Research on electric field distribution of UHVDC transmission lines and body surface during live working

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Abstract. Electric field distortion emerges around personnel working on live Ultra High Voltage Direct Current UHVDC transmission lines, especially when they move from ground-potential to equipotential positions. Unreliable protection threatens the safety of both workers and transmission lines. The current study investigates the electric field distribution of body surface during live working under transmission lines. To provide safety advice, live working person and tower models were established. The body surface field was calculated in different positions under ±800 kV transmission lines, and the distribution of the electric field was summarized.

1 Introduction

Live working consists of testing, maintaining, and component exchanging of electric applications under working conditions[1]. Furthermore, it facilitates economic improvement and is one of the most important methods for maintaining transmission lines while they are active and the workers’ safety is ensured[2]. Compared to 1000 kV AC projects, the ion flow around the ±800 kV DC transmission lines complicates the electromagnetic environment because it contributes to electric field distortion, which is a major concern in live working. When a human wearing a shielding material is within the electric field, inductive charges emerge from the body surface influencing it[3]. If there is any protruding point from the body, the distortion multiplies the original energy conduction to 10 times. This condition may result in partial discharge when the value of the electric field reaches breakdown limits[4]. The current paper established the live working person and tower models and analyzed the body surface field at different representative positions under ±800 kV transmission lines. The analysis contributes to the standard method of operation during live working and to the safety of the workers.

2 Model analysis of live working

Equipotential operation is a representative method of live working when the potential of workers and transmission lines is equal. The electric field changes drastically when workers move between the zero potential and equipotential positions[5]. The two typical means to enter equipotential are climbing the tower to the same height of the constructor and then moving horizontally to the lines and climbing to the top the tower and then dropping vertically to the constructor. The current thesis analyzes the two methods in the electric field distribution.
2.1 Tower model
The plane built by the constructor, as well as the tower and the pole arm are chosen to analyze the electric field distribution because this plane has the thinnest air isolation. The typical tower used in an ±800 kV DC transmission system is shown in Figure 1. The height of the constructor is 33 m, the distance between the constructor and the tower is 11 m, the height of the tower is 44 m and its length is 4 m, the distance between the constructor and the pole arm is 10 m, the height of the pole arm is 2 m and its length on one side is 22 m.

2.2 Human body model
The human body is extremely complex that it is nearly impossible to establish a model to show the entire structure of the body. With the ability to calculate and the demand of the research, the provisions for the model are as follows: (1) workers wearing shielding material can be treated as conductors; (2) a two-dimension model according to the outline of the human body is established; (3) the protruding position of the body is considered while other body changes are ignored. The model of human body is shown in Figure 2 according to the data of GB10000-88. Some necessary amendments were made when workers wore the shielding material.

2.3 Typical live working positions
The calculating area of the electric field during live working is shown in Figure 3.
Positions ①, ②, and ③ represent the typical positions of the vertical route from the pole arm to the conductor. Positions ④, ⑤, and ⑥ represent the typical positions of the horizontal route from the tower to the conductor. Only the left area is considered because the tower is symmetrical. Positions ① and ④ specifically represent the position of ground-potential, positions ② and ⑤ represent the position of middle-position, and positions ③ and ⑥ represent the position of equipotential.

3 Electric field distribution analysis of typical live working positions

3.1 Analysis of ground-potential positions

When workers are at the ground-potential positions, positions ① and ④ should be considered. The distributions of the potential and electric field of position ① are shown in Figure 4, whereas the distributions of the potential and electric field of position ④ are shown in Figure 5.
For position ①, the potential distribution when workers are at the pole arm is shown in Figure 4(a), the partial distribution of the potential of the workers and the conductor is shown in Figure 4(b). Figures 4(a) and 4(b) illustrate that the potential near the wire changes distinctively. As the distance to the conductor increases, the potential declines and equipotential lines become sparse but gentle. Workers minimally influence the original potential when they simply leave the pole arm. The partial distribution of the electric field around the conductor and the workers is shown in Figure 4(c). The value of the electric field in the area near the workers is lower than the value near the conductor, and the distribution is homogeneous. This condition means that the workers have minimal distortive effects. Figure 4(d) shows the curve of the electric field changes at the dash line in Figure 4(c) along the y-axis. The value of the electric field reaches 2400 kV/m at the conductor and drops drastically along the y-axis. This value lessens significantly at the workers’ position. The maximum value at the feet of the workers is about 51.6 kV/m, which is 2.5 times the original value when the workers are absent.

![Figure 4(a)](image1)
![Figure 4(b)](image2)
![Figure 4(c)](image3)
![Figure 4(d)](image4)

Figure 5: The voltage distribution and electric field distribution in typical position ④

For position ④, the potential distribution when workers are at the tower is illustrated in Figure 5(a), whereas the partial distribution of the potential of the workers and the conductor is shown in Figure 5(b). The effect of workers located at the ground-potential and equipotential lines are gentle. Workers minimally influence the original potential. The partial distribution of the electric field around the conductor and the workers is shown in Figure 5(c). In the area near the workers, the electric field value is lower than that near the conductor, and the surface electric field of the workers have minimal distortive effects on the original field. Figure 5(d) shows the curve of the electric field changes at the dash line in Figure 5(c) along the x-axis. The value of the electric field reaches 2400 kV/m at the conductor and drops drastically along the x-axis. This value lessens at the workers’ position. The maximum value at the left side of the workers is about 38.8 kV/m which is 1.5 times the original value without the workers.

Comparing positions ① and④, workers minimally influence the original potential and electric fields both in the pole arm and tower. A human has a larger volume on the vertical than the horizontal direction; the surface value maximum of the electric field at position ① is larger than position ④, and position ① has a higher distortion factor as well.
3.2 Analysis of middle-potential positions

When workers are at the middle-potential positions, positions ② and ⑤ should be considered. The distributions of the potential and electric field of position ② are shown in Figure 6, whereas the distributions of the potential and electric field of position ⑤ are shown in Figure 7.

![Figure 6: The voltage and electric field distribution in typical position ②](image)

For position ②, the potential distribution when workers are 3 m from the wire is shown in Figure 6(a). The partial distribution of the potential of the workers and the conductor is shown in Figure 6(b). Equipotential lines are distributed intensively near the workers who, to some extent, influenced the surrounding potential. The partial distribution of the electric field around the wire and the workers is shown in Figure 6(c). In this area, workers have some distortive effects on the surrounding electric field. Figure 6(d) shows the curve of the electric field changes at the dash line in Figure 6(c) along the y-axis at x = -11. The electric fields of the foot and head are distorted, and the electric field value is large because the shielding clothing has a shielding effect on the human body and the middle electric field is zero. The maximum value of the electric field on the surface of workers is 120.0 kV/m in the head, which is about 3.5 times the original value when workers are absent; this is followed by the soles 95.5 kV/m which is about 2 times of the original value.
Figure 7: The voltage and electric field distribution in typical position ⑤

For position ⑤, the potential distributions when workers horizontally approaches the wire and when they are 3 m from the wire are shown in Figure 7(a), the partial distribution of the potential of the workers and the wire is shown in Figure 7(b). Figures 7(a) and 7(b) indicate that the effect workers have on the potential distribution at position ⑤ is bigger than those at positions ① and ④, but smaller than those at position ②. The partial distribution of the electric field when workers are 3 m to the left side of the wire is shown in Figure 7(c). Figure 7(c) presents that workers have some distortive effect on the surrounding electric field. Figure 7(d) shows the curve of the electric field changes at the dash line in Figure 7(c) along the x-axis. The maximum value of the electric field is at the wire, but a distinct distortion around the workers is evident. The maximum value of the electric field on the surface of the workers is 112.1 kV / m, which is about 2.3 times of the original value without the workers.

Comparing positions ② and ⑤, the workers indicated some distortive influence on the original potential and electric field when they approach the wire; furthermore, the closer they get, the more distinctive the effects become. This finding is similar to the conditions of ground-potential positions, the maximum surface value of the electric field at position ② is bigger than position ⑤, and position ② has a higher distortion factor as well. Workers should approach the wire from the horizontal route to avoid danger.

3.3 Analysis of equipotential positions

When workers are at the equipotential positions, positions ③ and ⑥ should be considered. The potential and electric field distributions of position ③ are shown in Figure 8, whereas the potential and electric field distributions of position ⑥ are shown in Figure 9.
For position ③, the potential distribution when workers step on the wire has the same potential as the wire as depicted in Figure 8(a). The partial distribution of the potential of the workers and the wire is shown in Figure 8(b). No potential difference and equipotential lines between the wire and the workers is found because workers achieved the same potential as the conductor. Equipotential lines are distributed symmetrically. The partial distribution of the electric field around the wire is shown in Figure 8(c). Figure 8(c) presents that the electric field between the operator and the wire is substantially zero. The electric field beneath the wire and the electric field at the top of the operator's head are large. Figure 8(d) shows the curve of the electric field changes at the dash line in Figure 8(c) along the y-axis. The maximum value of the electric field at 12.3 kV/m is at the wire, and it is smaller than the conditions when operators are at the ground- and middle-potential positions. The equipotential of the human and conductor is equivalent to increasing the equivalent radius of the conductor. As the y value increases, the electric field value becomes zero at the middle position between the human body and the conductor, and the electric field value reaches a maximum value of 701.7 kV/m at the head of operator, which is about 8 times the original value without the presence of workers that results in serious distortion. The electric field values on the left and right sides are 292.1 kV/m, indicating a certain degree of distortion. Furthermore, the electric field value decreases as y value increases.

For position ⑥, the potential distribution when workers horizontally reach the wire is shown in Figure 9(a). The partial distribution of the potential of the workers and the wire is shown in Figure 9(b). The operator and the wire reach the same potential at 800 kV. Figures 9(a) and 9(b) indicate that...
when the operator reaches the equipotential, the potential distribution is similar to the potential distribution at position ③, which distributes along the common external surface of the human body and the wire. The partial distribution of the electric field when workers are 3 m to the left side of the wire is illustrated in Figure 9(c). From Figure 9(c), the electric field value at the head of the operator is the largest, followed by the soles of the feet. In contrast, the electric field is small at the left side of the human body, with the shielding effect of the shielding material, owing to the equipotential with the wire, whereas the neck electric field values are relatively small. Figure 9(d) shows the curve of the electric field changes at the dash line in Figure 9(c) along the x-axis. The maximum electric field at about 603.4 kV/m is in the wire. As the distance to the wire increases, the electric field value decreases.

Given that the electric field value of human body is larger in the head and foot, further analysis is conducted for these two conditions. The electric field value at 632.3 kV/m at the head of operator is about 4 times of the original value without the workers. The increase from 149.9 to 519.7 kV/m, which is about 3.5 times, has serious distortions emerging from the feet of the operators as well. In summary, when the operator is standing on the side of the wire, serious distortion at the surrounding electric field is caused by the operator, especially at the human head; however this value is still less than the head value of position ③.

Comparing positions ③ and ⑥, workers indicated severe distortive influence on the original potential and electric field when they step on the wire. The maximum electric field is always near the head of the human body during equipotential live working. Therefore, special attention should be given to head protection.

3.4 Electric field distribution in the equipotential operation when workers are expanding arms

Workers have a certain range of actions during live working, and the greatest impact is stressed on the surrounding electric field when they expand their arms. The distribution of the surrounding electric field when operators expand their arms is shown in Figure 10(a), and the curve of the electric field changes at the dash line in Figure 10(a) along the x-axis is shown in Figure 10(b).

![Figure 10: The electric field distribution of expanding-arm model in equipotential position](image)

When operators expand their arms, the maximum electric field value at 1150 kV/m is at the wire, whereas the value is relatively large at the head as the arms are far from the wire and the feet of the body. The electric field value with arms far from the wire is 632.3 kV/m, which is nearly 6 times the original value of 110.7 kV/m. Distortion emerges at the head and feet. The electric field values increase from 109.9 and 192.9 kV/m to 519.7 and 581.2 kV/m, respectively 5 and 3 times the original values. In summary, operators should reduce the range of motions during live working to avoid severe distortions.

3.5 Electric field distribution when workers moves between the middle-potential to the equipotential positions

When workers approach the equipotential position from the middle-potential position, the distortion caused by the human body strengthens the average value of the electric field. The air gap when the field strength achieved a certain breakdown value caters to discharges. The potential distribution when
workers are 0.3 m from the wire is shown in Figure 11(a), whereas the curve of the electric field at the
dash line in Figure 11(a) along the x-axis is shown in Figure 11(b).

![Figure 11](image)

**Figure 11**: The electric field distribution from middle to equal potential position

Figure 11(a) shows that when the operator are 0.3 m from the wire, the electric field strength
between the wire and the human body is extremely high and that the maximum value is 3504 kV/m,
which reaches the air breakdown strength so that the air gap between the body and the wire will
discharge, forming a stable arc. Through the arc channel, the charges on the wire and the operator are
neutralized quickly in a very short period to form a larger current. The voltage between the operator
and the conductor decreases rapidly. When the voltage drops to a certain level, the arc channel is
blocked and the pulse discharge is terminated. Afterwards, the impedance between the wires and the
operator are gradually restored before a higher electric field reappears in the air gap. When electric
field strength increases to a certain extent, the operator and the air gap between the wires will break
down and a new process of discharging emerges. Thus, when workers approach the wire, the pulse
discharge will continue to appear until the operator contacts the wire. In this process, the discharge arc
will impact the human face, and it will continue to produce pulse currents, which may damage the
shielding service and affect the lives of workers. The transfer process should be rapid, and an electric
potential bar for potential transfer should be used when moving.

4 Conclusions
Six typical positions during live working and two special working conditions were analyzed.
Simplified operator and tower models were established. In live working of ±800 kV, the electric field
of the workers in different typical working positions and special cases were calculated and their
potential and electric field distribution were obtained. The conclusions are as follows:

1. When workers are in the ground-potential operating position, the surface field strength is
   relatively small, whereas the maximum at 51.6 kV/m emerges on the feet of the human body when
   workers are in the pole arm.

2. As the distance from the conductor decreases, the electric field of the body surface gradually
   increases and reaches the maximum value when workers get to the equipotential positions.

3. The electric field distortion in the vicinity of the conductor in the longitudinal direction is more
   serious than that in the vicinity of the conductor in the transverse direction, which is determined by the
   human body model.

4. During the equipotential operation, a strong distortion of electric field emerges on the head of
   the operator, and the maximum reaches 701.7 kV/m. Therefore, attention should be given to protecting
   the heads of workers.

5. When moving from the middle-potential to equipotential positions, discharge occurs in the gap
   between the wire and the operator; this is accompanied with discharge arc and intermittent impact
   current that affect the lives of workers. Therefore, the action of the operators should be rapid when
   moving, and the potential transfer rods should be used to attach the wire so that a greater distance can
   be maintained between the body and the wire decreasing the induced charge and the intermediate
   current. Finally, the equipotential influence of instantaneous impulse current on human body can be
   avoided.
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