2. It shows that the capacitance between the live working people and the line needed to be hooked decreases with the increase of the transfer distance.

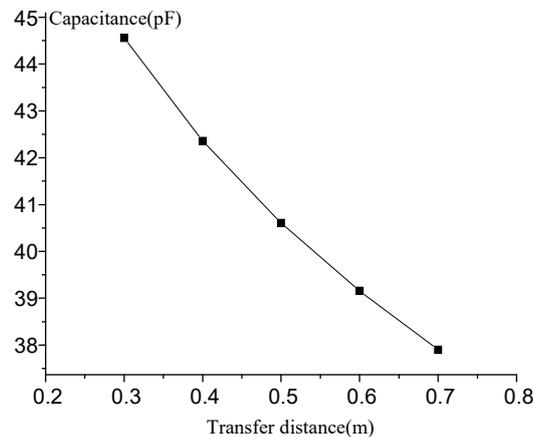


Figure 2. The capacitance values at different transfer distances

4. Calculation of the potential difference

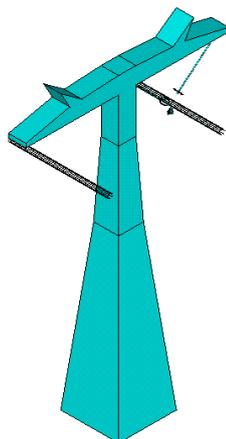


Figure 3. The finite element model in the process of potential shift

Figure 4. Field application of entering the electric field by the basket

In order to obtain the potential difference between the equipotential worker and the line needed to be hooked, the three-dimensional finite element model is established according to the actual filed situation of ± 800 kV DC transmission lines[7-8]. The ± 800 kV straight-line tower is used as the tower model, its

total height is 63.5m and the nominal height is 57m. The wire is arranged as regular hexagon and its type is ASCR-720/50; its bundle spacing is 450 mm and the diameter of the branch wire is 36.24 mm. The whole model is shown in Fig.3, the diagram of entering the electric field by the basket is shown in Fig.4, and the partial enlarged view of the finite element model in the process of the potential shift is shown in Fig.5.

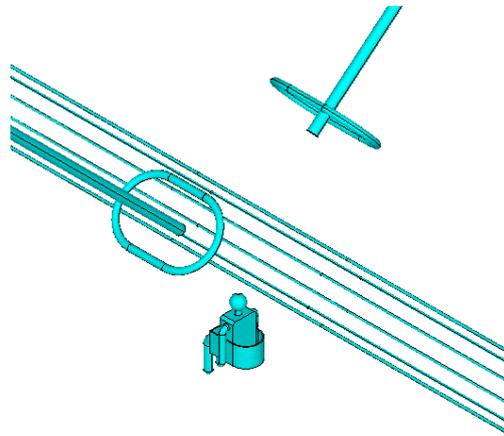


Figure 5. The enlarged view of the finite element model in the process of potential shift

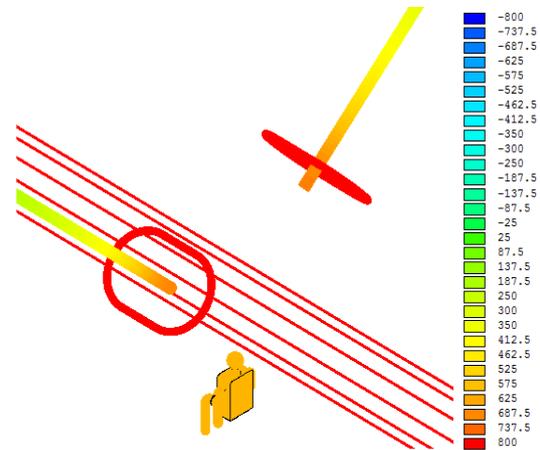


Figure 6. Potential distribution of entering the electric field by the basket

In order to ensure the solution accuracy on simulating calculation, the border area is 5 times of the actual model and apply truncated boundary conditions. The ground is defined as the zero boundary, the line length is set as 30 m along the line direction. Impose +800 kV potential on the positive line, impose -800 kV potential on the negative line and impose zero potential on the tower, the ground lines and the ground. Couple the potential for the worker and the hanging basket if the worker does not touch the line. The potential of the worker is equal to the one of the touched line if the worker has touched the line [9]. The calculated potential distribution is shown in Fig.6. As can be seen from the Fig.6, the calculated result consistent with the actual situation.

Potential of the live working personnel and the potential differences between the worker and the wire needed to be hooked can be calculated based on the results of the finite element analysis. The results of the potential difference is shown in Tab.2.

Table 2. Potential difference values

The transfer distance/m	The potential of the live working personnel/kV	The potential difference U_{12} /kV
0.3	605.4	194.6
0.4	591.0	209.0
0.5	577.6	222.4
0.6	565.0	235.0
0.7	552.9	247.1

The Tab.2 shows that the potential of the live working personnel decreases and the U_{12} increases gradually with the increase of the transfer distance.

5. The calculation of the potential transfer energy

According to the calculation results of the formula (1), the curve of the transfer energy against the transfer energy can be calculated by the values of the C_{12} and the U_{12} in different transfer distances. The curve is shown in the Fig.7.

The Fig.7 shows that the transfer energy increases with the increase of the transfer distance. The calculated result of the transfer energy in the paper exceeds the pain energy threshold of the worker's physiological reaction to transient electric shock. Besides, the research results in relevant literature show that when the energy of the discharge system is about 1.37J, the root of the arc would act

directly on the conductive gloves and the conductive gloves would be ablated[10]. The results of this paper show that, during the live working on $\pm 800\text{kV}$ DC transmission lines, the potential transfer energy is 1.0J when the transfer distance is 0.5m and the potential transfer energy is 1.16J when the transfer distance is 0.7m. Therefore the potential rod should be used to ensure the worker's security during the equal-potential process.

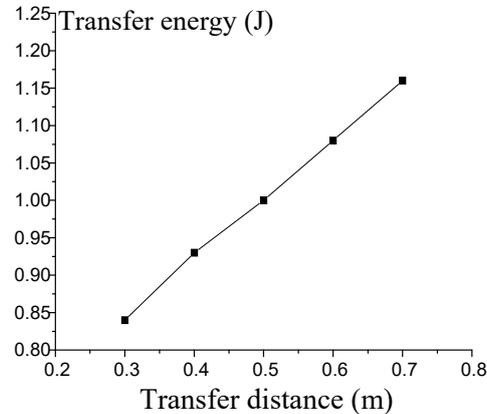


Figure 7. The potential transfer energy under different transfer distances

6. Conclusion

The potential transfer energy increases with the increase of transfer distance. And the potential transfer energy reaches to 1.0J when the transfer distance is 0.5m, therefore, the potential transfer rod should be used in the process of potential transferring on the $\pm 800\text{kV}$ DC transmission lines.

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