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Modeling of Electromagnetic Fields Created by Traction Networks in Emergency Modes

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***Abstract*- In traction power supply systems (TPSS) extreme modes occur in emergency situations with extreme electromagnetic fields (EMF). Short circuit (SC) is one of the extreme modes that lead to considerable current flows in catenary wires with significant growth of magnetic field strengths. SC modes duration is rather small, since they are, as a rule, removed by relay protection rather promptly. Therefore, taking into account EMF effect on personnel during SC short-time modes is inexpedient. However, due to higher values of magnetic field strength, in wires of adjacent disconnected power and communication lines significant induced voltage can emerge, whose even short-time affecting personnel and telecommunications low-voltage equipment can be extremely negative. Procedure of EMF modeling and modeling results are presented in the article. EMF modeling was performed using methods and means for determining modes in traction power supply systems and EMF in phase coordinates developed in Irkutsk State Transport University. The main advantage of the approach offered is the systematic description of extreme modes, where traction network is considered inseparably connected with complex external power supply system.**

Key words- traction network, emergency mode, electromagnetic safety

I. Introduction

Railroad traction networks (TN) are the sources of electromagnetic fields (EMF) of industrial frequency, especially AC systems [1, 2]. Traction network EMF is capable generating interference causing disturbances of electrical and electronic devices' normal functioning [3, 4]. These electromagnetic fields can result in serious personal injuries when operations are conducted on disconnected power supply lines or communication lines, when personnel is subject to induced voltage [5, 6]. High levels of EMF strengths are observed in extreme modes occurring in emergency situations [7].

Short circuit (SC) is one of the extreme modes that lead to considerable current flows in TN wires and rails and significant growth in magnetic field strengths. An usual way of EMF analyses is intensities' calculation with primarily applying of catenary voltage and current [4, 8]. Mode definition usually is calculated separately and often without of accounting of external power system [9, 10]. More aright approach is calculating mode defined by energy sources and traction loads or SC situation. This approach can be made by methods and software executed by article' authors [11].

Below the analysis of electromagnetic safety in SC modes for typical 25 kV traction network is made.

II. Modeling methods

Calculation design of magnetic field strength generated by AC traction network, have been conducted for a typical power supply system shown in fig. 1. Modeling was carried out using Fazonord software application [11] in three stages:

1) calculation of power supply system mode in phase coordinates, the results of which were used to determine potentials and currents of all wires of overhead system and rail lines;

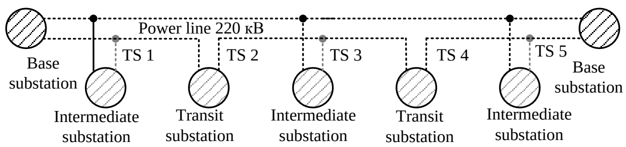

Fig. 1. Circuit of five traction substations power supply

2) based on obtained values of potentials and currents calculations of vertical and horizontal components of electrical and magnetic fields strengths $\dot{E}_x, \dot{E}_y, \dot{H}_x, \dot{H}_y$;

3) calculation of strengths amplitude values $E_{\max}, H_{\max}$ with provision for possible fields elliptical polarization.

III. Modeling Results of Traction Network EMF for Short Circuit Faults

SC currents' calculations were performed for short circuits in traction networks of an inter-substation zone between TS1 and TS2 substations as shown in fig. 1. Lengths of power supply line sections between substations are 50 km, in which case complete transposition of line wires was assumed. Transformer 40000/230/27.5 were modeled in a two-winding option with short circuit voltage equal to 11 %. Overhead system models corresponded to a two-way option 2×(PBSM-95+MF-100+2R-65) with 50 km inter-substation zones.

Fragment of calculating circuit for determination of SC currents in the catenary wires near TS2 substation and EMF calculation are shown in fig. 2. Coordinates of wires and rail lines, assumed in the analysis, are represented in fig. 3. A load mode was modeled for comparison purposes with short circuit, at which in nodes 16 and 17 loads were applied 10 + *j*10 MVA. Mode of catenary wires connected to zero potential point was considered.

The modeling results are summarized in tables I and II and illustrated in fig. 4 – 8. Parameters designations of table I are provided in fig. 2.

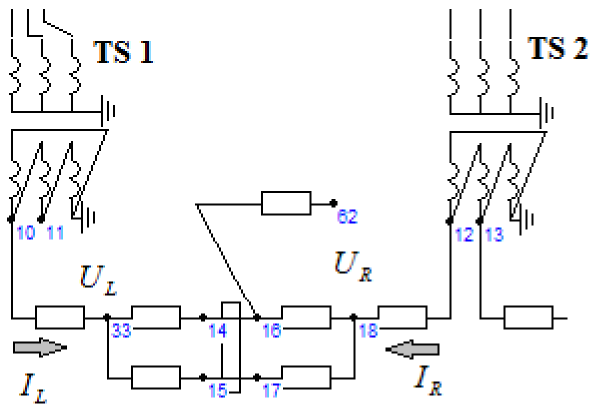

Fig. 2. Fragment of Fazonord' calculating circuit

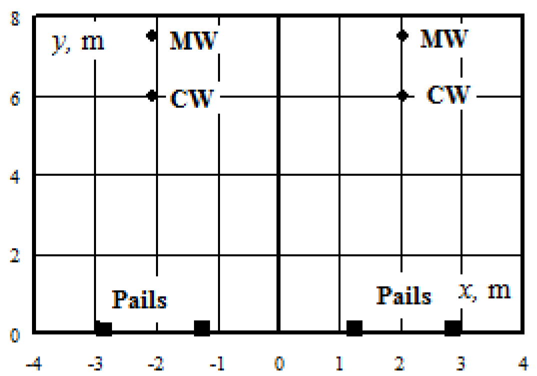

Fig. 3. Conductive elements' coordinates: MW – messenger wire; CW – contact wire

TABLE I – Mode Parameters

Parameter	SC	Loads 10 + *j*10 MVA	Ratio
I_L, A	1180	241	4.90
I_R, A	4461	930	4.80
U_L, kV	19.2	27.2	0.71
U_R, kV	5.7	24.2	0.24

TABLE II – Results of EMF Strength Calculation at the Start of ISZ-1

Parameter	SC		Loads 10 + *j*10 MVA		Difference, %	
	E_{Max}, kV/m	H_{max}, A/m	E_{Max}, kV/m	H_{max}, A/m	Between 1 and 3	Between 2 and 4
	1	2	3	4		
Average	2.24	80.6	3.17	16.5	–41.6	79.5
Maximum	2.55	98.6	3.60	20.2	–41.6	79.5

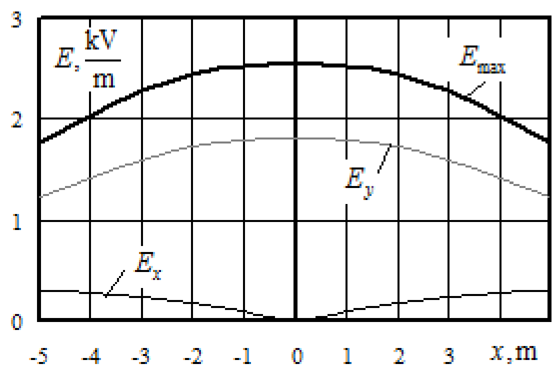

Fig. 4. Dependence of electrical field strength components located on 1.8 m height on *x* coordinate in short circuit mode.

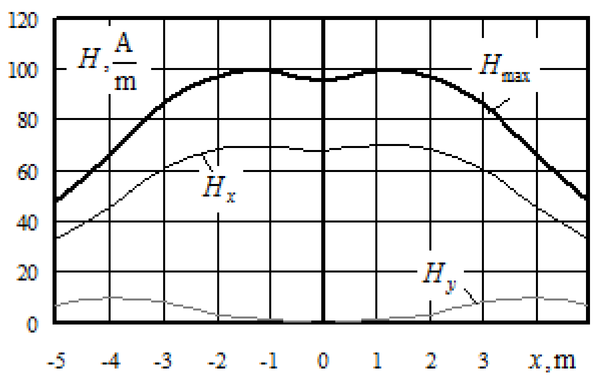

Fig. 5. Dependence of magnetic field strength components located on 1.8 m height on *x* coordinate in short circuit mode.

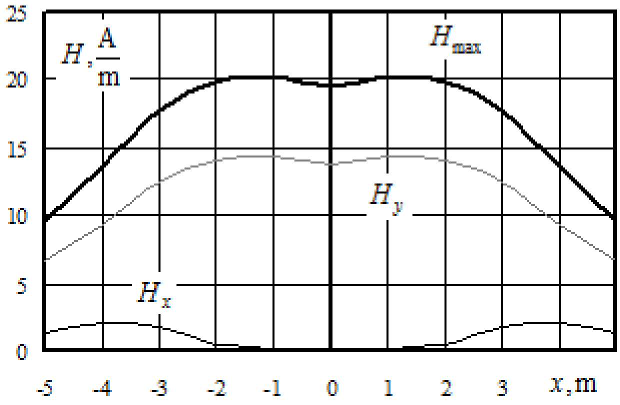

Fig. 6. Dependence of magnetic field strength components located on 1.8 m height on *x* coordinate in the load mode

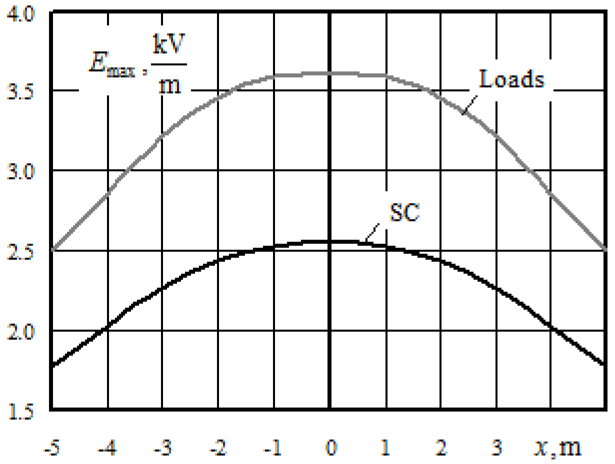

Fig. 7. Comparison of short circuit and load modes' electrical field located on 1.8 m height

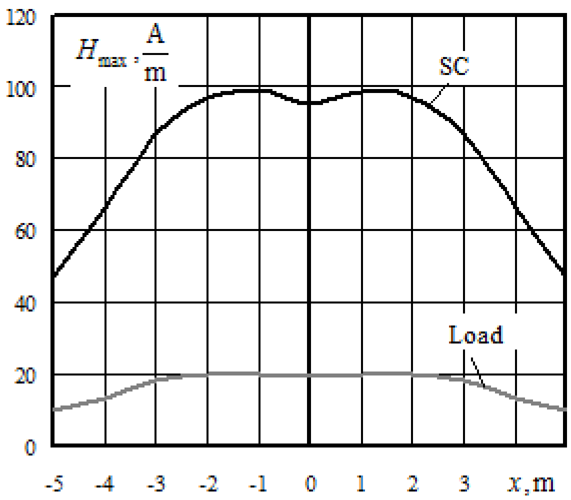

Fig. 8. Comparison of short circuit and load modes' magnetic field located on 1.8 m height

2. In short circuit mode electrical field strengths are reduced by 40 % at the beginning of inter-substation zone due to significant voltage drops.

The modeling results allow formulating the following conclusions.

1. In the example under study short circuit currents exceed about 5 times the currents of load mode which is close to maximal one. Magnetic field strengths increase in the same ratio.

IV. Emergency Modes EMF for Unearthed Catenary Supporting Poles

When catenary supporting poles are earthed on the rail, rail circuits reliability is reduced, and track maintenance operations without switching-out of catenary voltage are complicated due to necessity of earthing leads disconnection from rails [6].

When pole earth resistance is less 100 Ohm, its connection with rail is accomplished through the spark gap, which requires a large work to examine and replace faulty elements. Therefore, the task of studying the possibility of supporting poles disconnection from rails acquires a special urgency. In particular, in work [11] it is shown that for a majority of practically meaningful conditions, the probability of hazardous situations emergence on sections with supporting poles, disconnected from rails, is significantly lower than a similar factor for sections with poles earthed on rails. In this situation the need of electromagnetic fields analyzing arises for unearthed supporting poles, in particular, when emergency modes occur.

Such modes modeling were performed for double-track road section of AC railroad, shown in fig. 9. In this diagram, power was suppled to two adjacent traction substations from 220 kV power transmission line with wires ASO-300. Line length from power source to the left traction substation equals to 113 km, Line length from TS1 to TS2 equals to 40 km. Transformers 40000/230/27,5/11 are installed at substations. Idle run voltage on traction substations buses equals to 27.9 kV. Catenary of each track includes MF-100 contact wire and PBSM-95 messenger wire. The rail network is formed by four R-65 rails, DT-1-300 impedance bonds with secondary windings are installed on rails insulated joints.

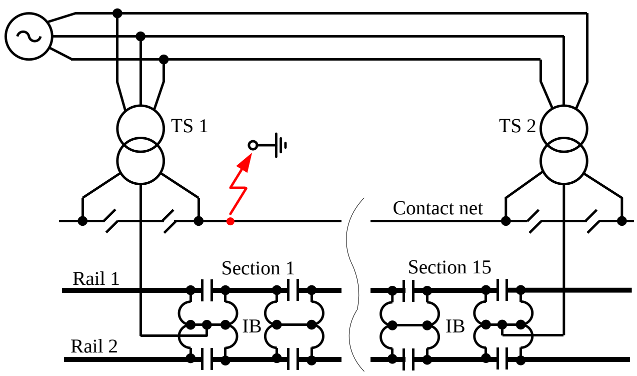

Fig. 9. Original diagram. In order to simplify it, traction network of only one track is represented; IB – impedance bond

In Fazonord model traction network of 45 km inter-substation zone is divided into 15 sections, each being 3 km long. The diagram contains models of traction transformers, external power supply lines, multi-wire traction network and impedance bonds. Short circuit was modeled by connection of RL-element between the required node of the multi-wire system and zero potential point.

Currents dependences are built based on modeling results, the currents flowing through self-earthed supporting poles when catenary insulation is spark-over, with currents depending on the following parameters: L, distance from TS1 substation to the spark-over point, pole self-earthing resistance (or a group of poles connected by the earthing wire) R_S, rail line transition resistance – earth r_p. The simulation results are shown in fig. 10, 11.

In fig.10 dependence of current through low-ohm supporting pole with self-earthing resistance $R_S = 10$ Ом on the distance from spark-over point to TS1 is shown. As could be expected, transition resistance rails – earth (which is connected to the short circuit loop along with substations earthing equipment) affects current value and pole potential insignificantly.

Induced currents of magnetic influence are flowing in rails. Fig. 11 shows dependence of total current in two rails of each track when catenary insulation of even track is spark-over. Current magnitude through self-earthed pole, in this case, is equal to 1870 A. Rail currents are low close to the spark-over point and reach a steady-state value at distances of about 8 km from point. Current in rails of the track where spark-over occurred exceeds current of the neighboring track a little.

Fig. 12 shows dependences of SC current on the distance between TS1 substation and SC location for different resistances of the supporting pole self-earthing. Current values in case of fault to the self-earthed poles become comparable with currents of SC catenary – rails when the support self-earthing is about 5 Ohm. Since operating currents of the overhead system feeders can reach 1... 1.5 kA, to provide tuning-out of feeder protection against SC from normal mode currents, the poles resistance shall not exceed 5 Ohm. Evidently, such value can be reached only in case of poles group earthing with possible arrangement of additional earthing elements.

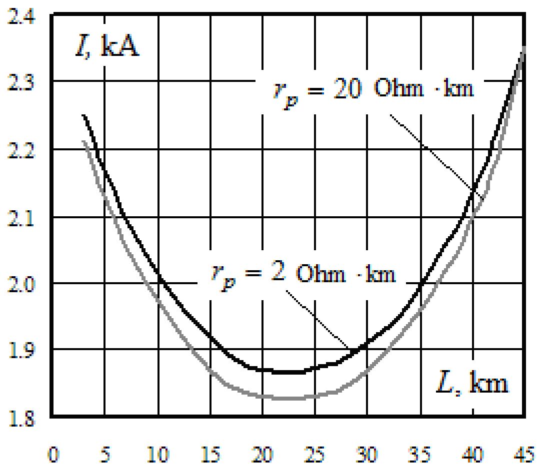

Fig. 10. Dependence of current flowing through the supporting pole on the distance to TS1 when $R_S = 10$ Ом

EMF calculation results are summarized in table III and are shown in fig. 13 – 18.

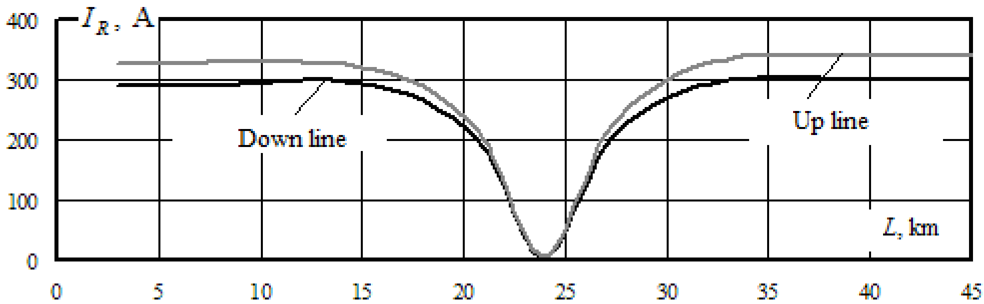

Fig. 11. Dependence of rails current on the distance to TS1: R_S = 10 Ohm; r_p = 2 Ohm·km; L_{K3} = 24 km

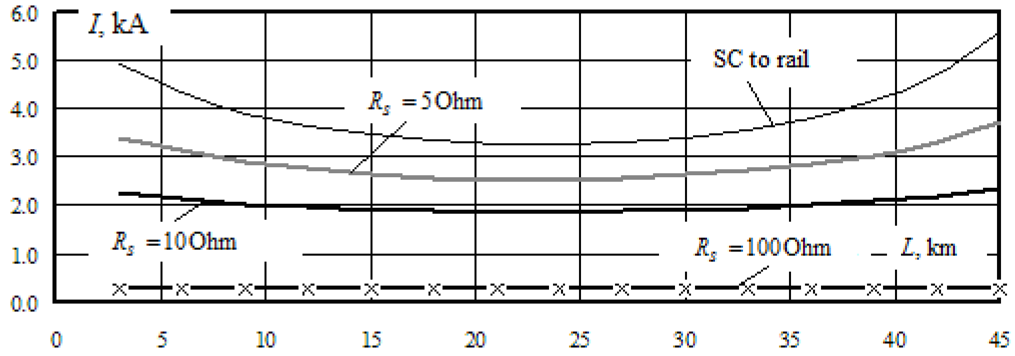

Fig. 12. Dependence of SC current on the distance from SC location to TS1, r_p = 2 Ohm·km

TABLE III – SUMMARIZED DATA ON EMF STRENGTHS AMPLITUDES

Parameter	SC to support		Metal SC		Ratio	
	E_{MAX}, kV/m	H_{MAX}, A/m	E_{MAX}, kV/m	H_{MAX}, A/m	*1/3*	*2/4*
	1	***2***	***3***	***4***		
Average	2.19	79.4	0.63	193	3.47	0.41
Maximum	3.25	174	0.97	357	3.33	0.49

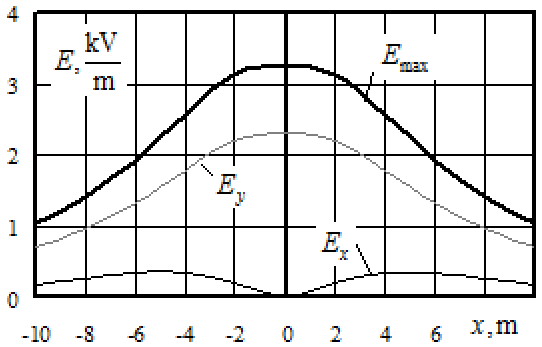

Fig. 13. Dependence of electrical field strength components on 1.8 m height on *x* coordinate under SC through the pole self-earthing: $R_S = 10$ Ом ; r_p= 2 Ohm

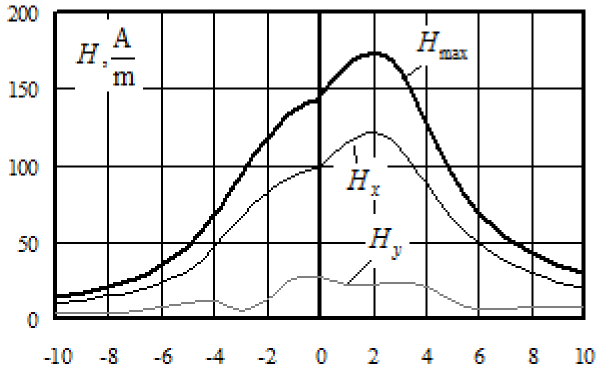

Fig. 14. Dependence of magnetic field strength components on 1.8 m height on *x* coordinate under SC through the support's self-earthing: $R_S = 10$ Ом ; r_p= 2 Ohm

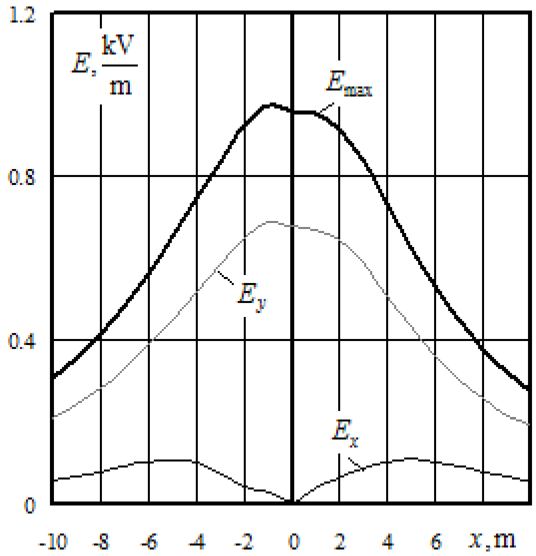

Fig. 15. Dependence of electrical field strength components on 1.8 m height on *x* coordinate under metallic SC to rails

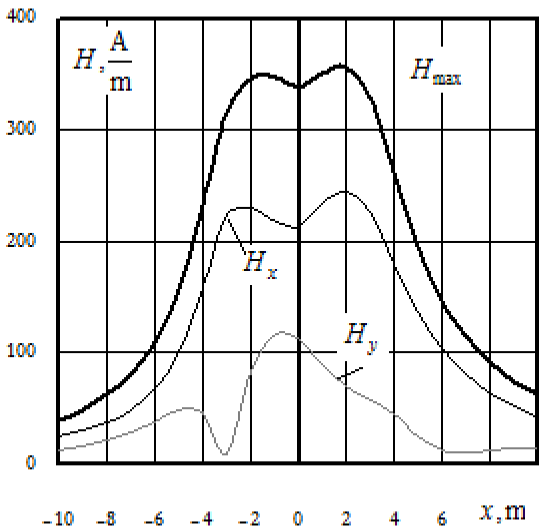

Fig. 16. Dependence of magnetic field strength components on 1.8 m height on *x* coordinate under SC to rails

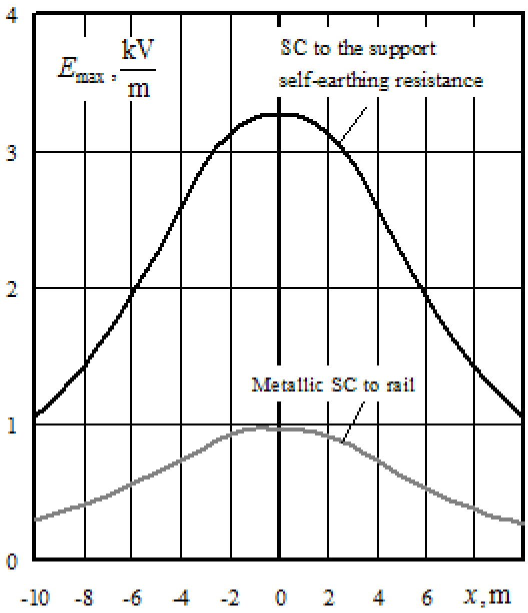

Fig. 17. Comparison of electrical field strengths amplitudes on 1.8 m height for different SC options

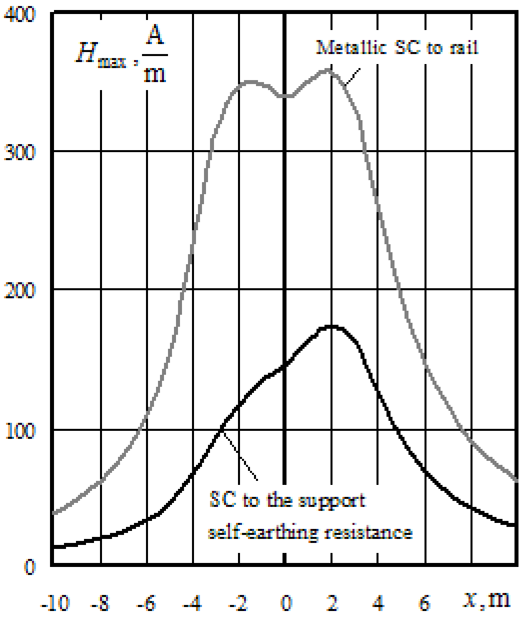

Fig. 18. Comparison of magnetic field strengths amplitudes on 1.8 m height for different SC options

V. CONCLUSION

Short circuits can occur in traction networks reaching ten kiloamperes. Strong magnetic fields created in this mode, can lead to failures in electronic equipment operation, and high values of induced voltages in adjacent lines. Therefore, the tasks of determining EMF occurring in emergency modes are urgent.

1. Modeling results indicate that in case of metallic SC to rail, magnetic field strength exceeds a similar value for SC to the supporting pole self-earthing resistance by three times at average.

2. In the example analyzed, catenary currents in case of short circuit exceed high load mode currents by approximately 5 times. The same ratio reveals magnetic fields strengths. Catenary electrical field in SC mode is reduced by 40% due to significant voltage reduction.

3. Short circuit to self-earthed supporting pole not connected with other poles and rails, is characterized by current level, which is by several times less than the current of short circuit to the rail. Consequently, magnetic field strength occurs also reduced.

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