

# Modeling Composite Aluminum Conductors for Electric Field Determination

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**Abstract**—The main goal of this paper is the investigation if the previously developed composite aluminum conductor's simplified model for current distribution, magnetic field and impedance per unit length calculation, will be also a good model for electric field determination.

Electric field, produced by high voltage overhead electrical system, depends on system's geometry and applied system's voltage. Having a circular composite aluminum conductor's cross section, the whole problem can be treated as two dimensional. In the case of a single conductor, applying cylindrical coordinate system, with axis  $z$  in the conductor's axis direction, electric field strength vectors is in  $r$ - $\varphi$  plane and its magnitude depends on coordinate  $r$ . In the case of coupled (bundled) conductors, Cartesian coordinate system is a right choice.

Due to big difference between radial and axial component of electric field strength vector, only conservative component of electric field strength vector can be observed. Since the axial component outside the conductor can be neglected, the problem could be satisfactory treated as the electrostatic one.

Comparing calculated electric field of a real conductor with the field of its simplified model, it was shown that the model is not satisfactory accurate as it was in previous calculations.

Electric field strength vector is determined numerically, applying COMSOL computer program package and the results are presented graphically.

**Keywords**—real ACSR and ACCR geometry; simplified model; electric field; Finite Element Method

## I. INTRODUCTION

The magnitude of electric field strength vector in vicinity of high voltage ACSR (Aluminum Conductor Steel Reinforced) or ACCR (Aluminum Conductor Composite Reinforced) frequently exceeds the critical value for the air, producing ionization and partial discharging close to the conductor's surface, known as corona effect. In the case of composite conductors this effect is even more emphasized comparing with the homogenous conductors with circular cross-section. For this reason, it would be interesting to investigate if the simplified model developed and presented in previous papers [1]-[4], can be satisfactory accurate in the electric field calculations. In all previous investigations, electric and magnetic field, together with the appropriate current distribution, were calculated taking into account more or less

significant skin effect and, in the cases of multiple conductors, proximity effect as well. In all these cases, emphasizing skin effect, only axial (induced) component of electric field strength vector was calculated, while its radial component was neglected. It was shown that, concerning the current distribution, magnetic field and impedance per unit length, at all investigated frequencies, the simplified model gives quite satisfactory results.

Nevertheless, due to complex composite conductor's geometry, with the typical cross-section shown in Fig. 1, it could be supposed that the results obtained applying a simplified model, presented in Fig. 2, might differ significantly from the real case. For that reason, the radial component of the electric field strength vector will be calculated for both, real composite conductor and its simplified model. The calculation results will be presented graphically, discussed and compared, giving an appropriate conclusion if the model could be applied in this case with the same accuracy as in previous calculations.

The problem will be solved numerically, applying COMSOL Multiphysics computer program package [5], based on Finite Element Method.

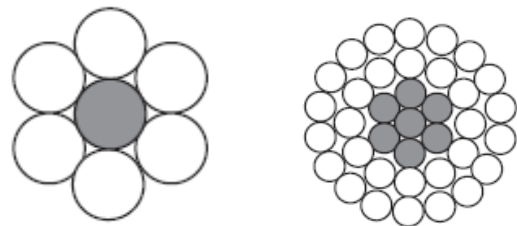


Fig. 1. Cross-section of a real ACSR or ACCR conductor.

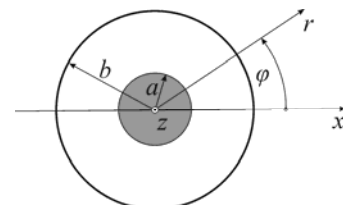


Fig. 2. Cross-section of a simplified model in cylindrical coordinate system.

II. THEORETICAL APPROACH

Electromagnetic fields calculation is usually performed via electric scalar potential,  $V$  and magnetic vector potential,  $\vec{A}$ , from which electric field strength vector and magnetic flux density vector are defined as,

$$\vec{E} = -gradV - \frac{\partial \vec{A}}{\partial t}, \quad \vec{B} = rot\vec{A}. \quad (1)$$

First of all, at all investigated frequencies, from basic industrial frequency, 50 Hz and up to 50<sup>th</sup> harmonic (2500 Hz), electric and magnetic fields could be treated separately, as quasi-stationary fields. In this paper only electric field will be investigated, omitting its axial component.

A single conductor’s cross-section geometry suggests the application of cylindrical coordinate system in two dimensions. The coordinate system is placed so that its  $z$  axis coincides with the conductor’s axis, as shown in Fig. 2, while the electric field strength vector is define in  $r$ - $\phi$  plane, depending only on distance from the conductor’s axis, the  $r$ -coordinate.

In the case of two bundled conductors, Cartesian coordinate system will be applied, with  $z$  axis in the same direction as the both conductor’s axes. Electric field strength vector exists in  $x$ - $y$  plane, depending on both  $x$  and  $y$  coordinates.

As presented in (1), electric field strength vector has two components, the conservative one, described by electric scalar potential,  $V$ , and the induced component, presented with magnetic vector potential  $\vec{A}$ . Outside the conductor, the radial component of electric field is dominant and its axial component can be neglected. Its axial component, the induced electric field strength vector is in  $z$  direction and if it can be omitted, only electric scalar potential can define the entire electric field. That means that the electrostatic solution could be the appropriate one. In this case, electric scalar potential is a solution of the Laplace partial differential equation,

$$\Delta V = 0. \quad (2)$$

As always in electrostatic cases, it is supposed that all conductor’s points are equipotential in  $r$ - $\phi$  plane. In order to solve the Laplace partial differential equation, some boundary conditions must be defined. Solving the problem with a single conductor, a large cylinder with radius  $R_b$  was placed coaxially with the conductor’s axis, limiting the domain of electrostatic field existence. In the case of two bundled conductors, according to geometry, a square with the side  $2R_b$  was established.

In both cases it was supposed that the electric vector potential has zero value in all boundary points, excluding existence of electrostatic field outside the boundaries.

In order to obtain an accurate view on electric field produced by a conductor with time varying potentials and currents, problem was also investigated in complex domain, comparing radial and axial components of electric field strength vector outside the conductor. Having harmonic potentials and harmonic currents, with the nonlinear steel core within the ACSR, which can easily be treated as linear, with

constant permeability [6], the problem can be defined and solved in complex domain.

Solving partial differential equation (2) in complex domain, the complex electric scalar potential,  $\underline{V}$ , is determined. From this complex value, the complex conservative component of electric field strength vector, which is also radial, normal to the conductor’s axis, can be calculated as,

$$\vec{E}_c = -grad\underline{V}. \quad (3)$$

These calculations showed that the complex radial component of electric field strength vector is much bigger that its axial component and that, outside the conductor, the axial component can be neglected. For this reason, without any significant impact on obtained results accuracy, the problem can be treated as electrostatic one, in which axial component does not exist. Hence, spatial distribution of electric field strength vector is defined by following expressions

$$\Delta V = 0 \quad \text{and} \quad \vec{E} = -gradV \quad (4)$$

and in this paper will be presented graphically.

III. INVESTIGATED MODELS

Since the corona effect is more significant at higher voltages, composite conductors for transmission voltage levels 110kV, 220kV and 400kV, applied in Serbia, were investigated.

The electric field was calculated for four different types of ACSR conductors and for three types of ACCR conductors. All calculations were performed at frequencies up to 2500Hz.

Basic constructive parameters of investigated ACSR conductors are given in TABLE I [7], while the basic constructive parameters of investigated ACCR conductors are given in TABLE II [8].

Calculated equivalent radiuses of simplified models, presented in [2] and [4], are shown in TABLE III.

TABLE I. PARAMETERS OF ACSR CONDUCTORS

Nominal cross-section	ACSR		
	Steel core	Aluminum part	
	N <sup>o</sup> of wires and its diameters $n \times mm$	N <sup>o</sup> of wires and its diameters $n \times mm$	N <sup>o</sup> of layers
125/30mm <sup>2</sup>	7(1+6) × 2.33	30(12+18) × 2.33	2
240/40mm <sup>2</sup>	7(1+6) × 2.68	26(10+16) × 3.45	2
360/57mm <sup>2</sup>	19(1+6+12) × 1.96	26(10+16) × 4.20	2
490/65mm <sup>2</sup>	7(1+6) × 3.40	54(12+18+24) × 3.40	3

TABLE II. PARAMETERS OF ACCR CONDUCTORS

Conductor type	ACCR		
	AlO <sub>2</sub> composite core	Outer aluminum part	
	N <sup>o</sup> of wires and its diameters $n \times mm$	N <sup>o</sup> of wires and its diameters $n \times mm$	N <sup>o</sup> of layers
Ostrich 300	7(1+6)×2.1	26(10+16)×2.7	2
Hawk 477	7(1+6)×2.70	26(10+16)×3.40	2
Martin 1351	19(1+6+12)×2.4	54(10+16+28)×4.0	3

TABLE III. EQUIVALENT RADIISES OF COMPOSITE CONDUCTORS

Composite conductor	Diameter [mm]			
	Core		Entire conductor	
	Real conductor	Model (2a)	Real conductor	Model (2b)
125/30mm <sup>2</sup>	6.99	6.165	16.10	14.173
240/40mm <sup>2</sup>	8.04	7.091	21.90	18.967
360/57mm <sup>2</sup>	9.80	8.543	26.60	23.057
490/65mm <sup>2</sup>	10.20	8.996	30.60	26.555
Ostrich 300	6.30	5.56	17.20	14.850
Hawk 477	8.00	7.140	21.60	18.750
Martin 1351	12.00	10.46	35.90	31.200

All cases were calculated at conductor’s potentials, defined from appropriate nominal voltage,

$$V_c = \sqrt{2} \cdot \frac{U_{nom}}{\sqrt{3}} \tag{5}$$

Conductivity values of ACSR conductors were measured,

$$\sigma_{Al} = 3.55 \cdot 10^7 \text{ S/m}, \quad \sigma_{Fe} = 0.559 \cdot 10^7 \text{ S/m},$$

while the conductivity values of ACCR conductor were taken from [8],

$$\sigma_{Al} = 3.48 \cdot 10^7 \text{ S/m}, \quad \sigma_{AlO} = 1.405 \cdot 10^7 \text{ S/m}.$$

Dynamic initial relative permeability of ACSR steel core was measured and calculated,  $\mu_r = 94.36$  [9].

IV. OBTAINED RESULTS

As said previously, all calculations were carried out applying COMSOL Multiphysics 3.5a computer program package. Typical model, designed for this program, for real ACSR conductor, together with defined mesh in the entire domain of interest is shown in Fig. 3a), while the real conductor and the mesh in vicinity of the conductor is presented in Fig. 3b).

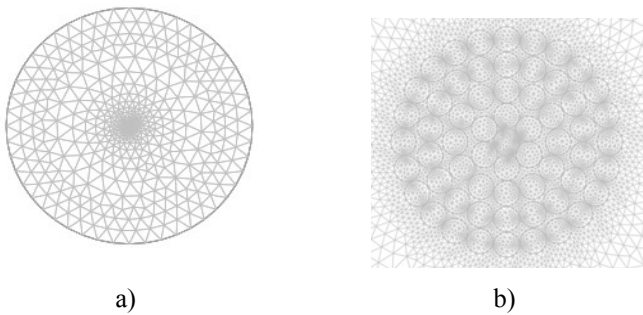


Fig. 3. a) Meshed entire domain, up to  $R_b$ , for single conductor, and b) part of the domain, close to the conductor.

Part of meshed domain in vicinity of two bundled conductors is shown in Fig. 4.

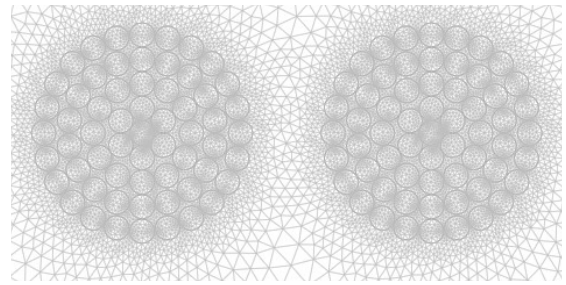


Fig. 4. Part of domain, for bundled conductors, close to the conductors.

COMSOL Multiphysics 3.5a computer program enables different graphical presentations of calculated results. One of the most convenient is the presentation with colors, like the example of electric field strength vector magnitude, for the single real ACSR conductor 490/65mm<sup>2</sup>, at 400kV voltage level, shown in Fig. 5.

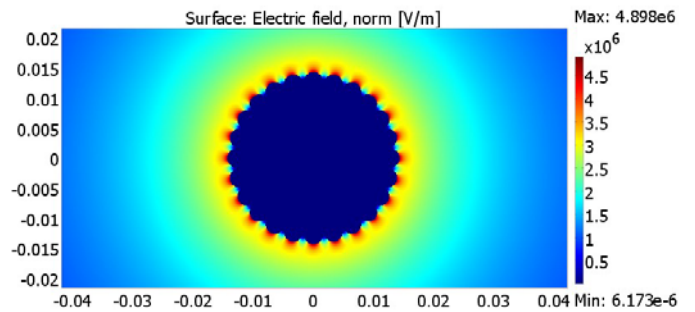


Fig. 5. Electric field strength vector magnitude for single real conductor.

Electric field strength vector magnitude of the same case, for simplified model, is presented in Fig. 6.

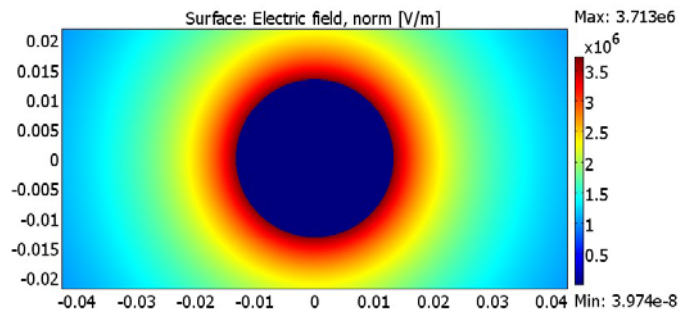


Fig. 6. Electric field strength vector magnitude for the simplified model.

The other possible presentation mode is the diagram of the electric field strength vector magnitude, as a function of distance from the conductor, along previously defined directions. Again as an example, this way of presentation - electric field strength vector of the same chosen case, for the single real ACSR conductor 490/65mm<sup>2</sup>, at 400kV voltage level, is shown in Fig. 7, while the appropriate diagram for the simplified model is presented in Fig. 8.

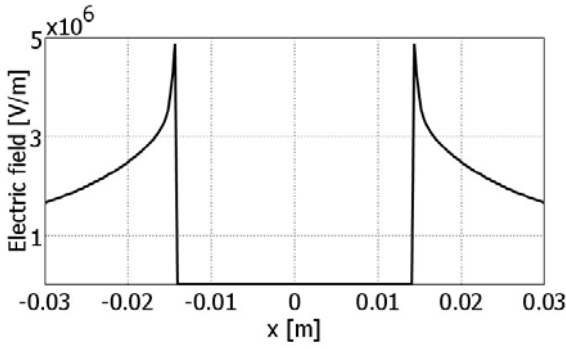


Fig. 7. Electric field strength vector magnitude of the real conductor, along  $x$ -axis ( $\varphi=0$ ).

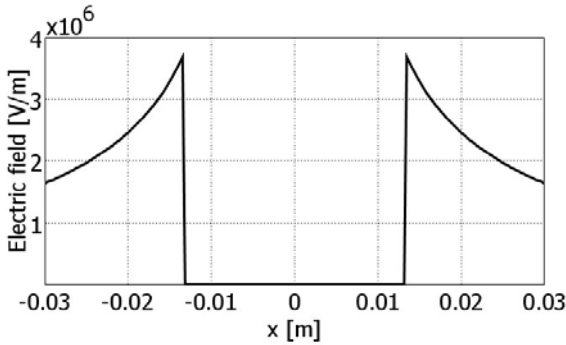


Fig. 8. Electric field strength vector magnitude of the simplified model, along  $x$ -axis ( $\varphi=0$ ).

As expected, the maximal values of electric field strength vector magnitude appear at the points most distanced from the real conductor's axis (4.898 MV/m) and these values are bigger than the corresponding values of the simplified model, which are 3.713 MV/m. The difference between the results leads to the conclusion that the previously defined model, in the case of electric field strength vector calculation is much less accurate comparing with the cases of current distribution, magnetic field or resistance per unit length calculation [1]–[4].

Obviously, corona effect will be more emphasized in vicinity of a real conductor, than close to a simplified model, but the volume of ionized air is smaller comparing to the model. This means that the model might properly describe the corona effect losses as well, but it must be investigated in the future. Moreover, the real case is not electrostatic one, so two more effects, skin effect and proximity effect will take part of electric field determination.

Electric field strength vector magnitude for bundled real ACSR conductors,  $2 \times 490/65\text{mm}^2$ , again at 400kV voltage level, with the standardized distance between the bundled conductors,  $d = 400\text{mm}$ , is shown in Fig. 9, while the same case for the simplified model is presented in Fig. 10. The same cases are presented also as the diagrams of electric field strength vector magnitude as the functions of  $x$ -axis, are presented in Fig. 11 and Fig. 12.

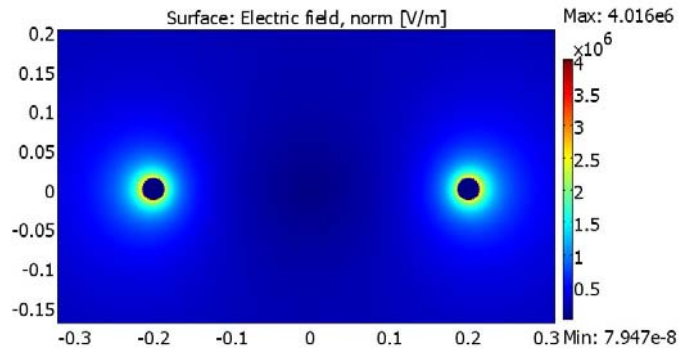


Fig. 9. Electric field for two bundled, real conductors.

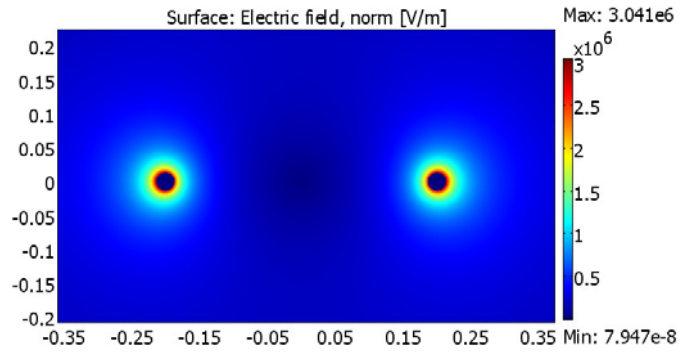


Fig. 10. Electric field for the simplified model of two bundled conductors.

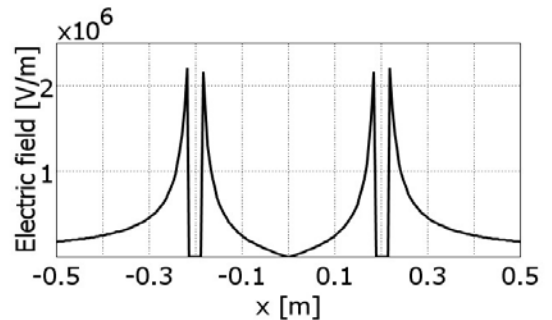


Fig. 11. Electric field strength vector magnitude of two real bundled conductors, along  $x$ -axis ( $\varphi=0$ ).

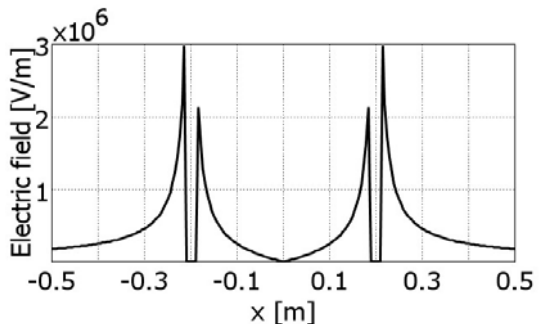


Fig. 12. Electric field strength vector magnitude of the simplified model of two bundled conductors, along  $x$ -axis ( $\varphi=0$ ).

In order to decrease the corona effect, in electric transmission system practice the conductors are frequently bundled or even tripled or multiplied. The result of coupling conductors is obvious from Fig. 9 to Fig. 12. In the case of two real bundled conductors, maximal electric field strength vector magnitude ( $E_{max} = 4.016$  MV/m) is smaller than at the surface of a single conductor ( $E_{max} = 4.898$  MV/m). As well known, this means that the losses due to the corona effect, at double increased transmission capacities, are smaller comparing the case with the single conductor power transmission systems.

## V. CONCLUSION

Investigations of electric field distribution in vicinity of real standardized high voltage ACSR and ACCR conductors, as well as their simplified models, gave expected results. Electric field strength vector magnitude of real conductors has the biggest value at the conductor's points the most distanced from the conductor's axis. In the presented cases the magnitude values are bigger than 3 MV/m, provoking ionization in the air. The magnitude decreases rapidly with increasing distance from the conductor's axis for all investigated cases.

As expected, the simplified model of single or two bundled conductors, which was an excellent approximation regarding current distribution across the conductor's cross-section, magnetic field and conductor's resistance per unit length, does not give an appropriate picture of electric field distribution close to the conductor's surface. As shown in the paper, the places and the values of electric field strength vector magnitude, produced by real conductor or its simplified model, differ significantly, close to the conductor's surface, outside the conductor. These differences decrease with increasing distance from the conductor's axis.

In the case of two bundled conductors it was shown again that the corona effect is less emphasized and that electric field between the conductors is negligible. This fact is also important for an electromagnetic environment pollution point of view, because the electromagnetic field is smaller even in vicinity of high voltage power electrical transmission systems.

The results presented in this paper could also be applied in electrical transmission systems planning and construction.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] K. Kasaš-Lažetić, M. Prša, N. Mučalica, V. Bajović, "Electromagnetic Field and Resistance per Unit Length of Single and Two Coupled ACSR Conductors," (in Serbian), 54<sup>th</sup> Conference on electronics, telecommunications, computing, automation and nuclear techniques ETRAN 2010, Donji Milanovac, Serbia, Paper No EE1.6-1-4. Abstract proceedings, pp. 30, 2010.
- [2] K. Kasaš-Lažetić, M. Prša, N. Mučalica, "More Precise Determination of Frequency Dependent Radiuses of Steel Cored Aluminum Conductors," (in Serbian), International scientific – professional symposium Infoteh-Jahorina 2011, Jahorina, Bosnia and Hercegovina, Vol 10. Ref D-13 pp. 334-338, 2011.
- [3] M. Prša M., K. Kasaš-Lažetić, N. Đurić, "Determination of Frequency Dependent Radiuses of Steel Cored Aluminum Conductors," 2nd International Conference on EMF-ELF, Paris, France, Paper No A-P-05 pp. 117-123, 2011.
- [4] N. Mučalica, M. Prša, K. Kasaš-Lažetić, D. Mučalica, "Determination of Frequency Dependent Radiuses of Two Coupled Steel Cored Aluminum Conductors," (in Serbian), International scientific – professional symposium Infoteh-Jahorina Jahorina, Bosnia and Hercegovina, Vol 10. Ref D-12, pp. 330-333, 2011.
- [5] COMSOL MULTIPHYSICS, CLS 3.5a documentation 2008.
- [6] B. D. Popović, Electromagnetics, 2<sup>nd</sup> ed., (in Serbian), Beograd: Građevinska knjiga, 1986. pp. 23-27.
- [7] "Ropes for overhead lines", brochure in PDF format, (2010), retrieved February 13, 2015, from [http://www.elka.hr/media/katalog/14/alu-celicna\\_uzad\\_za\\_nadzemne\\_vodove.pdf](http://www.elka.hr/media/katalog/14/alu-celicna_uzad_za_nadzemne_vodove.pdf)
- [8] „3M™ Aluminum Conductor Composite Reinforced (ACCR)“, Catalog in PDF format, issued by the manufacturer.
- [9] D. Herceg, K. Kasaš-Lažetić, M. Prša, N. Mučalica, "Determination of magnetic characteristics of some ferromagnetic structures," (in Serbian), XI International scientific – professional symposium Infoteh-Jahorina 2012, Jahorina, Bosnia and Hercegovina, Vol 11. Ref ENS 1.8 pp. 104-107, 2012.