INFLUENCE OF GEOMETRIC PARAMETERS ON THE CORONA LOSS OF 220 AND 400 KV OVERHEAD TRANSMISSION LINES

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Due to the rapid increase of system voltages, the problem of corona phenomenon on high voltage overhead power transmission lines came more and more into prominence. Power and energy loss, respectively, due to corona is an undesirable effect, so keeping this loss on a low value is a substantial point of view in transmission line design. The mean annual value of corona loss on appropriately dimensioned overhead transmission lines must not exceed 10% of the total power loss of the line; is the line inadequately dimensioned, then its corona loss can be compared with its power loss. Besides, suitably dimensioned transmission lines, too, have sometimes considerable corona, e.g. when during the peak period of the network system a temporarily appreciable loss occurs due to unfavourable weather conditions; in such cases restrictions of the consumption, too, can be necessary. Appropriate dimensioning of transmission lines is important also because of radio interference being incident to corona.

According to the evidence of practical experiences and engineering literature, corona is a rather complicated phenomenon. It has an acceptable qualitative explanation; its quantitative theoretical approach is, however, rather difficult, as its process is influenced by a number of factors, the presence of which is to be considered as stochastical. Some of these factors are known, others, very likely, for the time being unknown. Among the factors which affect corona the surface voltage gradient is foremost. This is influenced by many other factors, the most important of which are the voltage applied to the conductors, the geometric arrangement of the conductors and the smoothness of their outside surface. Considerable factors are furthermore weather conditions; finally the phenomenon is in a small degree influenced by the load current, too.

Prediction of corona loss

Because of the difficulties mentioned above, actual loss values are all over the world determined by means of measurements carried out on operating lines or on experimental lines. Nevertheless, there are several calculation methods described in the engineering literature for the quantitative approach of this phenomenon; but all these methods yield different results.

The Department of Electric Power Transmission and Distribution of Polytechnical University of Budapest has worked out a calculation method for lines with both single and bundle conductors based upon measurements and upon statistical evaluation of data obtained by meteorological observations; the results of calculations carried out with application of this method are in a good correspondence with those published in the engineering literature [1].

The method in question gives four different curves for four weather types (fine weather, rain, snow and sleet) as work-helps for calculating losses occurring in different weather conditions as well as average losses deriving from these; the curves represent values of corona loss (P) plotted against the actual voltage (U). In case of a particular transmission line type, loss can be expressed as an exponential function of the actual voltage; consequently, the relationship

$$\log \frac{P}{f U_0^2} = \varphi \left(\frac{U}{U_0} \right)$$

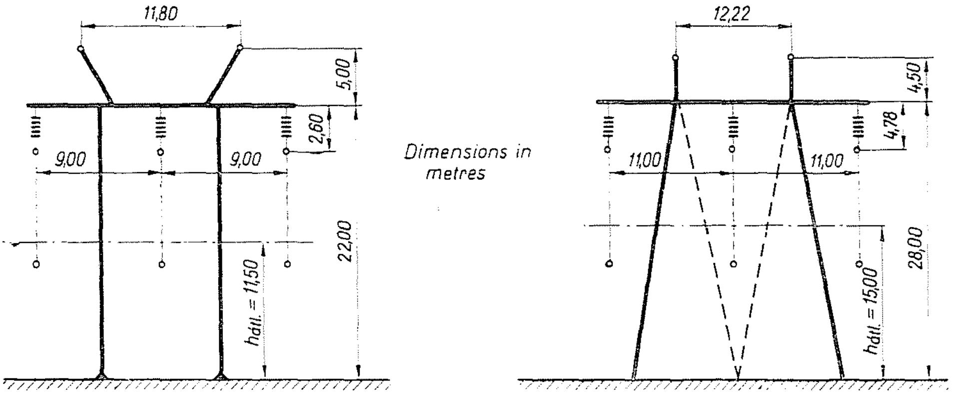
is assumed to be linear (U_0 is the critical voltage of corona, decisive for losses at a given transmission line type; f is the system frequency). The mean annual loss calculated from the average weather data of Hungary comes to a value which is 1.5 to 2 times so high as it is in fine weather. The present paper does not describe the method in details; it will be the subject of another paper which is to be published later.

Investigations on the influence of geometric parameters

In the following section the dependence of corona loss on geometric parameters of transmission lines is examined by means of the method mentioned above, keeping in view particularly transmission line design standpoints. Corona loss on extra high voltage transmission lines can not be neglected, consequently, it is important that the value of the corona loss of a line could be predicted and the alternatives which can be taken into consideration could be compared with respect to corona. Furthermore, it is desirable to know which parameters and in which sense should be varied in order to reduce corona loss.

In the present paper diagrams are published which make possible the prediction of corona loss on different 400 and 220 kv transmission lines. Geometric parameters of a line are, of course, chosen under simultaneous consideration of various viewpoints (both technical and economic, such as mechanical and electric strength, operation and short-circuit loads, losses, practicability, etc.). As already stated above, the present paper deals only with the problem of corona loss.

Several possibilities present themselves for comparing transmission lines of different geometric parameters with respect to corona loss. The most adequate comparisons seem to be those made under consideration of losses in fine weather. This latter is the most frequent of all weather types, as from the viewpoint of corona any weather when there is no rain, snow, fog or sleet is to be considered as fine weather. Consequently, this weather type can be defined most easily. Besides, another parameter which could come into consideration as a basis of comparison, namely the mean annual loss greatly depends upon weather conditions of the area in question; thus, losses in fine weather are more adequate for this purpose. On the other hand, foreign engineering literature, too, generally applies losses in fine weather as a basis of comparing different transmission lines.



Type Gödöllö suspension tower (220 kV)

$D_{átl.} = 11,34$ $3 \times (2 \times 185\ mm^2)$ Alac+ $2 \times 70\ mm^2$ A.C. III.

Stayed suspension tower for 400 kV (Munkács-Göd line)

$D_{átl.} = 13,86$ $3 \times (3 \times 400\ mm^2)$ Alac + $2 \times 70\ mm^2$ A.C. III.

Fig. 1

Furthermore, it proves useful to express losses in relative units, considering that our investigations are of general character. The transmission line Sajószöged—Zugló I has been chosen as a reference for 220 kv, and the transmission line Munkács—Göd, which is the only existing 400 kv line in Hungary, for 400 kv lines. Configurations of these lines are illustrated in Figs 1a and 1b,

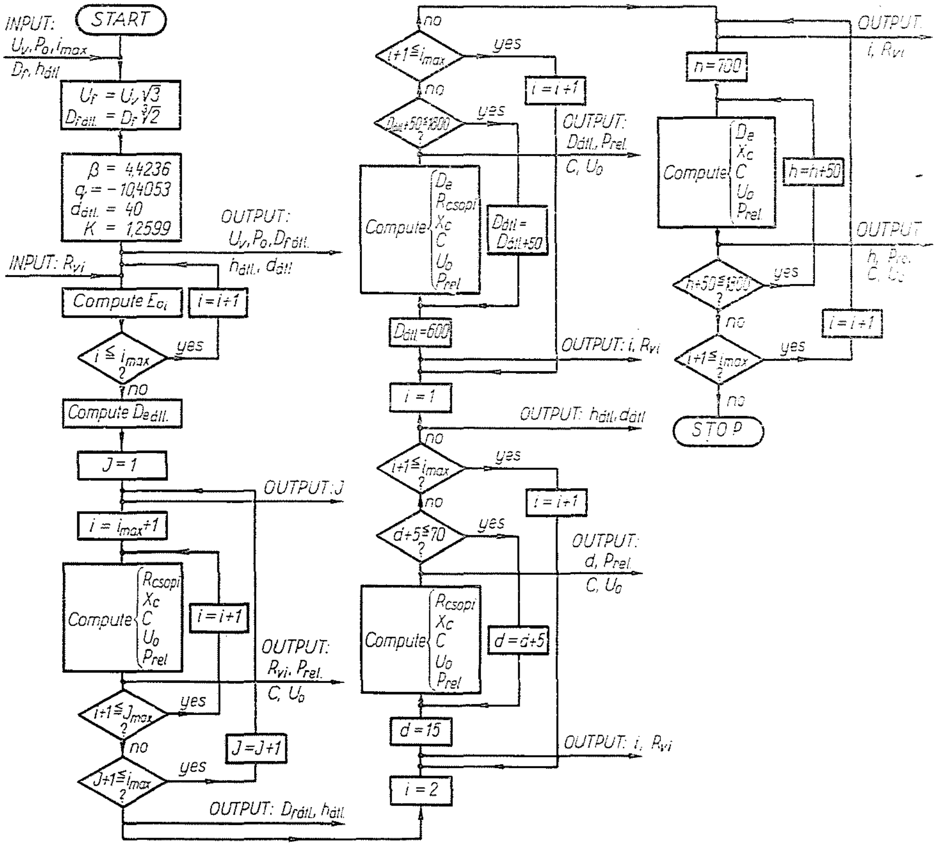


Fig. 2

showing also geometric dimensions. (The pictures are not true-to-scale!) Three-phase loss values per unit length have been determined by means of the method mentioned above, applying a computer programme. The three-phase reference values for fine weather and for rated voltage are the following:

$$P_{0\,400} = 0.466 \text{ kilowatts/kilometre},$$

$$P_{0\,220} = 0.090 \text{ kilowatts/kilometre}.$$

As stated above, variations of the relative values of losses in fine weather are examined in dependence on geometric parameters as listed below:

- average height of the conductors above ground (h);
- average distance between the phase conductors (D_{av});
- bundle spacing (d), supposing a symmetrical arrangement of the subconductors;

— number of subconductors of a bundle (n);

— radius of the conductors (r).

The calculations have been performed with a RAZDAN 3 type computer of VEIKI (Research Institute of the Electric Utility Industry) by means of a computer programme written in ALGOL. Fig. 2 illustrates the scheme of the calculations.

In the programme use has been made of the straight line representing the relationship

$$\log \frac{P}{fU_0^2} = \varphi \left(\frac{U}{U_0} \right)$$

mentioned earlier [3]; the slope of the line is $\beta = 4.42$ and it intersects the y-axis at $q = -10.40$. Thus, the relationship serving for determination of the relative value of loss is the following:

$$\frac{P}{P_0} = \frac{3}{P_0} f U_0^2 \exp \left(q + \beta \frac{U}{U_0} \right) .$$

The critical voltage U_0 has been calculated by means of the following relationship:

$$U_0 = \pi \sqrt{2}\, \varepsilon_0 \frac{rnmE_0(r)}{\left[1 + 2(n-1) \frac{r}{d} \sin \frac{\pi}{n} \right] C} \quad \text{line-to-ground kv,}$$

where, in addition to the notations given earlier:

$$E_0(r) = 24.5 \left(1 + \frac{0.613}{r^{0.4}} \right) \quad \text{peak kv/cm,}$$

r is the conductor radius in metres,

$m = 0.82$ is the relative smoothness factor of the surface of the stranded conductor (an average value with good approximation),

C is the positive-sequence capacitance per phase conductor, calculated as the average value of the three phase line, under consideration of the influence of ground, neglecting the presence of ground wires, in nanofarads/kilometre (this simplification is permissible, as the relative deviation from the capacitance determined correctly, by means of the method of potential coefficients, is less than 2%).

The results obtained are illustrated by diagrams in Figs 3 and 4, Fig. 3 contains curves regarding 220 kv, Fig. 4 those concerning 400 kv transmission lines. At the examination of the influence of the individual parameters on corona loss, all the other parameters have been chosen constant and identical with those of the reference line. Calculations have been performed for single conductor as well as for bundle conductors containing two, three and four subconductors, supposing that the total cross sectional area per phase is constant. This supposition is justified by the fact that a given power can be transmitted in several different ways, and it is desirable, however, to keep current density on a constant value determined by technical and economic viewpoints. In accordance with this requirement, the curves in Figs a, b and c concerning to 220 kv lines refer to cross sections of 1 ×350 mm^2, 2 ×185 mm^2 and 3 ×120 mm^2, that of 400 kv refer to cross sections of 1 ×800 mm^2, 2 ×600 mm^2, 3 ×400 mm^2 and 4 ×300 mm^2. The 1 ×800 mm^2 conductor does not meet this requirement, but larger sizes are nowhere produced; as for the total cross sectional area of 1200 mm^2, it is identical with the size of the only 400 kv transmission line in Hungary as well as of a number of 400 kv lines built with bundle conductors abroad, consequently it was desirable to keep to it. On the other hand, applying single conductors at 400 kv would be unfounded from all viewpoints; this curve has been presented only for good measure. Examination of a bundle conductor consisting of four subconductors at 220 kv has not been accomplished, as its practical implementation would not be reasonable from any point of view.

Analysis of the results obtained

As the diagrams show, increase of the number of subconductors in a bundle results in a rapid decrease of corona loss.

The curves in Figs 3a and 4a plotted against the average height of the conductors above ground (h) show that corona loss varies only slightly in the usual range of heights determined by different viewpoints, so it is to be considered practically constant. There is a similar situation concerning average distance between the phase conductors (D_{av}), illustrated in Figs 3b and 4b, this approximation seems to be coarser, the usual distances between phase conductors, however, vary in a narrower range. Consequently, the applicability of the following diagrams does not decrease to a considerable extent by adopting given values of the average distance between the phase conductors as well as of the average height of the conductors above ground, choosing both identical with corresponding dimensions of the reference lines.

Examining corona loss in the dependence of the bundle spacing (d), the curves in Figs 3c and 4c indicate in general minimum values. Loci of the minimum loss values vary with the voltage; at 400 kv it is at about 30 centimetres, at 220 kv, however, it is approximately at 20 centimetres. According to the present practice in Hungary the bundle spacing is identically 40 centimetres, i.e. it does not coincide exactly with the optimum value from the point of view of corona loss. In determining the bundle spacing, there are of course other viewpoints, too, playing important parts, such as mechanical forces created by short-circuit current flows, swinging of conductors together, the necessary number of spacers, etc., justifying the usual distance of 40 centimetres between the subconductors.

A distance of 20 centimetres between the subconductors would reduce corona loss at 220 kv by about 6%; turning to 30 centimetres at 400 kv would cause only about a 3% decrease of corona loss. On the other hand, mechanical forces loading spacers, created by short-circuit current flows would increase to a cca 3.5 times so high value at 220 kv [4], and they would be doubled at 400 kv, if such changes were made in the spacings. This would considerably influence spacer design, and it would increase investment costs. Consequently, subconductor spacing of 40 to 50 centimetres are generally applied all over the world.

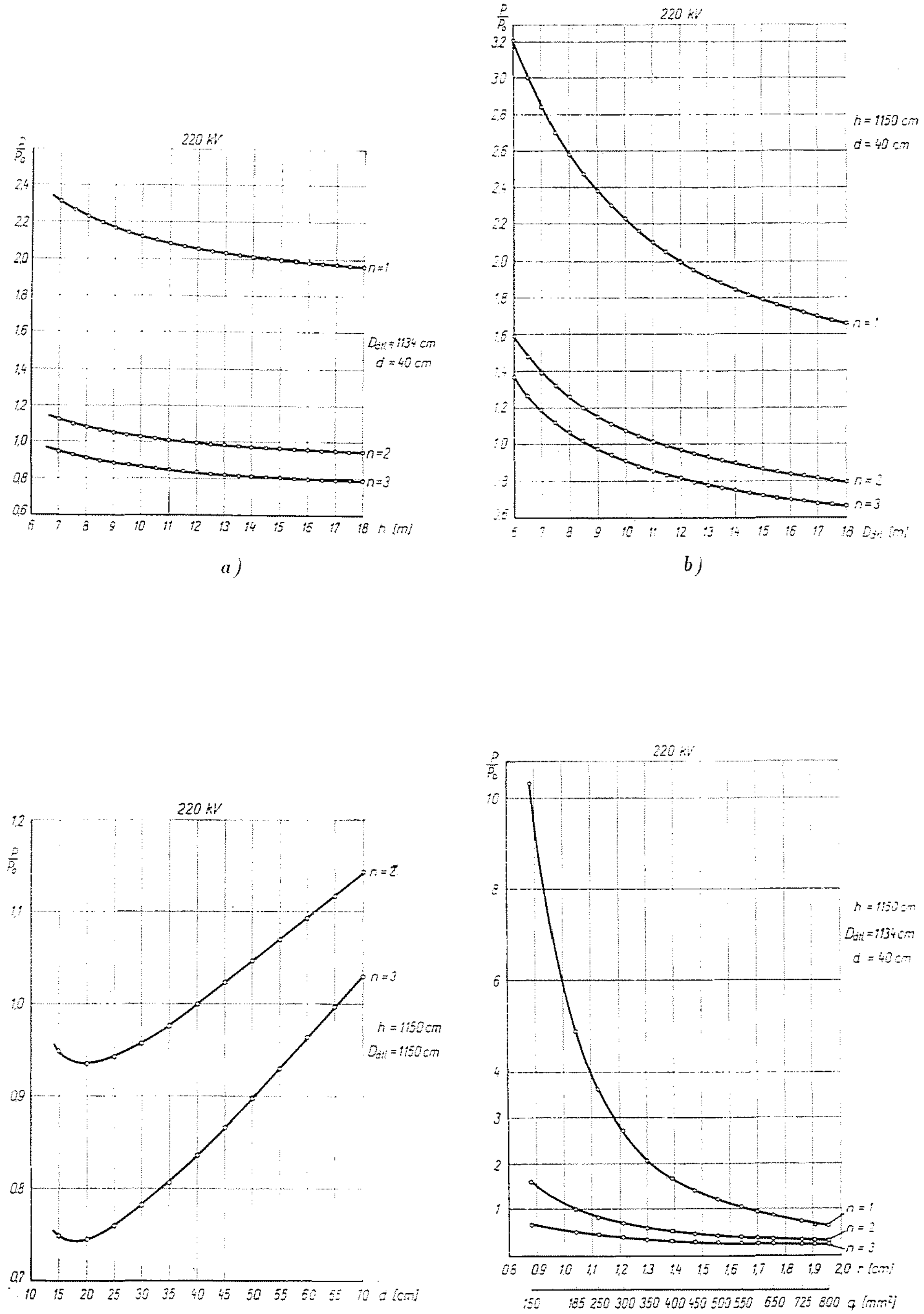
Conductor radius (r) is the geometric parameter influencing corona loss in the largest measure. The curves in Figs 3d and 4d refer to subconductor spacings of 40 centimetres and to D_{av} and h determined by dimensions of the reference lines, consequently they are suitable for predicting corona loss of any 220 and 400 kv transmission line, respectively, with a good approximation. Both sets of curves are to be applied with good success as work-helps for transmission line design as well as for economy calculations associated with it, as corona loss values at different subconductor numbers, at different conductor radii and at all conductor arrangements coming into consideration can be read simply, and the influence of occasional modifications on corona loss can be easily and clearly followed.

Let us consider e.g. the 220 kv transmission line Munkács—Sajószöged. Its relative corona loss in the present construction with 1×350 mm^2 conductors is 2.1; with 2×185 mm^2 bundle conductors having nearly the same total cross sectional area, it would decrease to 1. resulting in a more than 50% melioration regarding corona loss.

The 400 kv transmission line Munkács—Göd has been built with 3×400 mm^2 conductors. Its relative corona loss is equal to the unit. Should a similar 400 kv power transmission line be constructed with 2×500 mm^2 and 2×600 mm^2 bundles, respectively, then its relative loss would be 1.8 and 1.5, respectively; applying 4×300 mm^2 bundles, its relative loss would be as low as 0.15. Considering absolute loss values (0.466 kilowatts/kilometre at 3×400 mm^2), even 2×500 mm^2 and 2×600 mm^2 versions seem to be not too bad, as 1.5 and 1.8 times this value, respectively, is relatively low itself.

The really best version can be chosen only on the basis of circumstantial economic comparisons, with respect to the full service life and considering every viewpoint.

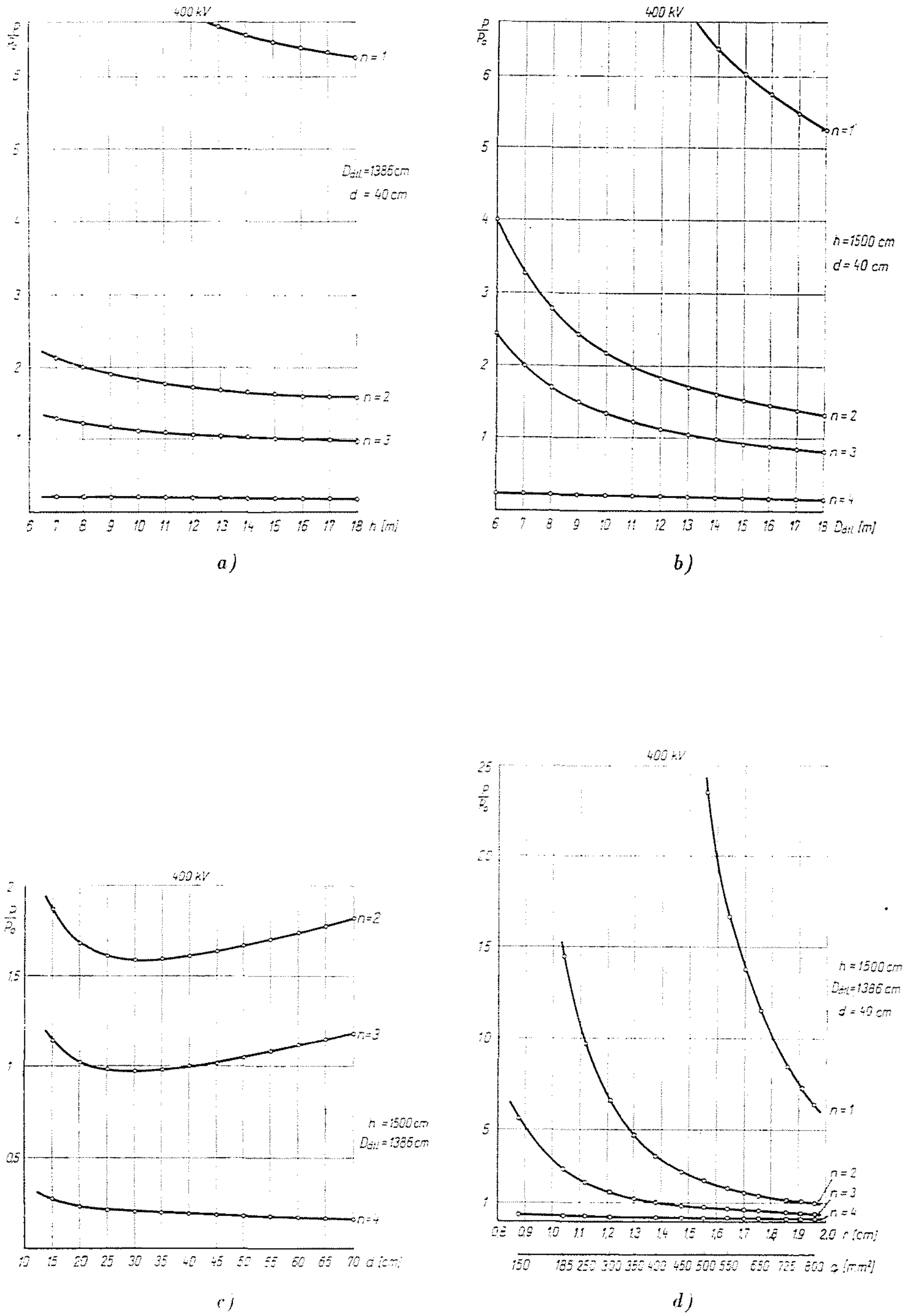
Optimization investigations carried out for a great number of transmission lines [5] show the following general regularities:


220 kV
$\frac{P}{P_0}$
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
n=1
n=2
n=3
$D_{átl}$ = 1134 cm
d = 40 cm
6 7 8 9 10 11 12 13 14 15 16 17 18 h [m]
220 kV
$\frac{P}{P_0}$
3,2
3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
h = 1150 cm
d = 40 cm
n = 1
n = 2
n = 3
6 7 8 9 10 11 12 13 14 15 16 17 18 $D_{átl}$ [m]
220 kV
$\frac{P}{P_0}$
1,2
1,1
1,0
0,9
0,8
0,7
n = 2
n = 3
h = 1150 cm
$D_{átl}$ = 1150 cm
10 15 20 25 30 35 40 45 50 55 60 65 70 d [cm]
220 kV
$\frac{P}{P_0}$
10
8
6
4
3
2
1
h = 1150 cm
$D_{átl}$ = 1134 cm
d = 40 cm
n = 1
n = 2
n = 3
0,6 0,9 1,0 1,1 1,2 1,3 1,4 1,5 1,6 1,7 1,8 1,9 2,0 r [cm]
150 185 250 300 350 400 450 500 550 650 725 800 q [mm²]

a) b)

c) d)

Fig. 3


400 kV
P/P_0
n = 1
n = 2
n = 3
D_all = 1386 cm
d = 40 cm
6 7 8 9 10 11 12 13 14 15 16 17 18 h [m]
400 kV
P/P_0
n = 1
n = 2
n = 3
n = 4
h = 1500 cm
d = 40 cm
6 7 8 9 10 11 12 13 14 15 16 17 18 D_all [m]
400 kV
P/P_0
n=2
n=3
n=4
h = 1500 cm
D_all = 1386 cm
10 15 20 25 30 35 40 45 50 55 60 65 70 d [cm]
400 kV
P/P_0
n = 1
n = 2
n = 3
n = 4
h = 1500 cm
D_all = 1386 cm
d = 40 cm
0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 r [cm]
150 185 250 300 350 400 450 500 550 650 725 800 q [mm²]

a) b)

c) d)

Fig. 4

1. The most favourable conductor arrangement depends to a great extent upon system parameters (operation parameters of the line as well as economic variables), consequently every case must be examined individually.

2. Optimum subconductor number increases with load increase related to the surge impedance loading of the transmission line.

The statements made above seem to be verified by the fact that there are transmission lines with bundle conductors in operation at 69 kv (in the USA) as well as lines with single conductors at 287 and 345 kv, respectively, (similarly in the USA). According to the practice in Europa, bundle conductors are applied at 220 kv and higher voltages, namely there are transmission lines in operation at 400 kv with bundle conductors consisting of 2 and 3 subconductors, respectively, in the transmission line system of France and Sweden, with 3 subconductors in the USSR and with 4 subconductors in Germany.

It is to be seen that the here published diagrams offer a good help for the designers and may give essential data for economic calculations.

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Summary

The present paper deals with the influence of geometric dimensions on corona loss, considering overhead transmission line design view-points. Diagrams are presented as a result of calculations performed by means of digital computers, demonstrating corona loss values plotted against geometric dimensions of single and bundle conductor lines, respectively.

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