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Optimalization of the overhead lines insulation system

***Abstract**. The optimalization of medium voltage overhead lines with covered conductors will be solved within this paper. The distribution of electric intensity around the tower of overhead lines will be specified by Finite Elements Method in the concrete. The mathematical modelling will be used as a support for design of new geometrical settlement of covered conductor in the towers. The mathematical program ANSYS will be used as an optimalization program in the concrete. The increasing of safety and reliability of medium voltage system is possible with using results from these mathematical simulations.*

***Streszczenie** Artykuł przedstawia rozwiązanie zadania optymalizacji linii napowietrznych średniego napięcia z przewodami izolowanymi. Do określenia rozkładu natężenia pola wokół słupów linii napowietrznych została użyta metoda elementów skończonych. Modelowanie matematyczne wykorzystano jako wsparcie dla zaprojektowania nowych geometrii rozmieszczenia przewodów. Do optymalizacji użyto matematycznego programu ANSYS. Wyniki przeprowadzonych symulacji pozwalają zwiększyć bezpieczeństwo i niezawodność linii SN. (**Optymalizacja linii napowietrznych z przewodami izolowanymi**).*

Keywords: ANSYS, electric field, overhead lines, medium voltage
Słowa kluczowe: ANSYS, pole elektryczne, linie napowietrzne, srednie napięcie

Introduction

The PAS-type system originated through a line construction in Finland in 1976. Such lines started to be built also in Sweden and Norway and gradually they arrived to other countries as well including the Czech Republic. The design of such lines do not differ anyhow from the overhead lines with bare conductors. A significant change is the XPE insulation of the PAS system which allows for shortening the distance among phases down to 1/3 the distance of the system with bare conductors.

Nowadays the programs such as ANSYS are increasingly used for physical fields simulation. Modelling physical fields brings a lot of precious information to the area of using insulated suspended conductors for overhead lines.

The paper discusses the electrostatic field for various geometric configuration of overhead line conductors. The calculation using the finite element method and subsequent graphical display of results provides the possibility to find the most suitable geometric configuration of overhead line conductors or propose some better configuration.

The ANSYS program solved both electric intensity and electric potential in the conductors surroundings. The values of electric intensity were calculated for time interval t = (0,001–0,02) s after 1 ms in operating state (U_f= 13kV). The paper also presents the calculations of the dependence on insulation thickness and the distance among individual conductors on the pole design.

This data can be also used for further optimization of both geometric layout of conductors at the poles and the production of overhead line conductors themselves. [8]

Description of the elements and their parameters necessary for calculation

Conductor SAX – W (PAS - W) 22 kV

An insulated conductor for overhead lines with the XPE insulation of the PAS system.

Table. 1. Mechanical properties of insulated conductors [1]

Nominal voltage (kV)	22
Nominal cross-section (mm^2)	70
Nominal insulation thickness (mm)	2,3
Minimum insulation thickness (mm)	1,98
Informative conductor diameter (mm)	14,7

Fig. 1. SAX-W 22 kV

Used geometric conductor layout at the consoles for the calculation in ANSYS program

For the calculation in the ANSYS program the values of the distance among phases were selected as per the following types of design:

1. Anchorage console 3x IZV with overhang to JB and DB pole (distance among phases 600 mm)
2. Corner running console 3x IZV to JB and DB pole (distance among phases 950 mm) see Fig. 2.
3. Vertical anchorage console 3x IZV to JB pole (distance among phases 500 mm)
4. Vertical anchorage console 6x IZV to DB pole (distance among phases 600 mm)
5. Horizontal console 6x IZV to DB pole (distance among phases 600 mm)

Explanation of abbreviations:
IZV – insulated line,
JB - concrete pole,
DB - double concrete pole,

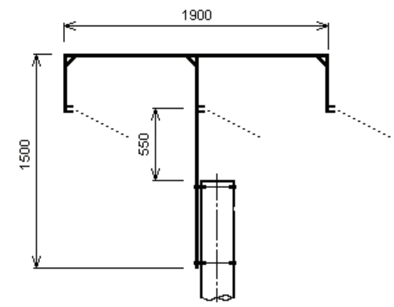

Fig. 2. Example of conductor layout at console No. 2

Solution in ANSYS program

Parameters needed for calculation

To do calculations in the ANSYS program, it is necessary to define the electric properties of individual used materials. Such properties are defined by means of permitivity whose values are shown is Table 2.

Table. 2. Material permitivity

Material	Permitivity (-)
Aluminium	10^6
XPE	2,4
Air	1
Ground	20

As it was a 2D calculation, the element PLANE 121 was used which is applied to the formulation of scalar electric potential and is generally used for 2D electrostatic and timely harmonic analyses of electric field and thus it is very appropriate for calculating the locations with a very high local value. [8]

The voltage value for the calculation will be U_f= 13 *kV* and the length of recording t=(0,001 – 0,02) *s*.

Calculations of the real conductor arrangement at the pole console

Here the electric fields are calculated at various pole types as they are used in practice. Fig. 3 shows an example of the intensity distribution around conductors fixed at the console No. 2 for voltage value U_f= 13 *kV*.

(1) $$U_f = \frac{U_S}{\sqrt{3}} \quad (V;V)$$

$$U_f = \frac{22000}{\sqrt{3}} = 12702 \ \ V = 13 \ \ kV$$

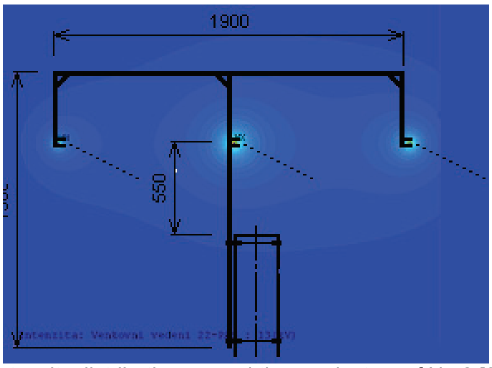

Fig. 3. Intensity distribution around the conductors of No.2 [8]

In the results Chart. 1 the courses of calculated values can be seen as the changes in electric intensity and electric potential depending on the distance from the conductor centre. The values are assessed within the distance of 59 *cm*.

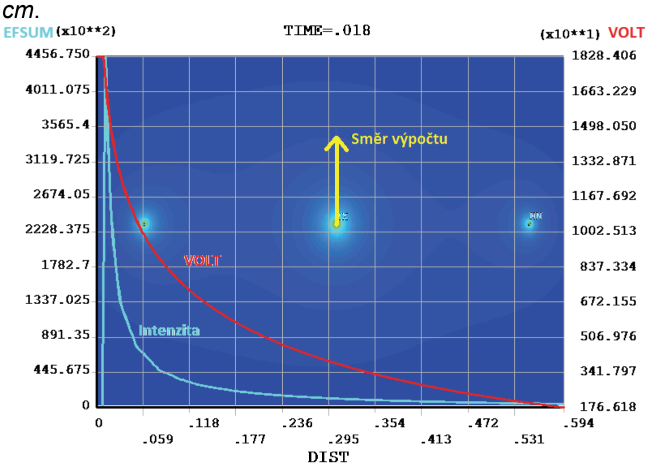

Chart. 1. Dependence of electric intensity and electric field depending on the distance from the conductor centre.

All calculated values of electric intensity (within time interval t= 0,001 – 0,02 *s*) for each conductor layout are shown at diagram see Chart 2. This diagram shows that the lowest values were for the console No. 2 where the maximum intensity value was E_{max}= 0,56 $kV.mm^{-1}$. The highest values of electric intensity were recorded for the console No. 3 where the maximum intensity values were around the value E_{max}= 0,64 $kV.mm^{-1}$.

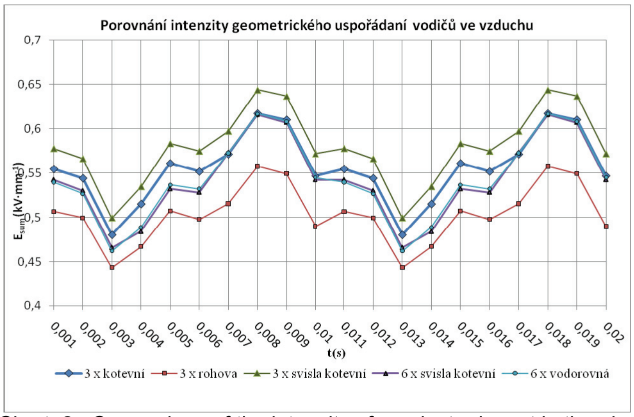

Chart. 2. Comparison of the intensity of conductor layout in the air [8]

As it can be seen from the diagram, the material used for insulation has very good insulation properties and that is why the intensity values are around neglectable values. For better orientation the results of maximum intensity values are shown in the diagram – seeChart 3.

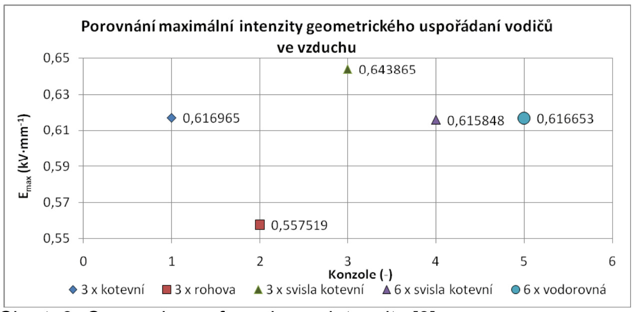

Chart. 3. Comparison of maximum intensity [8]

Calculation of electric intensity depending on conductor distances

This part of the paper shows the values of calculated electric intensity depending on the distance of conductors from each other. The first calculation is done for the distance of *l*= 0,01 *mm* among conductor insulations where the maximum intensity of electric field is E_{max}= 19,2 $kV{\cdot}mm^{-1}$ see. Fig. 4.

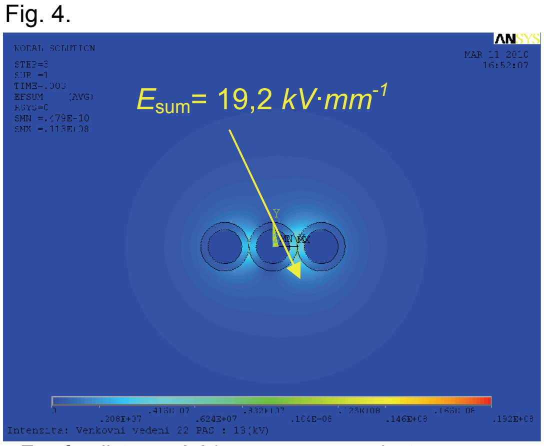

Fig. 4. E_{max} for distance 0,01 *mm* among conductors

Another calculations were made for distances 50, 100, 150, 200 *mm* among the centres of individual conductors. For distance l= 50 *mm* the value of maximum intensity was E_{max}= 1,52 $kV \cdot mm^{-1}$, for distance l= 100 *mm* it was E_{max}= 1,07 $kV \cdot mm^{-1}$, for distance l= 150 *mm* it was E_{max}= 0,9 $kV \cdot mm^{-1}$ and for distance l= 200 *mm* it was E_{max}= 0,82 $kV \cdot mm^{-1}$.

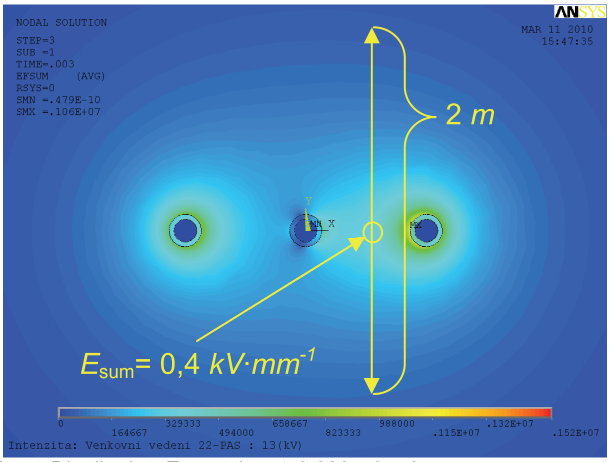

Fig. 5. Distribution E_{max} at time t=0,003s, l= 50 *mm*

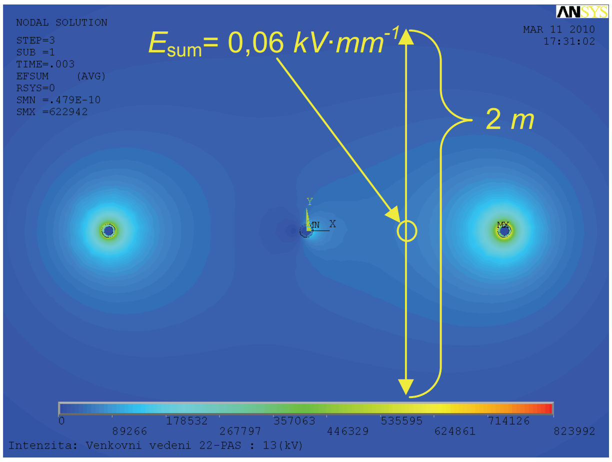

Fig. 6. Distribution E_{max} at time t=0,003s, l= 200 *mm*

In the diagram see. Chart 4 shows the values of calculated courses of electric field intensity for conductor distances 50 *mm* and 200 *mm*. The diagram values for both distances were read in the direction indicated by the yellow arrow at Fig. 5 andFig. 6.

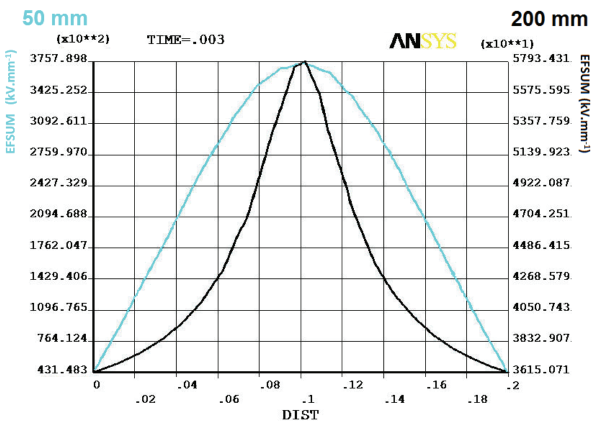

Chart. 4. Evaluation of the intensity among conductors in the distance 50 and 200 *mm*

Figures 5 and 6 show an example of electric field distribution in time t= 0,003 *s* for conductor distances 50 and 200 *mm*. According to the distribution of electric field colours at the figure the value of electric field intensity was read at the point that is in the centre among conductors marked with the yellow arrow. Especially the comparison of electric intensity depending on conductor distances needed to be made here. At Fig. 5 the intensity was E_{sum50}= 0,4 $kV \cdot mm^{-1}$ and at the figure Fig. 6 the intensity was E_{sum200}= 0,08 $kV \cdot mm^{-1}$.

The courses of intensity for all calculations are shown at the diagrams see Chart 5 and Chart 6.. For XPE insulation material the value of specific dielectric strength is presented approx. at 30 to 40 $kV \cdot mm^{-1}$. As it is apparent from the graphical display, the values of material dielectric strength are not exceeded even for the conductor distance of zero.

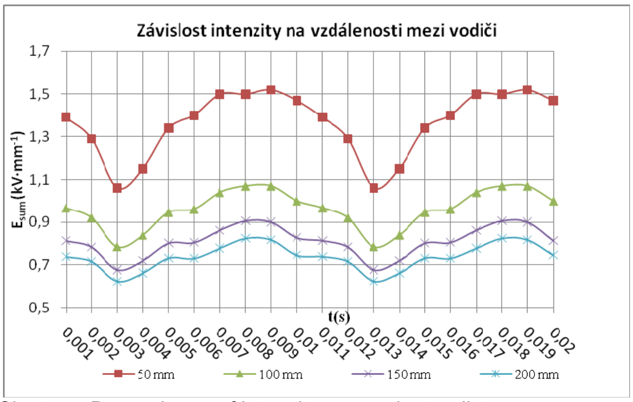

Chart. 5. Dependence of intensity on conductor distance

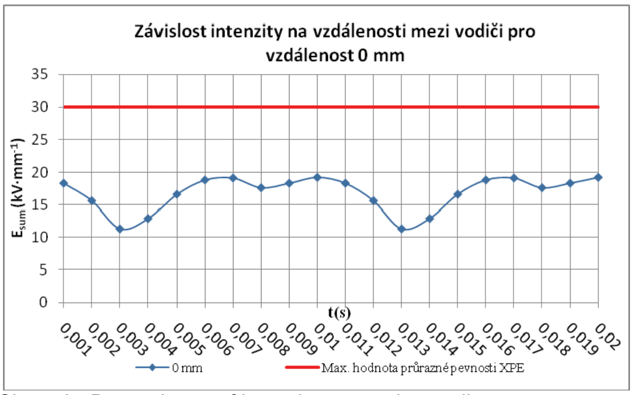

Chart. 6. Dependence of intensity on conductor distance

The review of maximum values of electric intensity are shown at Chart 7..

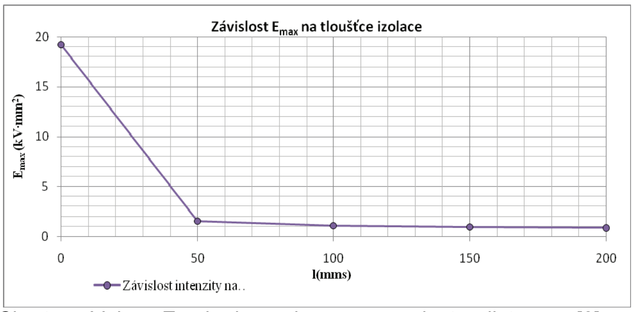

Chart. 7. Values E_{max} in dependence on conductor distances [8]

Calculation of electric intensity depending on the thickness of conductor insulation

Another task was to compare how the electric field changes in dependence on the thickness of conductor insulation In the calculation the insulated suspended conductor 22-PAS 70 mm^2 was used with the insulation thickness of 2 *mm*. Then the insulation thickness was increased by 0,5 *mm* to 2,5 *mm*. The calculation was made for mutually twisted conductors. So the calculation using ANSYS program was made for the triangle conductor layout.

The maximum value of electric intensity for insulation thickness 0,73 *mm* was E_{max}= 46 $kV{\cdot}mm^{-1}$, for 1,03 *mm* it was E_{max}= 36,2 $kV{\cdot}mm^{-1}$, for 1,23 *mm* it was E_{max}= 28,8 $kV{\cdot}mm^{-1}$, for 1,98 *mm* it was E_{max}= 24,6 $kV{\cdot}mm^{-1}$, for 2,23 *mm* it was E_{max}= 24,6 $kV{\cdot}mm^{-1}$ (see. Fig. 8) and for insulation thickness 2,48 *mm* the value of intensity was E_{max}= 15,5 $kV{\cdot}mm^{-1}$. Fig. 8 shows the field area of electric intensity A, which is also shown in the diagram, see Chart 8. As it can be seen from the diagram, also in this part of the field the decrease of electric intensity regarding the distance was smaller which also stems from the diagram itself.

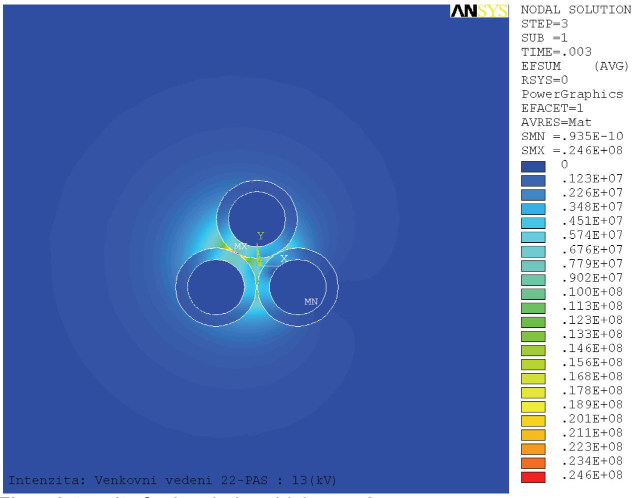

Fig.7. Intensity for insulation thickness 2 *mm*

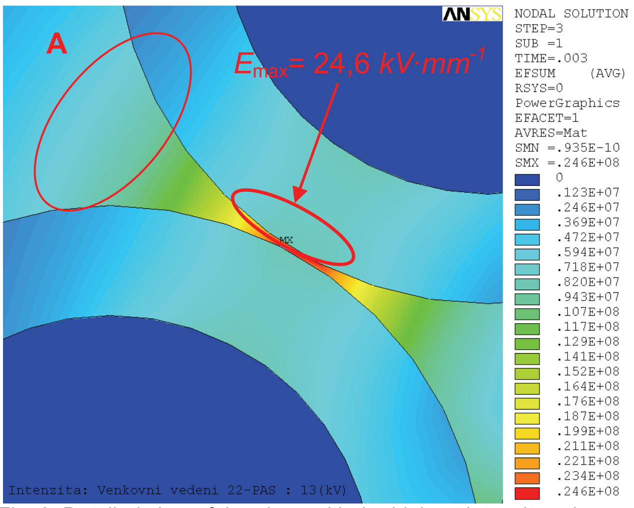

Fig. 8. Detailed view of the place with the highest intensity value

The dependence of electric intensity on insulation thickness in time interval t=(0,001–0,02)*s* is shown in the diagram, see Chart 9. The diagram clearly shows that for insulation thickness 1,23 *mm* the insulation still conforms to the maximum breakdown strength for the XPE insulation. When calculating for insulation thickness 1,03 *mm*, it can be seen that at this minimum difference the XPE insulation does not conform to required parameters anymore. From that it can be derived that even a small mechanical damage to insulation can have cause a defect of HV insulated overhead lines.

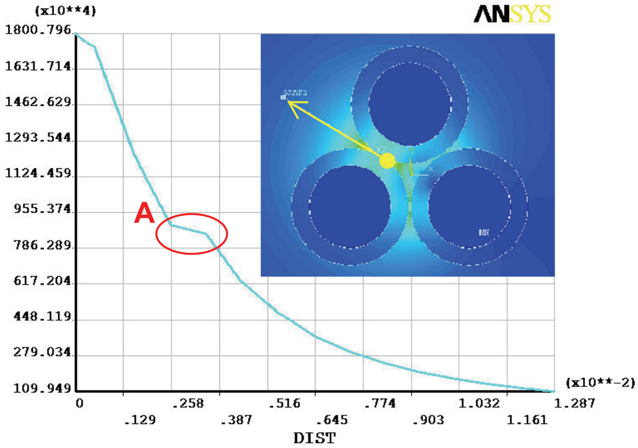

Chart. 8. Evaluation of electric field intensity

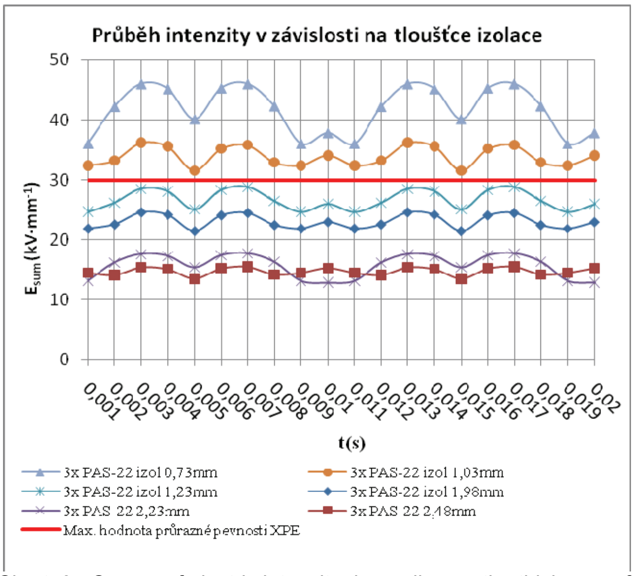

Chart. 9. Course of electric intensity depending on the thickness of conductor insulation

The results show that even a small change in insulation thickness can contribute to higher reliability of insulated overhead conductors. It can be presumed that such a geometric conductor layout could be implemented in practice.

Acknowledgment

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Conclusion

Nowadays insulated suspended lines are increasingly used for overhead lines.

This paper discussed the electric intensity for various geometric conductor layout at pole consoles. The reason for doing such a calculation was to get a general overview of electric intensity and its influence on the insulation system of insulated suspended lines. The diagram Chart 1 shows the changes in electric intensity and electric potential depending on the distance from the conductor centre. The appearance of electric field and the calculation direction shows the diagram, see Chart 1.

Further calculations analyzed, using the finite element method, electric field around conductors at various distances from each other. The goal was to find out how far the conductors can be arranged from each other so that electric intensity action does not exceed the value of insulation breakdown strength E_p = (30 – 40) $kV\cdot mm^{-1}$. For the lowest distance l = 0,01 *mm* the maximum intensity of electric field was E_{max}= 19,2 $kV\cdot mm^{-1}$ see. Fig. 4. This value conforms to the required values of breakdown strength for insulation XPE. More details about the solution and conclusion are in the text itself.

Then the dependence of electric intensity on the thickness of conductor insulation was resolved. For the calculation the example is presented when the conductors are mutually twisted and the intention was to determine whether such geometric conductor layout conforms to the limits of electric strength of XPE material. The calculated maximum value of electric intensity for insulation thickness 2,23 *mm* was E_{max}= 24,6 $kV\cdot mm^{-1}$ see. Fig. 7 and for insulation thickness 2,48 *mm* the value of intensity was E_{max}= 15,5 $kV\cdot mm^{-1}$. For insulation thickness 1 *mm* the value was E_{max}= 36,2 $kV\cdot mm^{-1}$ which means that for this insulation thickness the value of breakdown strength for insulation XPE was crossed. The results presented in this part show that even a small change in insulation thickness of mere 0,5 *mm* has a large impact on the electric field intensity around conductors which decreased down to 10 $kV\cdot mm^{-1}$.

At point **A** in Fig. 8 the electric intensity decrease is smaller which is apparent also from the diagram, see Chart 8. The reason is that they were at a larger area with similar electric intensity due to the distance and direction of values calculation.

The results obtained though solving electrostatic field for various geometric conductor layout at pole consoles can be further used for lead optimalization and the design of new lead-supporting structures or changing the parameters of insulated suspended conductors in such a way that the conductor electric properties are improved. Then these changes can have a share in saving the material for production the consoles for fixing suspended insulated conductors and in protecting the environment.

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