Possible Methods for Limiting Exposure to the Electric Fields of High Voltage Power Lines on Active Implantable Medical Devices in the Human Body

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Abstract— The aim of the study is to consider the effect of additional shielding objects (with and without voltage) to reduce the electric field intensity under high voltage power lines. Results from electric field calculations generated by a 400 kV power line with a horizontal phase arrangement, additional shielding wires, and a row of trees are presented. It is concluded that plantings near the power lines can be used as a means of limiting exposure to electric fields on active implantable medical devices in the human body.

1. INTRODUCTION

According to earlier studies [1, 2], the electric fields (EFs) under a 400 kV power line (PL) in some conditions may disturb active implantable medical devices (cardiac pacemakers, implantable cardioverter defibrillator, and others) in the human body and affect their functioning. Therefore, it is reasonable to consider possible ways to limit the impact of EFs, generated by PLs, on medical devices.

One of the known methods of limiting EF intensity under PLs without changing the design of lines is to plant trees and shrubs under the power lines. The second simplest method of limiting the field intensity of PLs is to install grounded wires (shields) under lines' wires. It is economically feasible to connect shields under the line wires to a voltage source and thus ensure effective utilization of the cross section. In all these cases, the induced charges on grounded wires partially compensate for the EF produced by line wires and restrain the field intensity.

The aim of the study is to examine the shielding effect of additional objects (with and without voltage) to reduce the EF intensity under high voltage PLs as well as estimate the shielding effectiveness and the possibility of its application.

2. MATERIALS AND METHODS

The field intensity under power lines at the height h above the ground level in cases with shield wires (Figure 1) can be calculated utilizing a two-dimension formula similar to [3], but taking into account the presence of shields. The charges on shield and line conductors are determined by solving the system of Maxwell's potential equations, where voltages on grounded shields (passive

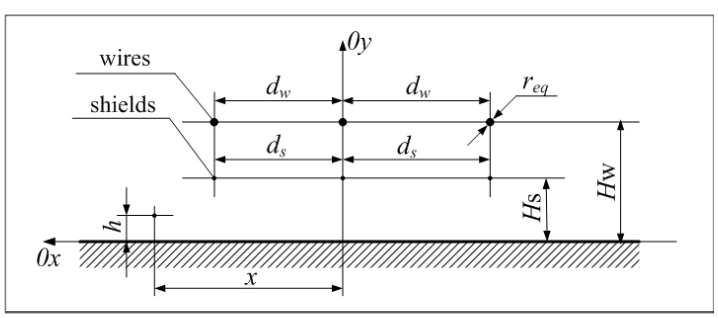

Figure 1: Scheme of PL wires and shield locations (H_w is the suspension height of the wires; H_s is the suspension height of the shields; d_w is the distance between the wires; d_s is the distance between the shields; r_{eq} is the equivalent radius of the wires; and x is the distance from the observation point).

shielding) are equaled to 0 or have the opposite sign to the voltages on the corresponding line wires (active shielding).

In cases with tree and shrub plantings, EFs can be calculated using the method above, assuming a row of trees or shrubs to be conductive cylinders with zero voltage. The geometrical parameters of these cylinders (the radius r and the height of the center of the cylinder above the ground surface H_{tr}) are approximately defined from equality of perimeters for the cross-section of the crown and cylinder.

3. RESULTS AND DISCUSSION

To consider the shielding effect of additional objects, a 400 kV PL with horizontal phase wires was chosen. The phase parameters were $a = 45$ cm, $n = 3$, $r_0 = 0.0165$ m, and $r_{eq} = 0.149$ m. The distance between the wires was 9 m. The distance from the wires to the ground was equal to 10 m. The height of the observation point above the ground surface was 1.8 m.

Table 1 presents the results of the EF calculations, generated by a PL of 400 kV, under grounded shield wires of different suspension heights.

It is seen from Figure 1 and Table 1 that the charges on grounded wires are induced, and the sign of these charges has the opposite sign to the charge on the corresponding wire. Therefore, the field intensity under the PL is reduced. Under an increase of suspension height of the shield wires, located under the PL, maximum values of the EFs in proximity to the PL decrease, but at the same time, the field values far from the system of wires remain almost unchanged in magnitude.

Table 2 shows the results of the EF calculations generated by a PL of 400 kV and shield wires with different voltage values U_s based on the phase voltage of the PL U_{PL}.

In the case of active shielding, as with the grounded wires, the charge on the lower wire has the opposite sign to the charge on the corresponding wire. However, the presence of potential on the lower shield wire increases the charge and, consequently, the shielding effect.

As it is seen from Table 2, when we increase voltages on shield wires, maximum EF intensity in proximity to the PL is decreased until it reaches a critical value. This value for the considered PL with horizontal phase wires is $0.25U_{PL}$. After this value, EF intensity begins to increase. It is

Table 1: EF intensity distribution under 400 kV PL and three passive shields with different H_s and d_s = 9 m.

Parameters of shields	Maximum EF intensity	EF intensity at distance 20 m from middle wire	EF intensity at distance 30 m from middle wire
without shields	7.51	3.31	1.16
$H_s = 2.5$ m	6.12	3.19	1.13
$H_s = 3$ m	5.91	3.16	1.13
$H_s = 4$ m	5.64	3.09	1.11
$H_s = 5$ m	5.48	3.02	1.09
$H_s = 6$ m	5.42	2.94	1.07

Table 2: EF intensity distribution under 400 kV PL and three active shields with $H_s = 4$ m, $d_s = 9$ m under different voltage U_s.

Parameters of shields	Maximum EF intensity	EF intensity at distance 20 m from middle wire	EF intensity at distance 30 m from middle wire
without shields	7.51	3.31	1.16
$U_s = 0$	5.64	3.09	1.11
$U_s = 0.1\ U_{PL}$	4.87	2.95	1.08
$U_s = 0.15\ U_{PL}$	4.55	2.88	1.06
$U_s = 0.2\ U_{PL}$	4.26	2.80	1.05
$U_s = 0.25\ U_{PL}$	4.00	2.73	1.03
$U_s = 0.3\ U_{PL}$	4.46	2.66	1.01
$U_s = 0.35\ U_{PL}$	5.61	2.59	1.00
$U_s = 0.4\ U_{PL}$	6.78	2.51	0.98

most likely caused by prevalence of the field produced by the shields over the field generated by the PL wires. The behavior of the field values far from the PL are the same for all voltages, i.e., under an increase of shield voltages, the EF intensity decreases.

Furthermore, calculations show that the most shielding effect for the investigated PL is obtained under 25% from U_{PL} (i.e., under 38 kV of phase-to-earth or 66 kV of phase-to-phase voltages). The shielding efficiency for this voltage is 47%, significantly more than 25%, which is obtained in the case of the grounded shields.

Since the maximum field intensity values for the PL with horizontal phase wires are observed directly under the outside wires and EF under the middle conductor field is much smaller than under the outside wires (Figure 2), it is possible to achieve a more rational construction with using one or two grounded shields, placing them under the outside wires, instead of three.

Therefore, the results of the EF calculations, produced by a PL of 400 kV and one or two shield wires, are presented in Tables 3 and 4, respectively.

From Tables 3–4, the calculated EF values generated by the PL with one or two passive shields are almost the same as in Table 1 for the case of three shield wires. Further, a shield wire decreases EF intensity in its vicinity, but EF far from it is quite similar. Therefore, if it is necessary to reduce EF under PLs as well as near an object to be protected, an additional shield can be arranged near

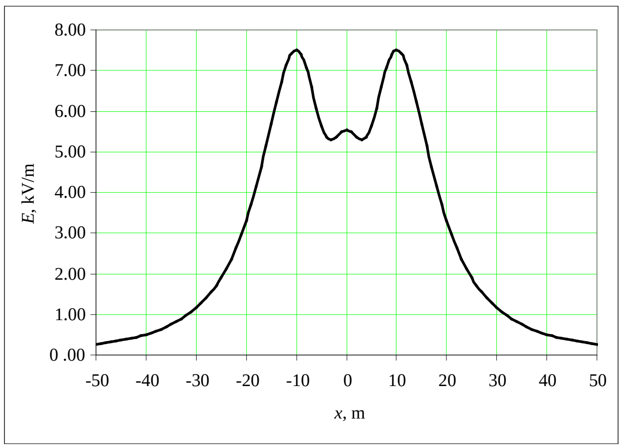

Figure 2: EF distribution under 400 kV PL without additional shielding objects.

Table 3: EF intensity distribution under 400 kV PL and one passive shield, located under an outside wire, with different H_s and d_s.

Parameters of shield	Maximum EF intensity (from shield's side)	EF intensity at distance 20 m from middle wire	EF intensity at distance 30 m from middle wire
without shields	7.51	3.31	1.16
$H_s = 4$ m; $d_s = 9$ m	5.70	3.10	1.11
$H_s = 4$ m; $d_s = 12$ m	6.06	2.88	1.07
$H_s = 4$ m; $d_s = 18$ m	7.30	2.02	1.02
$H_s = 4$ m; $d_s = 30$ m	7.50	3.26	0.59

Table 4: EF intensity distribution under 400 kV PL and two passive shields, located under the outside wires, with different H_s and d_s.

Parameters of shields	Maximum EF intensity	EF intensity at distance 30 m from middle wire	EF intensity at distance 30 m from middle wire
without shields	7.51	3.31	1.16
$H_s = 4$ m; $d_s = 9$ m	5.65	3.09	1.11
$H_s = 4$ m; $d_s = 12$ m	6.04	2.87	1.07
$H_s = 4$ m; $d_s = 18$ m	7.30	2.00	1.02
$H_s = 4$ m; $d_s = 30$ m	7.50	3.26	0.58

Table 5: EF intensity distribution under 400 kV PL and one row of trees located under an outside wire, with $H_{tr} = 4$ m, $r_{tr} = 1$ m and different d_{tr}.

Parameters of cylinder, representing a row of trees	Maximum EF intensity	EF intensity at distance 20 m from middle wire	EF intensity at distance 30 m from middle wire
without shields	7.51	3.31	1.16
$d_{tr} = 9$ m	5.61	2.64	1.00
$d_{tr} = 12$ m	5.58	1.97	0.89
$d_{tr} = 18$ m	6.91	1.08	0.74
$d_{tr} = 30$ m	7.51	3.31	0.64

this object.

In general, the presence of additional wires leads to an appreciable increase in the cost of a PL. Maintenance of double-circuit PL with different systems of voltages facilitates operational difficulties caused by the mutual electromagnetic influence between the circuits and a significant change in the parameters of both circuits in comparison with a single-circuit PL, especially for the lower circuit. Therefore, limiting EF intensity under PLs without changing the design of lines can be achieved by using trees and shrubs, which have a height of 4–5 m and relatively high conductivity during the whole year [4].

Table 5 shows the results of the EF calculations generated by a PL of 400 kV with a row of trees planted under an outside wire.

It is gathered from Table 5 that a row of trees, similar to the grounded wire, reduces EF intensity under the PL. EF distribution has more complex behavior than the case with the single grounded shield due to a larger radius and induced charge. For example, EF intensity close to a place where a row of trees is located jumps in magnitude. Moreover, it is obtained that the shielding effect at a distance from this place (at distances 20 and 30 m for $d_{tr} = 9$, 12 and 18 m) is greater than that achieved by the grounded shield.

4. CONCLUSION

Based on the received results, it can concluded that installing additional grounded or energized wires and planting trees and shrubs generally reduce EF intensity under PLs significantly by using a number of objects or rows. On the contrary, the possibility of a practical application of the considered additional wires is not always economically feasible because it leads to an increase in cost or maintenance problems. Therefore, it is better to use trees and shrubs for the purpose of limiting EFs. In the presence of planting areas with a height of 4–5 m under PLs, the electromagnetic environment, including the safety of people with active implantable medical devices, can be improved.

In the future, to obtain more realistic results, it is necessary to conduct experimental studies and develop a detailed model of tree and shrubs plantings (with seasonal changes) based on numerical methods as a means of limiting EFs in proximity to PLs.

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