Refinement of Underground Power Cable Ampacity by Multiphysics FEA Simulation

Simon Dubitsky[1], George Greshnyakov[2], and Nikolay Korovkin[3]

[1]Tor Ltd., St. Petersburg, Russia
[2] Research Institute "Sevkabel", St. Petersburg, Russia,
[3]St. Petersburg State Polytechnical University, Russia

Abstract— The maximum current in underground cable line is limited by the rated temperature of conductor and insulation. The standard method for ampacity calculation in accordance the IEC 60287 standard is quite accurate for individual power lines laid in accordance to standard practice. However, when multiple power lines should be placed together in a limited space, it is necessary to consider the electromagnetic and thermal influence of cables to each other. The increase of losses due to mutual influence of cables may be greater than is commonly believed.

It is shown that the use of electromagnetic and thermal FEA simulation successfully solves this problem not only in the context of research, but also in the engineering practice. The FEA-based approach and the software tool is proposed for calculation ampacity of underground cable lines.

The electromagnetic FEA simulations can also assess the electromagnetic environment near power lines and quantitatively evaluate the effect of magnetic shielding.

The proposed method can be used in cases where the standard IEC 2087 calculation gives unreliable results due to unusual cable line formation, inhomogeneous soil, presence of metallic or concrete supports and other difficulties.

Keywords—Cable ampacity, buried cable, finite element analysis, multiphysics, magnetic shielding, proximity effect, cable duct bank

I. INTRODUCTION

The rated current of the underground electric power cable line is limited by the maximal allowable temperature of cable conductor, given by the standard or the cable manufacturer. The temperature raise in turn depends on resistive and dielectric losses in cable as well as on thermal conductivity of cables materials and the ability of surrounding media to conduct and dissipate the heat flux.

To calculate the ampacity of the cable line one must first

S. D. Dubitsky is with Tor Ltd., St. Petersburg, Russia (phone: +7 812 710 1659; e-mail: simon@tor.ru).

G. V. Greshnyakov, is with Sevkabel plant, R&D Department, St. Petersburg, Russia. He also works with the Department of Cable Engineering, St. Petersburg State Technical University, Russia (e-mail: g.greshnyakov@sevkab.ru).

N. V. Korovkin is a head of Electromagnetic Theory Department, St. Petersburg State Technical University, Russia (e-mail: nikolay.korovkin@gmail.com).

assess the AC resistive losses in conductive cable elements: conductor, screen and armor.

The classical method of ampacity calculation is given by the IEC 60287 standard. Its theoretical background is a Neher-McGrath model [2], which was generalized later by many authors, in particular G.J. Anders [3]. The Neher-McGrath model relies on the thermal equivalent circuit technique. The parameters of the equivalent circuit are calculated by using a simplified 1D-model of the thermal field. Electromagnetic part of a calculation intended to assess the resistive and dielectric losses in the cable, is also based on a simplified model of the skin effect and proximity effects.

Taking into account the details of cable laying in full extent lead to the fact that manual calculation of the ampacity according to IEC 60287 standard is a challenging and cumbersome task. Therefore a number of software tools are proposed for both professional use (like CymCap) and for education [16].

When the cables are located close to each other, it is necessary to take into account their thermal and electromagnetic interference. Electromagnetic interference is the proximity effect and the skin effect, and the fact that, depending on the chosen grounding mode, the screens and sheaths appear electrically connected into a closed loop.

Many authors noted insufficient accuracy of the standard methods of evaluating the proximity effect. For example, the paper [17] describes the special study of electromagnetic interaction of subsea cables, which has the metallic armor thicker than usual.

The thermal interference is that neighboring cables warm up to each other and the surrounding soil. Accounting of the mutual heating is especially complicated when cables are laid out in the open air or in restricted airspace - in a pipe or a rectangular conduit. In such case, the multiphysics model should be supplemented with fluid dynamics analysis.

Today FEA software [12] allows combining into a single model the AC electromagnetic analysis, grounding electric circuit, and the thermal analysis. Because the material properties, such as electric resistivity, depends on the temperature, one have to repeat electromagnetic and thermal analyses iteratively until the solution converges. Complexity of

the model, however, is quite acceptable for engineering practice.

The advantages of FEA model is particularly evident when power cable line has rather complex structure of the , i.e. includes soil layers with different properties, strong electromagnetic interference between cables, metallic supporting structure, crossing pipelines e.t.c.

In this paper, we consider only steady-state cable ampacity calculation. Nevertheless, the FEA based approach, allows the ampacity calculation in transient conditions: the long-term transient, where the a priory known load curve allows a short-term uprating due to the inertia of thermal processes, and short-term transient, such as the raise of cable temperature due to short circuits of different kinds.

The history of FEA analysis for cable ampacity calculation begins presumably with [4], where the transient heat transfer FEA analysis was used three-phase buried cable line. Later many authors have contributed to application of the FEA technique for accurate predicting the ampacity of a cable line. Those include: clarification of the model geometry – the shape and the size of modelling area, optimal mesh density [5], short-term and long-term transient simulations [6], [7], taking into account the effect of the temperature on the cable losses, combining the heat transfer analysis with fluid dynamics [8], [9], estimation of resistive AC losses using the electromagnetic FEA model [10]. The accumulated engineering experience of the FEA simulation of the temperature field of cable lines was summarized in the IEC technical report [11].

The contribution of this paper is the combining of AC magnetic FEA simulation, Kirchhoff's equations of the grounding circuit , and steady state heat transfer FEA analysis into a single model of the power cable line.

II. ELECTROMAGNETIC MODEL

A. Equations of AC Magnetic Field

The governing equations of quasi-stationary magnetic field in frequency domain are written with respect to the phasor of the vector magnetic potential **A**, which has in the 2D-domain only one nonzero component $A = A_z$ [11]:

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A}{\partial y}\right) = -j_{extern} + j\omega\sigma \cdot A, \qquad (1)$$

where μ – is the absolute permeability (H/m), σ – electric resitivity (S/m), ω – cyclic frequency (rad/s), j_{extern} – the external current density (A/m^2).

The need of taking into account of the grounding circuit (with one end, with two ends or with transposition) requires combining the field equation (1) with the Kirchhoff's equation of the connected circuit. The equation of a circuit branch containing a solid conductor in magnetic field looks like this:

$$I = \frac{U}{R} = -\sigma\int_{\Omega} i\omega A \cdot ds, \qquad (2)$$

where U – is the conductor voltage drop (V), R – the DC resistance (Ohm), The integration is made over the conductor's

cross-sectional area Ώ.

Solving the equations (1) and (2) one obtains the distribution of the current density in all conductive parts of the model: conductor, shield, metallic sheath, and some metallic supporting structure.

B. Model Geometry

With two dimensional electromagnetic FEA simulation the model geometry contains the cross-sections of all cables, buried into the soil on the given depth. The left and right side borders of the modelling area located far enough to assign on it the no-field border condition.

Our experiments show that for a model containing one cable line increasing the model width over 15 m does not effect on the solution accuracy. The model allows taking into account the electric conductivity of soil as well as supporting metallic parts or pipes nearby.
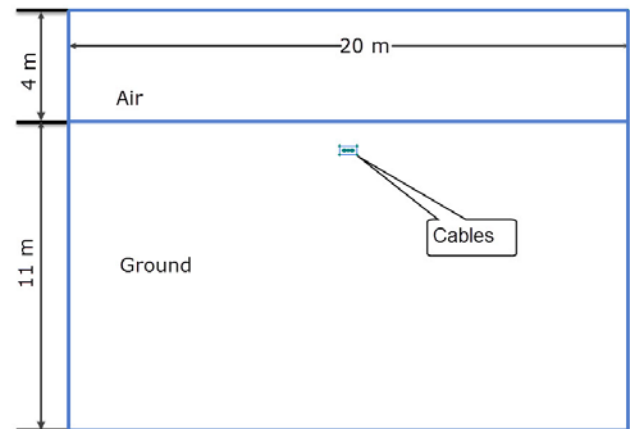

Fig. 1 The model geometry

The discretized cross section of the cable is shown on the figure 2.

In the real world, the conductive parts of the cable are made from separate wires or strips. Constructing the FEA model one can include the detailed geometry of wires or replace them by a solid metal cylinder. In many cases, the conductor wire structure plays an important role and cannot be neglected, for example with modelling of a pulse mode, high frequency losses and others. In our case – the steady state simulation by the fundamental frequency – the exact representation of the conductor's structure does not increase the accuracy, but requires much more resources. Moreover, the exact modelling of the wires is not an easy task because of some uncertainty of the shape of deformed wires and the contact resistivity between them.
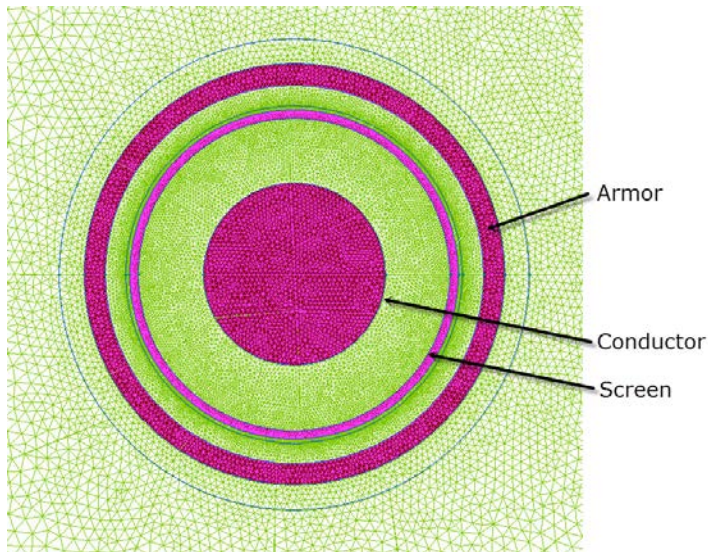
Fig. 2 The cable cross section with the FEM mesh

A separate question is how to choose properly the cross section and the conductivity of the solid cylinder representing the stranded conductor. In our experience, the best results can be obtained by choosing the inner and outer diameters of the conductor the same as in reality. Acting in this way we set the total cross sectional area a bit more than the sum of cross section area of all wires. To compensate that we propose proportionally decrease the electric conductivity and the thermal conductivity of the simplified conductors.

C. Single Point and Both Ends Grounding

The shield of a cable section can be grounded with one side or with two sides. With two-side grounding the closed loop is formed for circulating current. This current is induced by the alternating magnetic field created by the cable conductor current. The one-side grounding does not provide the loop for induced currents. On the other hand on the unbounded end of the cable shield the induced voltage is observed, that should be limited for sake of safety. We have to note that even with one-side grounding of the cable having both a screen and metallic sheath, these two are always electrically connected with both sides of the cable. This forms a closed loop for circulated current even with one-side grounding.

Presence or absence of a closed loop significantly affects on the amount of losses in the shield and sheath. To consider those one have to couple field equations (1) with the circuit equations (2).
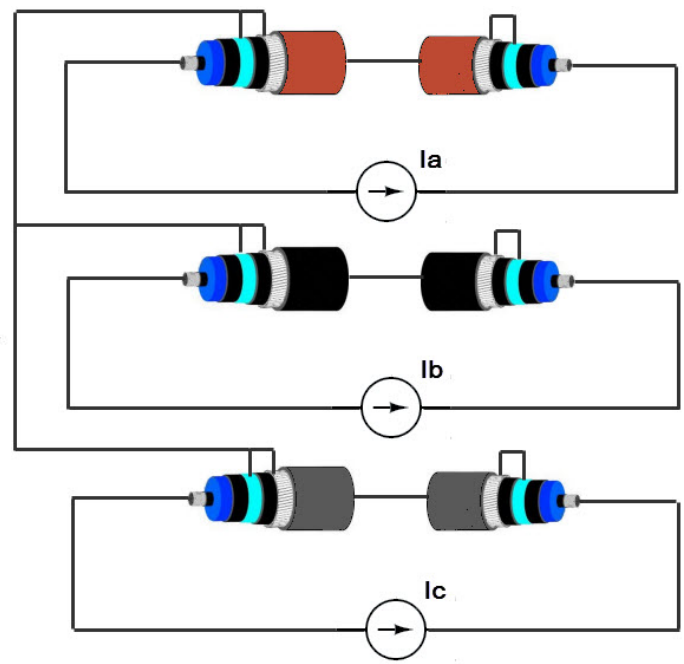
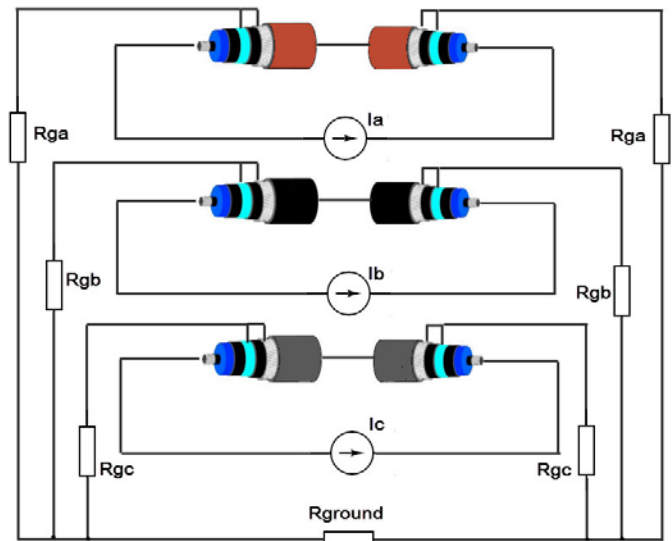Fig. 3 Grounding the cable with one side

Fig. 4 Grounding the cable with two sides

The values of resistance in the grounding scheme are known with some degree of uncertainty. Therefore, we evaluated the sensitivity of the FEA solution to the values of the resistances R_{gX} and R_{ground}. The study shows that the variation of resistance R_g in the range from 1 to 10 Ohms has virtually no effect on the integral value of losses. The earth resistance R_{ground} has almost no effect for our model until the three phase cable loading is symmetric and zero sequence current is almost zero.

D. Dielectric Losses

According to IEC 60287-1-1 the dielectric losses per unit length of the cable can be calculated by the known value of the dielectric loss factor tgδ:

$$W_d = \omega C U^2 \cdot tg\delta , \qquad (3)$$

where ω = 2πf, C is the capacitance per unit length (F/m), U_o – is the voltage to earth (V).

The capacitance of a cylindrical capacitor is calculated by:

$$C = \frac{2\pi\varepsilon\varepsilon_0}{\ln\left(\frac{D_i}{d_c}\right)} \qquad (4)$$

As long as we remain in the class of cables and conductors with cylindrical conductors and screen screens the refinement of formulas (3) and (4) by means of FEA is not required. The FEA model of dielectric losses may be needed for more complex geometry configurations such as cable joint and termination.

III. HEAT TRANFER MODEL

The thermal state of the loaded power cable line is defined by the partial differential equation of thermal conductivity. With steady state analysis it is reduced to:

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right) = -q, \qquad (5)$$

where T is the temperature (K), t – time (c), λ – the thermal conductivity (W/(m·K)), q – the heat source density (W/m³).

The thermal conductivity equation (5) is solved numerically on the same computational domain as the magnetic field equation (1) (see fig. 1) with the difference that the air above the ground surface is excluded from the domain. On the side boundaries of the domain we define the boundary condition of thermal insulation, on the bottom border – an isothermal boundary condition with the value of 4 deg. C, which is almost constant throughout the year. On the earth surface the convective boundary condition is set with the ambient temperature $T_0=25 \ deg \ C$ and the convection coefficient α. The suitable value of the convection coefficient we choose by the dimensionless empirical equation:

$$Nu = 0.54 \cdot (\mathrm{Pr} \cdot Gr)^{0.25}, \qquad (6),$$

where Nu is the Nusselt number, Pr is the Prandtl number, and Gr is the Grashof number.

From (6) obtain the convection heat transfer coefficient α:

$$\alpha = Nu \cdot \frac{\lambda}{L_{ref}}, \qquad (7)$$

where L_{ref} is a characteristic length of the model.

Using the equation (6) takes into account the average wind speed if such data are available.

IV. SIMULATION RESULTS

The long-term research agenda in FEA modeling of coupled electromagnetic and thermal fields of underground power cable lines is as follows:

1. Formulate the mathematical model, evaluate the impact of the assumptions made;
2. Obtain FEA solution for the standard practice of cable laying – the flat and trefoil formations, compare results of FEA model with IEC 60287 calculation and tune the FEA-model;
3. Identify the cable formations where the IEC 60287

standard gives not enough accuracy in thermal state due to high influence of cables to each other;
4. Develop the software tool for gradual replacement IEC calculation by FEA modeling where it is applicable.

Here we discuss pp, 1 and 2, and some preliminary considerations about p. 3.

A. FEA Model of Common Cable Formations

The modern approach to field simulation in electrical equipment often is multidisciplinary [13] in order to catch the mutual interference of processes from different domains of physics.

The steady-state simulation loop begins with magnetic field simulation (1.) for obtaining the spatial distribution of the restive losses. The calculated resistive losses are summed up with the dielectric losses (2.) and transferred to the heat transfer analysis (3.). The thermal simulation gives us the temperature field, which is used for adjusting the conductivity of copper and aluminum (4.). Then the loop (1. – 4.) is repeated until the solution converges (normally 3-4 loops is sufficient).

The simulated cases include the flat cable formation (fig. 5 and 6) and the touching trefoil formation (fig. 7, 8).
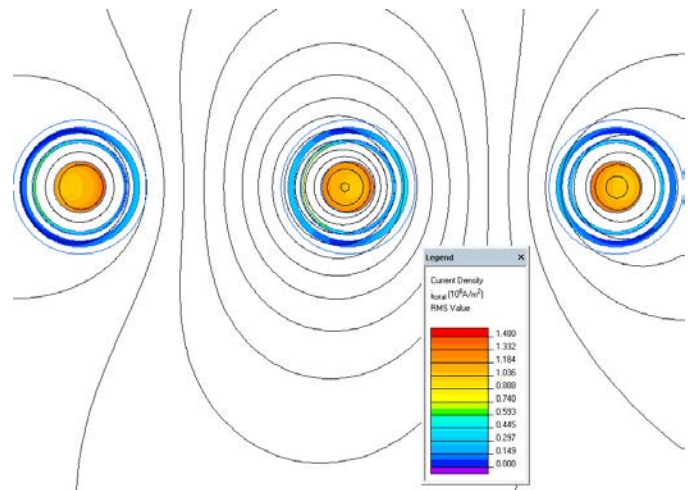

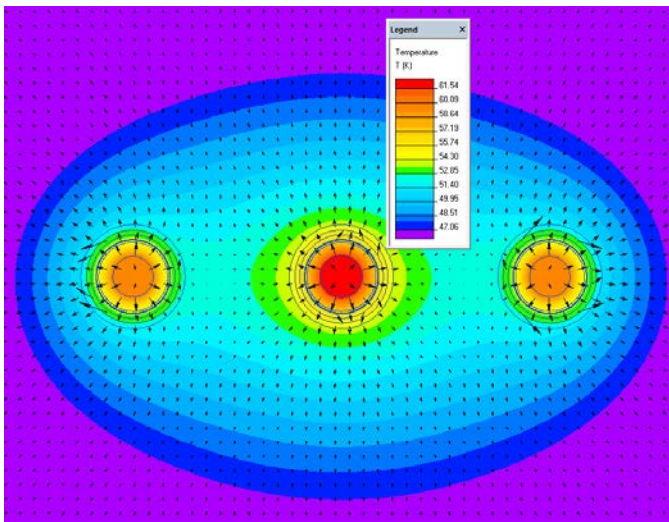Fig. 5 Magnetic field and current density with line cable formation

Fig. 6 Temperature field and heat flux vectors with line formation
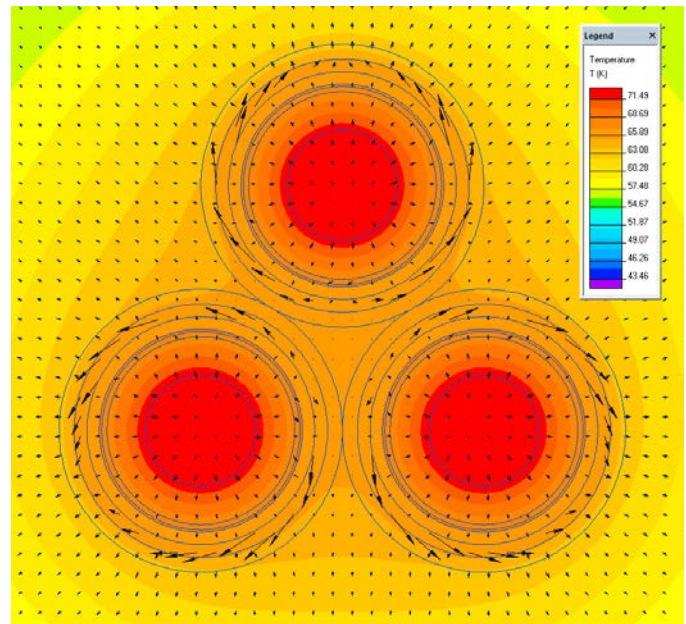

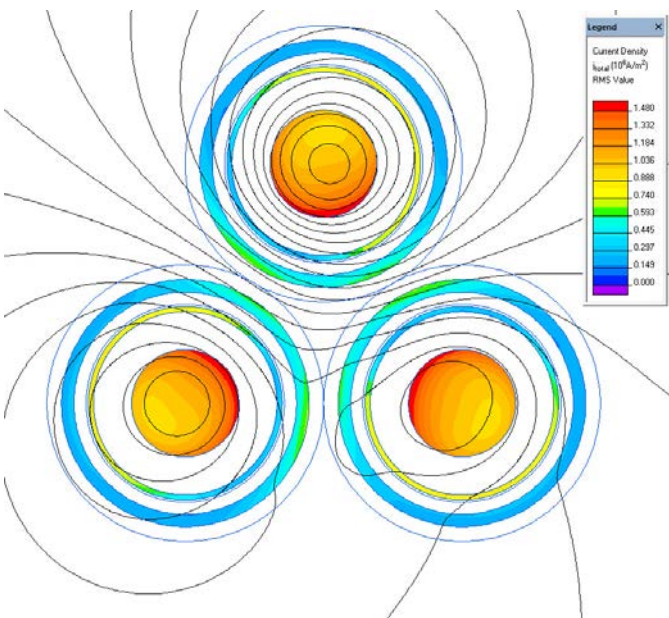Fig. 8 Temperature field and heat flux with triangle formation

Fig. 7 Magnetic field and current density with triangle formation

The resistive losses in cable conductors, screens and sheaths with two different formations are summarized in the table 1:

Table 1: Resistive losses in cable elements

CURRENTS AND LOSSES: GROUNDING WITH BOTH SIDES

		LAYOUT IN LINE				LAYOUT IN TRIANGLE		
		PHASE B	PHASE A	PHASE C		PHASE A	PHASE B	PHASE C
CONDUCTOR	Current, A	700	700	700	Current, A	700	700	700
	Losses, kW/km	15.27	15.27	15.27	Losses, kW/km	15.57	15.57	15.57
SCREEN	Current, A	47.6	50.4	47.5	Current, A	75.9	76.3	76.1
	Losses kW/m³	1.07	0.93	1.09	Losses kW/m³	1.52	1.53	1.53
ARMOUR	Current, A	27.3	32.9	27.3	Current, A	62.1	58.0	58.2
	Losses kW/m³	0.72	0.73	0.74	Losses kW/m³	3.03	3.03	3.04

B. Cable Duct Bank Analysis

In urban areas is often needed to lay a number underground power cable lines in a limited space. For example, in St. Petersburg, Russia, the input of eight 110 kV cable lines and two 330 kV lines to the Vasileostrovskaya substation should be constructed in a well developed urban area under the street with heavy traffic. Another complication is that the owners and designers of different lines are different. The common part of all ten lines is the 400 meter long corridor, which can be implemented as a concrete duct bank shown in the fig. 9.

The individual cables in the duct bank affects to each other in both electromagnetic and thermal ways. The electromagnetic influence is that the alternative current in each conductor induces eddy currents in conductors and shields of other cables. The induced currents critically depend on screen grounding with one side, both sides or with transposition. Anyway, the induced eddy currents create stray losses in all cables.

We have developed a script creating the geometric model of virtually arbitrary underground cable system. The complete

installation is described in XML using the specially designed XML-scheme. That provides good flexibility, semi-automatic syntax checking, and allows easily create a suitable graphical user interface, if necessary.

failure mode the transient thermal analysis is needed to know for how long time each line can be overloaded. The significant amount of calculation requires some software tool or script to automate repetitive tasks.
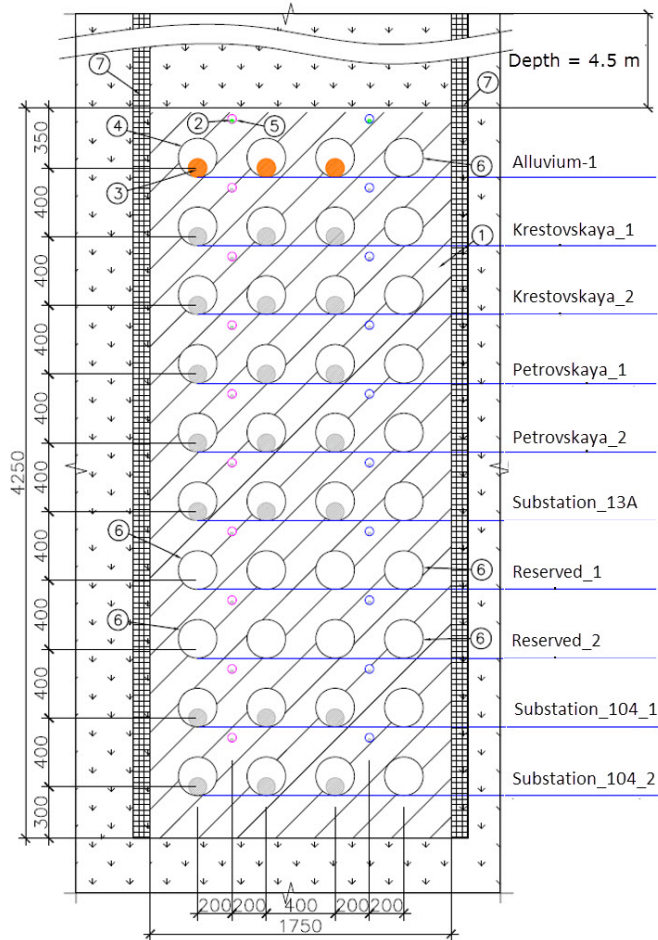
Fig. 9 The concrete duct bank

The computational scheme remains mostly the same as described above. We start with AC magnetic analysis coupled with grounding electric circuit. Electromagnetics analysis allows to estimate the increase of Ohmic losses due to proximity and skin effect (fig 10).

Next, the calculated Ohmic losses are summed with dielectric losses and transferred to the thermal analysis, either steady-state or transient one.

The assumption that needs to be verified and validated is the replacement the convective and radiative heat transfer inside the duct to an equivalent conductive heat transfer. To do that we choose some equivalent value of heat conductivity for the air inside the duct, which is four time greater when the heat conductivity of air by the same temperature and pressure. It is considered that this replacement to certain extent is equivalent to the convective and radiative heat transfer from the cable to the internal surface of the duct.

For successful design of the duct bank the extensive series of calculation should be done, with both normal operational load and various failure modes, when one or two lines switched off whereas some other are overloaded. In heavy
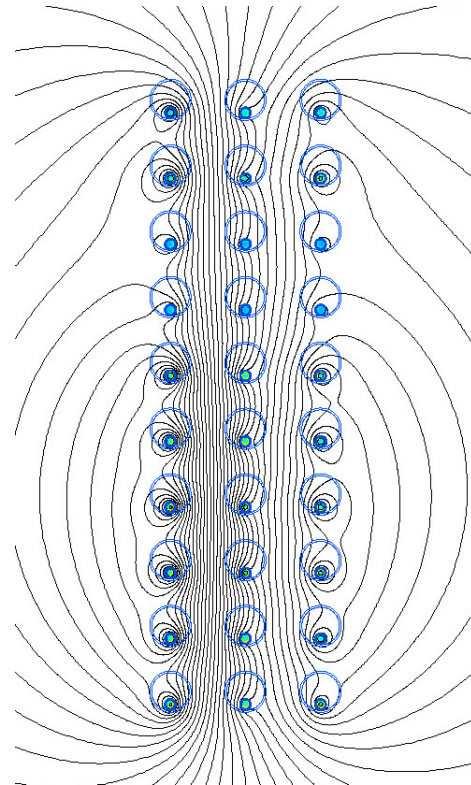
Fig. 10 Electromagnetic field in the cable duct bank

located close to the center of the duct bank. The value of this ration as high as 1.92…1.98 should be considered by planning

Table 2: Losses and temperature of the cables in the duct bank

| Line	Current	Cond. CrossSect	DC Losses I²R	Phase A (left)					Phase B (centered)				
				Conductor			Screen		Conductor			Screen	
Name	A	mm²	W/m	Temperature, deg C	Losses, W	AC / DC Loss Ratio	Temperature, deg C	Losses, W/m	Temperature, deg C	Losses, W/m	AC / DC Loss Ratio	Temperature, deg C	Losses, W/m
Alluvium-1	232	1400	662.9	50.9	947.9	1.43	50.9	14.3	51.8	980.0	1.48	51.7	32.2
Krestovskaya_1	366	1200	1924.7	59.5	2 555.5	1.33	59.4	20.1	61.0	2 621.3	1.36	60.8	60.8
Krestovskaya_2	366	1200	1924.7	65.2	2 560.9	1.33	65.0	23.3	67.0	2 643.4	1.37	66.8	74.6
Petrovskaya_1	286	800	1762.8	70.0	2 074.4	1.18	69.8	24.8	72.0	2 130.6	1.21	71.9	74.0
Petrovskaya_2	286	800	1762.8	75.5	2 082.8	1.18	75.4	32.1	78.1	2 149.9	1.22	77.9	90.7
Substation_13A	351	2000	1062.1	81.3	1 864.9	1.76	81.2	61.9	84.9	2 101.9	1.98	84.8	169.4
Reserved_1	1000	2500	6896.6	100.2	12 659.3	1.84	99.6	97.8	105.6	13 262.5	1.92	104.9	333.1
Reserved_2	1000	2500	6896.6	100.3	12 661.9	1.84	99.6	97.4	105.7	13 278.0	1.93	105.0	339.3
Substation_104_1	446	1400	2449.7	83.4	3 519.9	1.44	83.2	63.0	87.0	3 727.8	1.52	86.8	179.2
Substation_104_2	446	1400	2449.7	74.9	3 477.0	1.42	74.7	39.0	77.0	3 571.1	1.46	76.8	91.7
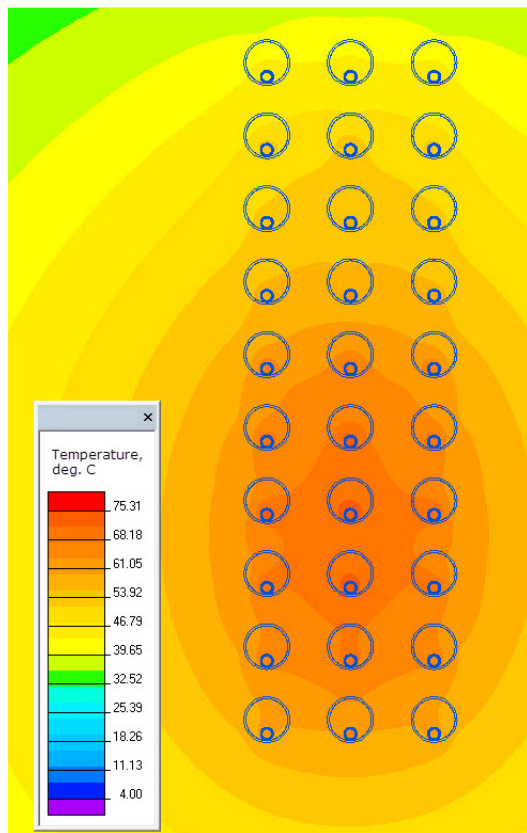
Fig. 11 Steady-state temperature field in the duct bank

The calculation result of one of normal operation mode of the duct bank is show in the table 2. The table two gives the data for further analysis. In particular, it is of interest the increasing of Ohmic losses due to proximity effect. The AC/DC loss ratio is, as expected, much higher for the cables

the load of each individual line.

V. CONCLUSION

Proposed further development of prediction the ampacity of underground cable line using multiphysics FEA simulation. The main contribution is the detailed consideration of cable grounding, taking into account more than one electromagnetic screen (namely the copper shield and the aluminum sheath). The proposed approach combines in a single model the AC magnetic FEA simulation, the grounding circuit, and the heat transfer FEA. The first two parts coupled by the strong link, i.e. they produced a single matrix after discretization. The magnetic and thermal parts of the model a coupled together by a two-directional loose (consecutive) link.

The FEA based calculation gives almost the same result as the standard IEC 60287 calculation when the construction of the cable line is ordinary. The dedicate software gives the answer almost as quickly as the IEC based software.

Benefits of the multiphysics FEA appears in situations more complex than those described in the standard, such as heterogeneous soil with thermal backfill, using of steel or concrete supporting construction. An important case is a line with two or more circuits.

Benefits of the FEA simulation also expected with very rapid transient conditions, such a direct lightning stroke [14].

Moreover, the FEA simulation of magnetic field gives exhaustive information about inductive interference of two or more circuits, both cable and overhead ones. In addition, the external magnetic and electric field profiles on the earth surface can be obtained. The minimization problem of external electromagnetic field from the point of view of circuit theory

was investigated in very general way [18-21] as an inverse problem of circuit theory. The FEA model also gives comprehensive information to fulfill the rules of electromagnetic ecology and designing magnetic shielding when needed.

REFERENCES

[1] IEC Standard-Electric Cables – Calculation of the Current Rating – Part 2: Thermal Resistance – Section 1: Calculation of the Thermal Resistance, IEC Standard 60287-2-1, 1994–12

[2] J. H. Neher, M. H. McGrath, "Calculation of the temperature rise and load capability of cable systems," AIEE Trans., Vol. 76, Part 3, 1957, pp. 755-772.

[3] G. J. Anders Rating of electric power cables: ampacity computations for transmission, Distribution, and Industrial Applications. - McGraw Hill Professional, 1997, 428 c

[4] N. Flatabo Transient heat conduction problems in power cables solved by the finite element method. -IEEE Trans. on PAS. Jan, 1973 pp. 56-63

[5] [5] Aras F., Oysu C., Yilmaz G. An assessment of the methods for calculating ampacity of underground power cables //Electric Power Components and Systems. – 2005. – T. 33. – №. 12. – C. 1385-1402

[6] Liang Y. Transient temperature analysis and short-term ampacity calculation of power cables in tunnel using SUPG finite element method //Industry Applications Society Annual Meeting, - IEEE, 2013. - C. 1-4.

[7] Haripersad P. Uprating of cable current capacity for Utilities where load cycle profiles are known - Cigre 2005 Regional Conference paper, Capetown

[8] Sedaghat A., de Leon F. Thermal Analysis of Power Cables in Free Air: Evaluation and Improvement of the IEC Standard Ampacity Calculations. - IEEE Transactions on Power Delivery

[9] Mahmoudi A., Kahourzade S., Lee D. S. S. Cable ampacity calculation in heterogeneous soil using Finite Element Analysis //Power Engineering and Optimization Conference (PEOCO), 2011 5th International. – IEEE, 2011. – C. 416-421

[10] Labridis, D.; Hatziathanassiou, V. "Finite element computation of field, forces and inductances in underground SF6 insulated cables using a coupled magneto-thermal formulation", Magnetics, IEEE Transactions on, On page(s): 1407 - 1415 Volume: 30, Issue: 4, Jul 1994

[11] IEC Technical Report TR 62095, Electric Cables—Calculations for Current Ratings—Finite Element Method, 2003

[12] Claycomb J. R. Applied Electromagnetics Using QuickField and MATLAB. – Laxmi Publications, Ltd., 2010.

[13] Dubitsky S. D., Korovkin N.V., Hayakawa, M.; Silin N.V., Thermal resistance of optical ground wire to direct lightning strike //Electromagnetic Theory (EMTS), Proceedings of 2013 URSI International Symposium on. – IEEE, 2013. – C. 108-111.

[14] Korovkin N.V., Greshnyakov G.V., Dubitsky S.D. Multiphysics Approach to the Boundary Problems of Power Engineering and Their Application to the Analysis of Load-Carrying Capacity of Power Cable Line - Electric Power Quality and Supply Reliability Conference (PQ2014), 11-13 June 2014, Rakvere, Estonia

[15] Gómez F. Á. et al. Numerical study of the thermal behaviour of bare overhead conductors in electrical power lines //Proceedings of the 10th WSEAS international conference on communications, electrical & computer engineering, and 9th WSEAS international conference on Applied electromagnetics, wireless and optical communications. – World Scientific and Engineering Academy and Society (WSEAS), 2011. – C. 149-153.

[16] Aras, F. A. R. U. K., Yunus Bicen, and M. E. L. I. H. Inal. "Computer Assisted Teaching Of Underground Power Cables (Powcabgui) For Graduate Students." WSEAS Transactions on Advances in Engineering Education 3.8 (2006): 760.

[17] Chien, Chang Hsin, and Richard Bucknall. "Evaluation of the proximity effect upon the impedance characteristics of subsea power transmission cables." WSEAS Transactions on Power Systems 1.7 (2006): 1141.

[18] Adalev A.S., Hayakawa M., Korovkin N.V., Nitsch J.B., De-embedding and unterminating microwave fixtures with the genetic algorithm IEEE Transactions on Microwave Theory and Techniques. 2006. T. 54. No. 7. C. 3131-3139.

[19] Korovkin N.V, Adalev A.S., Hayakawa M. De-embedding microwave fixtures with the genetic algorithm В сборнике: IEEE 6th International Symposium on Electromagnetic Compatibility and Electromagnetic Ecology, 2005, Proceedings IEEE 6th International Symposium on Electromagnetic Compatibility and Electromagnetic Ecology, 2005. St. Petersburg, 2005. C. 190-194.

[20] Korovkin N., Kuchinsky G., Kozhevnikov M., Schilin O., Vekhoreva L., Selina E., Potienko A. Compact power high-voltage pulse capacitor for quasi-rectangular nanosecond impulses formation. - in: Digest of Technical Papers-IEEE International Pulsed Power Conference 12th IEEE International Pulsed Power Conference. Monterey, CA, USA, 1999. C. 1449-1452

[21] Korovkin N., Marthe E., Rachidi F., Selina E. Mitigation of electromagnetic field radiated by PLC systems in indoor environment. - International Journal of Communication Systems. 2003. T. 16. C. 417.

Simon D. Dubitsky is currently with Tor Ltd, St. Petersburg. He receives MsC degrees in electrical engineering in 1983 and in computer science in 2003 both from SPbSPU. His main area of activity is development of QuickField FEA software in cooperation with Tera Analysis company locates in Svendborg, Denmark. Main research interest is implementing FEA as a handy tool for everyday engineering practice, advanced postprocessing of electromagnetic field solution, multiphysics FEA analysis coupled with circuit equations and surrogate models.

George V. Greshniakov is currently a head of laboratory in the Sevcabel research institute. He receives the MsC and PhD degrees in electrical engineering from St. Petersburg technical university (SPbSPU) in 1983 and 1992 respectively. He is also a docent in SPbSPU teaching cable and insulation engineering. Author of more than 30 reviewed papers. His research interest is electromagnetics ant thermal analysis of power cable installation and development of advanced cable accessories.

Nikolay V. Korovkin, professor, is currently head of Electromagnetic Theory Department of St. Petersburg State Polytechnic University (SPBSPU). He received the M.S., Ph.D. and Doctor degrees in electrical engineering, all from SPbSPU in 1977, 1984, and 1995 respectively, academician of the Academy of Electrotechnical of Russian Federation, (1996) Invited Professor, Swiss Federal Institute of Technology (EPFL), Lausanne (1997), Professor, University of Electro-Communications, Department of Electronic Engineering, Tokyo, Japan (1999-2000), Professor EPFL (2000-2001), Otto-fon-Guericke University, Germany (2001-2004). Head of the Program Committee of the Int. Symp. on EMC and Electromagnetic Ecology in St. Petersburg, 2001-2011.

His main research interests are in the inverse problems in electro-magnetics, optimization of power networks, transients in transmission line systems, impulse processes in linear and non-linear systems, "soft" methods of optimization, systems described by stiff equations, the problems of the electromagnetic prediction of earthquakes and identification of the behavior of the biological objects under the influence of the electromagnetic fields