Regular paper

POSITIVE DC NON-LINEAR CORONA DESIGN

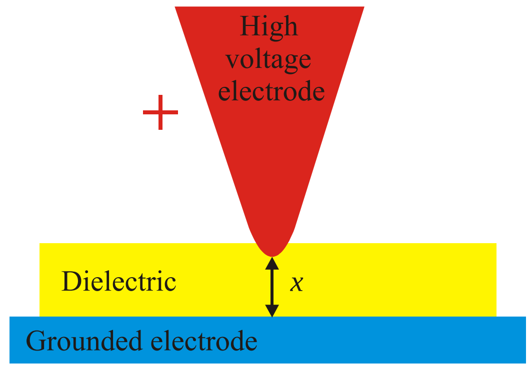
Saša S. ILIĆ[1], Bojana R. NIKOLIĆ[2], Slavoljub R. ALEKSIĆ[3]

Abstract: The paper is aimed at proposing one very simple but exact method for calculating an electric field and potential in the case when large charges are driven to an electrode and a DC non-linear corona effect is not neglected. All calculations can be applied to grounding systems by using analogies.

Keywords: DC Corona, Green's functions, Laplacian Field, Poisson Field.

INTRODUCTION

When relatively small charges are driven to the electrodes, the standard procedure gives linear relations between electrical values of interest. Thus, the potential and the electric field strength density linearly depend on the driven charge and on the electrode potential. There are no limitations within these linear relations. It often happens that the strength of the electric field on the electrode surface is of too large value. This is the case with peaks and sharp edges, even at small voltages. In principal, there are two theories that consider the problem of corona. One of them don't take into consideration space charge existing in the corona (Lapalacian field) and the other one that takes it into consideration (Poisson field). The method proposed in this paper corresponds to the second method.



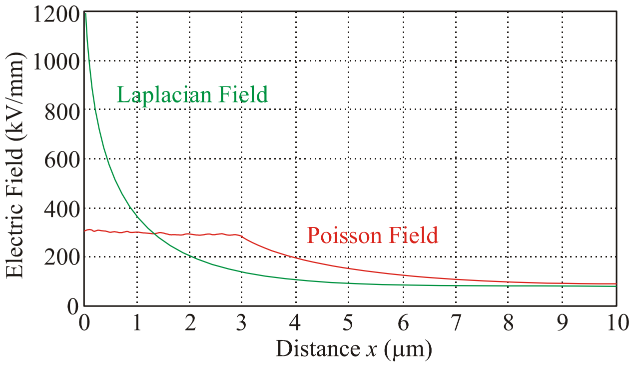


Fig. 1 – *An experimental result from Ref. [10]*

On the other hand, the experience shows that the strength of the electric field cannot be larger than so-called critical value, when sparking begins [10]. Therefore, linear relations are only applicable as long as the strength of the electric field is smaller or equal to the critical value (see Fig. 1 with measured value of electric field).

In cases when the electrode has mathematical peaks and/or sharp edges, the linear approaches cannot be applied. In general, when the driving charges are so large that the strength of the electric field would be larger than critical, a corona charge is formed around observed electrode and the limit effect begins. So the corona charge decreases strength of the electric field and limits resulting electric field to the critical value. This limiting effect contributes to the creation of non-linear and non-homogeneous region around this electrode. This automatically eliminates linear analysis and the problem becomes very complex, implying solving non-linear partial differential equations.

In order to find a simple practical solution of this problem, this paper elaborates one elementary, but generally applicable method, which is independent on the electrode shape and dimension.

This method is based on the presumptions that the corona charge does not distort the shape of force lines compared to the linear regime and that the electric field has uniform intensity along the force line in the corona region. Using boundary condition that the electrode is equipotential, the non-linear algebraic equations can be established, whose solution gives electric field strength and shape and dimensions of the corona region. This approach also enables calculation of an existing non-linear dependence between both charge intensity and electrode potential and, upon this, calculation of non-linear capacitance.

The theoretical research can be applied to the several practical electrodes: sphere, spherical capacitor, cilindrical capacitor, prolate and oblate ellipsoid electrodes, thin disk or thin rod.

OUTLINE OF THE METHOD

This method will be applied to an isolated electrode, which is in the air of dielectric permittivity ε_0 and of the strength of the critical electric field E_k (Fig. 1).

It is presumed that the potential distribution, φ_0, and the electric field strength, E_0, in the case of linear regime,

[1]University of Niš, Department of Theoretical Electrical Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mail: silic@elfak.ni.ac.yu.
[2]University of Niš, Department of Theoretical Electrical Engineering, Aleksandra Medvedeva 14, 18000 Niš,Serbia,E-mail: bojananik@elfak.ni.ac.yu
[3]University of Niš, Department of Theoretical Electrical Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mail: as@elfak.ni.ac.yu.

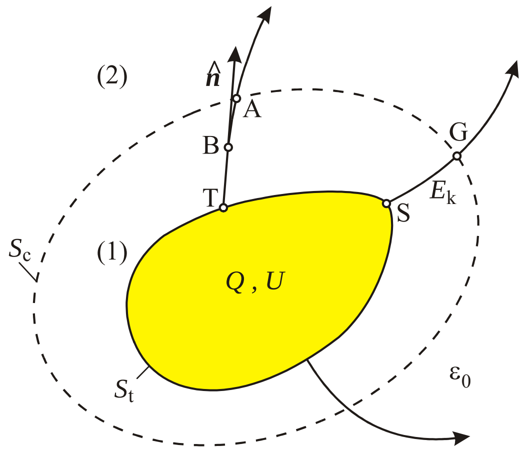


Fig. 2 - *An isolated electrode with arbitrary shape*

are known and could be presented as

$$\varphi_0 = Q_0 g(\boldsymbol{r}) \tag{1}$$

and

$$\boldsymbol{E}_0 = Q_0 G(\boldsymbol{r})\hat{\boldsymbol{n}} \tag{2}$$

where $g(\boldsymbol{r})$ and $G(\boldsymbol{r})$ are corresponding potential and electric field strength Green's functions and $\boldsymbol{r}$ is the position vector of the field point. Q_0 is the density of the charge driven to the observed electrode and $\hat{\boldsymbol{n}}$ is the unit vector associated to the electric field line.

If U_0 signifies a potential between the electrode and the zero potential point in the infinity, then the ratio

$$C_0 = Q_0 / U_0 \tag{3}$$

defines capacitance of the electrode. C_0 is always linear to the air permittivity, $C_0 = k\varepsilon_0$, where the coefficient k depends on shape and dimensions of the observed electrode. In the linear regime, this value is independent on the electrode potential. All of this can be applied until the charge intensity Q_0 is lower than the critical current value Q_k, when the electric field strength in the point S (peaks and/or sharp edges of the electrode) becomes of critical value,

$$E(\boldsymbol{r} = \boldsymbol{r}_\mathrm{S}) = E_\mathrm{k} = Q_\mathrm{k} G(\boldsymbol{r} = \boldsymbol{r}_\mathrm{S}).$$

If $Q_0 > Q_\mathrm{k}$, the electric field strength in the electrode surroundings determined by formula (2), becomes larger than the critical value E_k. That is not allowed, so the region which is defined by the electrode surface S_t and some other surface that comprehends the electrode, S_c, becomes a corona region (Region 1 in Fig. 2).

For finding a simple solution for the potential and the electric field in these cases, two following presumptions are inducted:

1) Corona charge does not distort the shape of force lines. Electric field lines are still normal on the electrode surface and field lines have radial direction on large distances from the observed electrode.
2) Electric field has uniform intensity along the force line in the corona region, E_c. The field intensities are different from line to line and on the force line that passes through point S (peak of the electrode) the electric field strength is the largest and equal to the critical value,

$$E_\mathrm{c}(\hat{\boldsymbol{n}} = \hat{\boldsymbol{n}}_\mathrm{S}) = E_\mathrm{k}.$$

With those presumptions, the electric field strength is

$$\boldsymbol{E} = \begin{cases} E_\mathrm{c}(\hat{\boldsymbol{n}})\hat{\boldsymbol{n}}, & \text{in the corona region 1} \\ QG(\boldsymbol{r})\hat{\boldsymbol{n}}, & \text{in the region 2,} \end{cases} \tag{4}$$

where Q is the charge driven to the electrode.

At the boundary point A spark disappears and the electric field strength has to change continuously, what gives a condition

$$E_\mathrm{c}(\hat{\boldsymbol{n}} = \hat{\boldsymbol{n}}_\mathrm{A}) = QG(\boldsymbol{r} = \boldsymbol{r}_\mathrm{A}). \tag{5}$$

$\boldsymbol{r}_\mathrm{A}$ is the position vector of the point A and $\hat{\boldsymbol{n}}_\mathrm{A}$ is the field line unit vector at the point A.

Taking into account equations (4) and (1), the potential in the region 2 can be expressed as

$$\varphi = Q\,g(\boldsymbol{r}). \tag{6}$$

The potential in the region 1 at the point B will be

$$\varphi = E_\mathrm{c} L_\mathrm{BA} + Q\,g(\boldsymbol{r} = \boldsymbol{r}_\mathrm{A}), \tag{7}$$

where L_BA denotes the length of the field line. The electrode potential related to the "infinite" point, can be put as

$$U = E_\mathrm{c} L_\mathrm{TA} + Q\,g(\boldsymbol{r} = \boldsymbol{r}_\mathrm{A}). \tag{8}$$

Point T denotes a point on the electrode surface lying on the field line BA.

Equation (8) can be applied on every field line and gives always the same value for the electrode potential. This equation could also be applied to the line drawn through the point S,

$$U = E_\mathrm{k} L_\mathrm{SG} + Q\,g(\boldsymbol{r} = \boldsymbol{r}_\mathrm{G}). \tag{9}$$

After equalizing equations (8) and (9) and taking into consideration relation (5), the following equations can be derived,

$$L_\mathrm{SG} + \frac{g(\boldsymbol{r}=\boldsymbol{r}_\mathrm{G})}{G(\boldsymbol{r}=\boldsymbol{r}_\mathrm{G})} = L_\mathrm{TA}\frac{G(\boldsymbol{r}=\boldsymbol{r}_\mathrm{A})}{G(\boldsymbol{r}=\boldsymbol{r}_\mathrm{G})} + \frac{g(\boldsymbol{r}=\boldsymbol{r}_\mathrm{A})}{G(\boldsymbol{r}=\boldsymbol{r}_\mathrm{G})} \tag{10}$$

and

$$E_\mathrm{c}(\hat{\boldsymbol{n}} = \hat{\boldsymbol{n}}_\mathrm{A}) = E_\mathrm{k}\frac{G(\boldsymbol{r} = \boldsymbol{r}_\mathrm{A})}{G(\boldsymbol{r} = \boldsymbol{r}_\mathrm{G})}. \tag{11}$$

Non-linear algebraic equation (10) is used for calculating shape and dimensions of the corona region 1 and its solutions define coordinates of the point A. First, coordinates of the point G are evaluated by equation (5) using

$$E_\mathrm{k} = QG(\boldsymbol{r} = \boldsymbol{r}_\mathrm{G}).$$

Then, the equation (11) can be used for getting the electric field strength on any field line.

The region 1 behaves as non-linear, non homogeneous medium whose equivalent corona region permittivity is determined by the following equation

$$\varepsilon = \varepsilon_0 Q \frac{G(\boldsymbol{r})}{E_c(\hat{\boldsymbol{n}})} . \qquad (12)$$

EXAMPLES

Example I - Isolated spherical electrode

An isolated spherical electrode of radius a is observed first (Fig. 3).

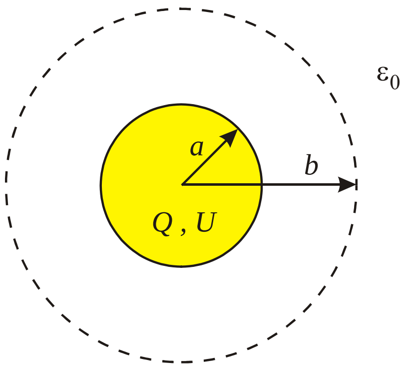


Fig. 3 - *Isolated spherical electrode*

When charge driven to the electrode is smaller than critical, there is no sparking,

$$Q < Q_k = 4\pi\varepsilon_0 a^2 E_k .$$

For $Q > Q_k$ sparking begins and the corona charges are formed in a spherical space

$$a < r < b = a\sqrt{Q/Q_k} .$$

The electric field vector has only radial component,

$$E = \begin{cases} E_k , & a \le r \le b \\ E_k b^2 / r^2 , & b \le r < \infty . \end{cases} \qquad (13)$$

Between charge Q and the electrode potential U related to the "infinite" point the following relation exists

$$4Q/Q_k = (1 + U/U_k)^2 , \qquad (14)$$

where $U_k = aE_k$.

The capacitance is

$$C/C_0 = (1 + U/U_k)^2 / (4U/U_k) , \qquad (15)$$

where $C_0 = 4\pi\varepsilon_0 a$ is the capacitance in the linear regime of the isolated sphere. In the Fig. 4.a potential distribution and electric field strength in the surroundings of the spherical isolated electrode, for the linear regime, are shown.

In the Fig. 4.b, those distributions are shown for the non-linear regime when the sparking exists. In the Fig. 5 dependence of the ratio C_0/C on the charge driven to the electrode is shown.

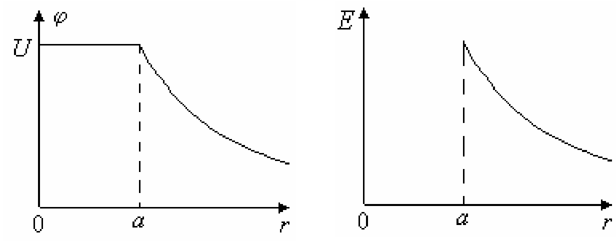


Fig. 4.a - *Linear regime*

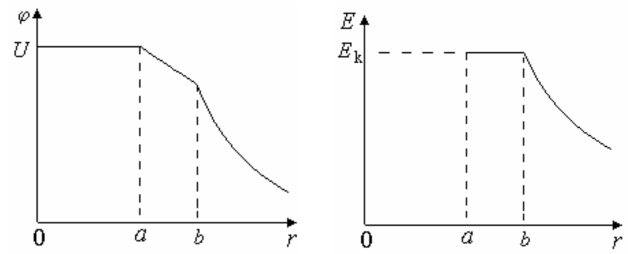


Fig. 4.b - *Non-linear regime*

From these results it can be concluded that when the charge density is too large, $Q >> Q_k$, the capacitance rises linearly in the function of the potential. Whereas the potential changes proportionally to the square root of the charge, following relations can be derived approximately,

$$C/C_0 = \frac{1}{4} U/U_k = \frac{1}{2}\sqrt{Q/Q_k} . \qquad (16)$$

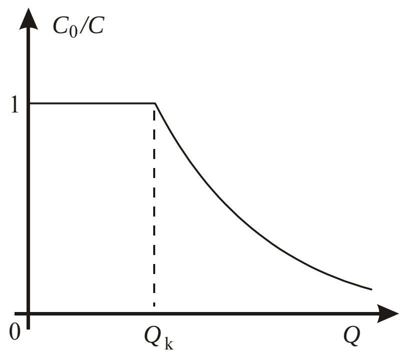


Fig. 5 - C_0/C *versus driven charge*

In the corona region, equivalent permittivity is

$$\varepsilon = \varepsilon_0 (a^2/r^2)(Q/Q_k) = \varepsilon_0 b^2/r^2 . \qquad (17)$$

Example II - Spherical capacitor

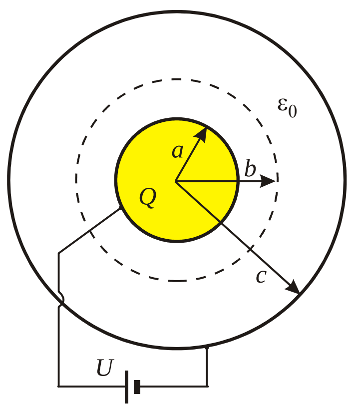


Fig. 6 - *Spherical capacitor*

When charge driven to the electrode is smaller than the critical value, there is no sparking,

$$Q < Q_k = 4\pi\varepsilon_0 a^2 E_k .$$

For $Q > Q_k$ sparking begins and the corona charges are formed in a spherical space

$$a < r < b = a\sqrt{Q/Q_k} .$$

The electric field vector has only radial component,

$$E = \begin{cases} E_k , & a \le r \le b \\ E_k b^2/r^2 , & b \le r \le c. \end{cases} \tag{18}$$

Using the expression (18), voltage between the electrodes of the spherical capacitor can be determined:

$$U = E_k(b-a) + \int_b^c E_k\left(\frac{b}{r}\right)^2 \mathrm{d}r , \tag{19}$$

i.e. the following formula is obtained:

$$\frac{U}{U_k} = \frac{(2b-a)c - b^2}{a(c-a)} , \tag{20}$$

where the radius of the corona b is calculated for ratio of voltages set before.

After solving the square equation having as unknown b and refusing the solution that has a sign '+', the following expression is obtained:

$$\frac{b}{a} = \frac{c}{a} - \sqrt{\left(\frac{c}{a}-1\right)\left(\frac{c}{a}-\frac{U}{U_k}\right)} . \tag{21}$$

The spherical capacitor capacitance can be calculated now as

$$\frac{C_0}{C} = \frac{U}{U_k} \bigg/ \left(\frac{b}{a}\right)^2 , \tag{22}$$

where C_0 is the spherical capacitor capacitance in the linear regime.

Table I - C_0/C versus U/U_k .

$c/a=2$		$c/a=3$	
U/U_k	C_0/C	U/U_k	C_0/C
1	1	1	1
1.2	0.982	1.2	0.987
1.4	0.932	1.4	0.954
1.6	0.855	1.6	0.909
1.8	0.746	1.8	0.855
2.0	0.500	2.0	0.795
-	-	2.2	0.731
-	-	2.4	0.662
-	-	2.6	0.586
-	-	2.8	0.499
-	-	3.0	0.333

In the corona region, equivalent permittivity is

$$\varepsilon = \varepsilon_0 b^2/r^2 . \tag{23}$$

Example III - Cylindrical capacitor

When the charge per unit length driven to the electrode is smaller than the critical value, there is no sparking,

$$q' < q'_k = 2\pi\varepsilon_0 a E_k .$$

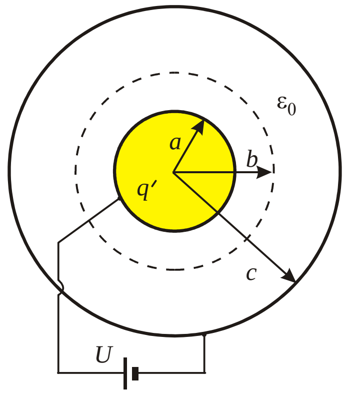


Fig. 7 - *Cylindrical capacitor*

For $q' > q'_k$ sparking begins and the corona charges are formed in a cylindrical space

$$a < r < b = a\frac{q'}{q'_k} .$$

The electric field vector has only radial component,

$$E = \begin{cases} E_k , & a \le r \le b \\ E_k b/r , & b \le r \le c. \end{cases} \tag{24}$$

Using the expression (24), the voltage between cylindrical capacitor can be edetermined as

$$U = E_k(b-a) + \int_b^c E_k \frac{b}{r} \mathrm{d}r . \tag{25}$$

Since $aE_k = U_k/\ln(c/a)$, after solving the expression given above, the transcendental equation as unknown b is obtained. From there b can be calculated after setting the ratio of voltages,

$$\frac{b}{a}\left(1+\ln\left(\frac{c}{b}\right)\right) = 1 + \ln\left(\frac{c}{a}\right)\frac{U}{U_k} . \tag{26}$$

Capacitance per unit length of the cylindrical capacitor can be calculated as:

$$\frac{C'_0}{C'} = \frac{U}{U_k} \bigg/ \frac{b}{a} , \tag{27}$$

where C'_0 is the capacitance per unit length of the cylindrical capacitor in the linear regime.

In the corona region, equivalent permittivity is

$$\varepsilon = \varepsilon_0 b/r . \tag{28}$$

Table II - C'_0 / C' versus U / U_k.

$c/a = 2$		$c/a = 3$	
U/U_k	C'_0/C'	U/U_k	C'_0/C'
1	1	1	1
1.1	0.993	1.1	0.996
1.2	0.969	1.2	0.983
1.3	0.925	1.3	0.963
1.4	0.840	1.4	0.935
-	-	1.5	0.899
-	-	1.6	0.852
-	-	1.7	0.789
-	-	1.8	0.682

Example IV - Isolated prolate ellipsoid electrode

An isolated prolate ellipsoid electrode of semi axes a and b is of permittivity ε_0.

In the linear regime the potential in the surroundings of the electrode is

$$\varphi_0 = \frac{Q}{8\pi\varepsilon_0 c}\ln\left(\frac{\operatorname{ch}u+1}{\operatorname{ch}u-1}\right), \tag{29}$$

where $c = \sqrt{a^2 - b^2}$.

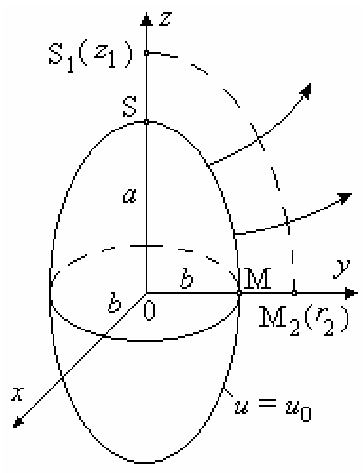


Fig. 8 - *Isolated prolate ellipsoid*

Q is the charge driven to the electrode and u, v, w are coordinates of the prolate ellipsoid. Between these coordinates and cylindrical coordinates, r, θ, z, the following relations exist:

$$r = c\operatorname{sh}u\sin v,\ z = c\operatorname{ch}u\cos v,\ \theta = w. \tag{30}$$

The equation of the electrode surface is $u = u_0$, where

$$a = c\operatorname{ch}u_0 \text{ and } b = c\operatorname{sh}u_0.$$

The electric field lines coincide with $u-$coordinate lines and the electric field intensity is

$$E_u = \frac{Q}{4\pi\varepsilon_0 c^2 \operatorname{sh}(u)\sqrt{\operatorname{sh}^2 u + \sin^2 v}}. \tag{31}$$

The capacitance in the linear regime can be calculated as

$$C_0 = 8\pi\varepsilon_0 \frac{c}{\ln\left(\frac{a+c}{a-c}\right)}. \tag{32}$$

On the electrode surface the electric field strength is the largest at the point $\mathrm{S}(u = u_0, v = 0)$ and the smallest at the point $\mathrm{M}(u = u_0, v = \pi/2)$. Relation between the field strengths in these points is

$$E_\mathrm{S} = \frac{Q}{4\pi\varepsilon_0 b^2} = \frac{a}{b}E_\mathrm{M}. \tag{33}$$

There is no sparking in the electrode surroundings if $E_\mathrm{S} < E_\mathrm{k}$, where

$$Q < Q_\mathrm{k} = 4\pi\varepsilon_0 b^2 E_\mathrm{k}. \tag{34}$$

If $Q > Q_\mathrm{k}$, it is very convenient to observe two privileged field lines which coincide with the $z-$axis and $y-$axis. The corona region is between S and $\mathrm{S}_1(z = z_1)$, along $z-$axis, and between M and $\mathrm{M}_2(r = r_2)$, along $y-$axis. Out of this region, along the privileged lines, the potential and the electric field strength are:

for $r = 0,\ z \ge z_1$:

$$\varphi = E_\mathrm{k}\frac{z_1^2 - c^2}{2c}\ln\left(\frac{z+c}{z-c}\right),\ E = E_\mathrm{k}\frac{z_1^2 - c^2}{z^2 - c^2} \tag{35}$$

and for $r \ge r_2,\ z = 0$

$$\varphi = E_\mathrm{k}\frac{z_1^2 - c^2}{2c}\ln\frac{\sqrt{r^2+c^2}+c}{\sqrt{r^2+c^2}-c}, E = E_\mathrm{k}\frac{z_1^2 - c^2}{r\sqrt{r^2+c^2}}. \tag{36}$$

In the region 1, on the $z-$axis, the electrical field is uniform and equal E_k. On the $y-$axis, the electric field strength at the point M_2 has value,

$$E = E_\mathrm{k}\frac{z_1^2 - c^2}{r_2\sqrt{r_2^2 + c^2}}. \tag{37}$$

After computing the potential of the electrode along $z-$ axis and $y-$axis, and equalizing derived values, the following relation between z_1 and r_2 is obtained:

$$\frac{z_1 - a}{z_1^2 - c^2} + \frac{1}{2c}\ln\left(\frac{z_1 + c}{z_1 - c}\right) = \frac{r_2 - b}{r_2\sqrt{r_2^2 + c^2}} + \frac{1}{2c}\ln\left(\frac{\sqrt{r_2^2 + c^2} + c}{\sqrt{r_2^2 + c^2} - c}\right), \tag{38}$$

where

$$z_1 = \sqrt{b^2\frac{Q}{Q_\mathrm{k}} + c^2} > a. \tag{39}$$

The capacitance can be calculated as

$$\frac{C_0}{C} = \frac{2c(z_1 - a) + (z_1^2 - c^2)\ln\left(\frac{z_1 + c}{z_1 - c}\right)}{(z_1^2 - c^2)\ln\left(\frac{a + c}{a - c}\right)} . \quad (40)$$

Example V - Isolated oblate ellipsoid electrode

For the oblate ellipsoid electrode, the critical value of the charge is

$$Q_k = 4\pi\varepsilon_0 abE_k . \quad (41)$$

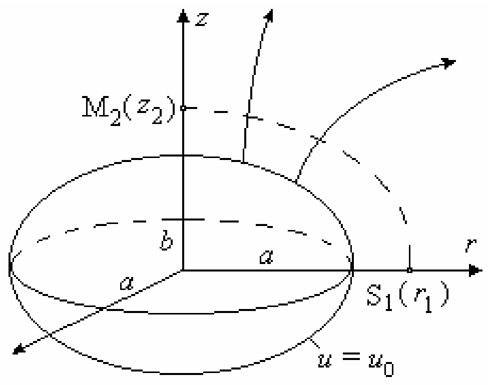


Fig. 9 - *Isolated oblate ellipsoid*

For $Q > Q_k$, the capacitance is determined by the following formula

$$\frac{C_0}{C} = \frac{\frac{c}{r_1}(r_1 - a) + \sqrt{r_1^2 - c^2}\left[\frac{\pi}{2} - \text{arctg}\left(\frac{\sqrt{r_1^2 - c^2}}{c}\right)\right]}{\sqrt{r_1^2 - c^2}\left[\frac{\pi}{2} - \text{arctg}\left(\frac{b}{c}\right)\right]}, \quad (42)$$

where

$$C_0 = \frac{4\pi\varepsilon_0 c}{\frac{\pi}{2} - \text{arctg}\left(\frac{b}{c}\right)}, \quad (43)$$

is the capacitance in linear regime,

$$r_1 = \sqrt{\frac{c^2 + \sqrt{c^4 + 4a^2b^2\left(\frac{Q}{Q_k}\right)^2}}{2}}, \quad (44)$$

where is $c = \sqrt{a^2 - b^2}$.

In Table III, a dependence of the ratio C_0 / C on the ratio Q / Q_k is shown, for prolate ellipsoid, sphere and oblate ellipsoid electrode.

Table III - C_0 / C versus Q / Q_k .

Q / Q_k	Prolate ellipsoid		Sphere	Oblate ellipsoid	
	b/a		b/a	b/a	
	0.05	0.1	1	0.1	0.01
1	1.000	1.000	1.000	1.000	1.000
1.5	0.990	0.988	0.966	0.994	0.998
2	0.974	0.968	0.914	0.983	0.995
3	0.942	0.928	0.821	0.957	0.994
4	0.914	0.895	0.750	0.930	0.993
5	0.891	0.866	0.694	0.904	0.990
6	0.870	0.842	0.650	0.879	0.987
7	0.853	0.820	0.613	0.856	0.984
8	0.837	0.801	0.582	0.834	0.980
9	0.823	0.784	0.556	0.813	0.977
10	0.811	0.769	0.535	0.795	0.974
20	0.724	0.665	0.397	0.659	0.943
30	0.672	0.604	0.332	0.578	0.913
40	0.635	0.561	0.291	0.522	0.885
50	0.606	0.528	0.263	0.480	0.859
100	0.518	0.430	0.190	0.364	0.754
500	0.326	0.240	0.087	0.178	0.455
1000	0.256	0.180	0.062	0.129	0.345
10000	0.098	0.063	0.020	0.042	0.122

CONCLUSION

The results in columns 2 and 6 in Table III correlate to thin rod and thin disk, respectively. The capacitance of these electrodes changes more slowly than in the case of spherical electrode or rotational ellipsoid electrode of definitive thickness. Otherwise, when the charge driven to the electrode increases, the capacitance increases, too. It is because the sparking induces “equivalent” increment of the observed electrode. When the charges are very large, $Q >> Q_k$, the results shown in equation (16) have a common character, so the following relations can be obtained, independently on the shape and the dimension of the electrode,

$$C / C_0 \sim U / U_k \sim \sqrt{Q / Q_k} . \quad (45)$$

With some modifications, this method can be applied to complex electrode systems (two-wire line, spherical sparkers, toroidal electrode etc.). In the cooperation with the standard numerical methods, this method can also be applied to the ground electrodes of arbitrary shape, which are shallowly intered. In that case a discontinuity on the earth surface can not be neglected.

REFERENCES

[1] Veličković D. M.: "Calculating of Non-Linear Corona Field", Proc. of Papers of the XXXIII Yugoslav Conference ETAN, pp. V95 - V101, Novi Sad, June 1989, Serbia.

[2] Veličković D. M.: "Calculating of Non-Linear Grounding Field", Proc. of Papers of the Second International Sympo-

sium “Computer in Power Engineering”, pp. 101 - 110, Tuzla, April 1990, Bosnia and Hercegovina.

[3] Veličković D. M., Raičević N. B.: "Approximate Solving of Non-linear Electrostatic Problems”, Proc. of Papers of the Third International Symposium of Applied Electrostatics 90, pp. 75 - 93, Niš, October 1990, Serbia.

[4] Veličković D. M.: "Variation of Capacitance under Extremely High Voltages", Serbian Academy of Science and Arts, IV International Nikola Tesla Symposium, pp. 195 - 201, 23 - 25 September 1991, Serbia.

[5] Veličković D. M., Nikolić B. R.: "One simple but exact approach for non-linear grounding design", International Conference on Grounding and Earthing & 3rd Brazilian Workshop on Atmospheric Electricity, Ground'2002 and 3rd WAE, Rio de Janeiro, Brazil, November 4 – 7, 2002.

[6] Veličković D. M.: "Charge Simulation Method in Electromagnetic Field Computations", Proceedings of the Summer School "Modern Aspects of Theoretical Electrical Engineering", Sozopol 2002, 29. 09. - 3.10. 2002, Sozopol, Bulgaria.

[7] J. J. Lowke, F. D’ Alessandro.: "Onset Corona Fields and Electrical breakdown criteria", Journal of Physics D: Applied Physics 36 (2003), pp. 2673-2683.

[8] Junhong Chen, Jane H. Davidson.: "Model of Negative DC Corona Plasma", Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN55455, USA.

[9] Junhong Chen, Jane H. Davidson.: "Electron Density and Energy distributions in the Positive DC Corona: Interpretation for Corona – Enhanced Chemical Reactions", Plasma Chemistry and Plasma Processing, Vol. 22, No 2, June 2002, pp. 199-224.

[10] Steven Boggs.: "Overview of Dielectrics", Electrical Insulation Research Center, University of Connecticut, USA, www.Electrical-Insulation.org.

Saša S. Ilić was born in Niš, (Serbia) on July 24, 1970. He finished the primary school in Grejač and the secondary school in Niš. He rewarded with diploma "Vuk Karadžić" (the primary school) and diploma "Mihajlo Petrović Alas" (the secondary school for physics, biology, mathematics and chemistry).

He enrolled in the Faculty of Electronic Engineering, University of Niš, Serbia in 1990. He received B.Sc. degree in 1995. He employed at the Faculty of Electronic Engineering of Niš as an research-assistant at the Department of Theoretical Electrical Engineering in 1995.

Now, he is involved in conducting auditing exercises for subjects Electrical Engineering I and II, Electrical Circuits Theory and Electromagnetics. He enrolled the postgraduate studies at the Faculty of Electronic Engineering in 1995 and passed all exams with the highest marks.

In December 2002, he got M.Sc. degree for the thesis entitled "*Atmospheric electric field distribution in the surroundings of an object with lightning protection rod*".

His researching areas are: lightning protection systems and micro strip transmission lines with isotropic, anisotropic and bianisotrpic media.