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EMC Problems caused by Combinations of EHV Transmission Lines and Electrified Railway Lines

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Abstract. The percentage of electricity produced by renewable energy sources grows rapidly during last years. But high-power renewable energy sources like offshore or onshore wind farms in coastal regions are located very often far from consumers. The task of the energy transport over long distances becomes more and more important. Due to the difficulties finding new corridors for the extra high voltage (EHV) transmission lines in densely populated countries with developed infrastructure is often recommended to combine the new transmission line with other infrastructure objects like railways, highways and other transmission lines. One of theoretical possibilities is the use of common pylons for the installation of a new EHV transmission line together with catenary of electrified railway lines. Another one is the laying of HVDC cable parallel to the rail line. The proximity of different current feeding systems causes the electromagnetic interaction between transmission line and catenary. These interferences can disturb the operation of both systems. On the base of mathematical modelling of electromagnetic interferences between transmission lines and catenary the interaction between both systems is considered in the offered paper.

Key words

Electromagnetic compatibility and electromagnetic interference, electromagnetic coupling, interference suppression, transmission lines.

1. Introduction

The increase of the percentage of electricity generated by renewable energy sources causes the necessity of the energy transport over long distances. Due to the difficulties finding new corridors for the extra high voltage (EHV) transmission lines in densely populated countries with developed infrastructure is often recommended to combine the new transmission line with other infrastructure objects like railways, highways and other transmission lines. One possible solution is the installation of several transmission lines with different rated voltages and/or different rated frequencies on common pylons. The use of common pylons causes the electromagnetic interaction between transmission lines positioned on the same pylons. If requirements of electromagnetic compatibility (EMC) are not enough considered in the design stage the electromagnetic interaction can disturb the operation of installed power lines.

EMC problems of the common use of the same towers for the installation of several transmission lines are investigated in a row of publications [1 – 7].

EHV and HV transmission lines with common pylons are realized over short distances in many cases worldwide. The offered paper deals with the analysis of the special case of the use of common pylons for the installation of new EHV transmission lines together with catenary of electrified railway lines.

EMC disturbances in telecommunication lines and signal circuits caused by the presence of HV transmission lines in close proximity to railroad lines are considered in many publications [8 – 11].

Electromagnetic interferences between power circuits of close disposed transmission lines and catenaries are usually considered for MV and HVAC lines [12 – 14].

The offered paper deals with the analysis of the influence on the power circuits of EHV AC and HVDC energy transmission lines as well railway systems. Different operating frequencies of electrified railways are taken into account.

The interaction of EHV AC, HVDC transmission lines and electrified railways over long distances are investigated in the offered paper. Both HVDC overhead lines (OHL) and underground cables are considered in the paper.

2. Mechanism of Interaction

The analysis of the electromagnetic interaction is based on the theoretical considerations for the overhead lines with ground return [15].

Fig. 1 illustrates simplified the influence on a single conductor due to the presence of other conductors.

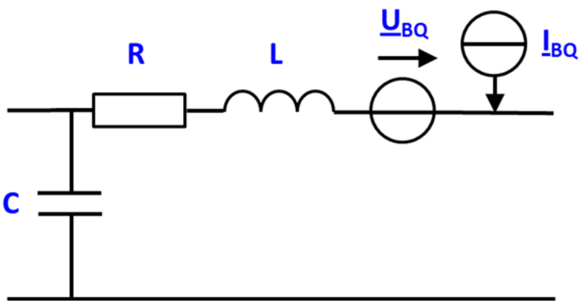

Fig. 1. A single conductor under the electromagnetic influence of other conductors

The current $\underline{I}_{BQ}$ which is shown in Fig. 1 is the result of the capacitive coupling between the conductor under consideration and other conductors of the line:

$$\underline{I}_{BQi} = \sum_{k=1;k\neq i}^{n} j\omega \cdot C_{ik} \cdot \underline{U}_k \tag{1}$$

where C_{ik} is the capacitance between conductors i and k, $\underline{U}_k$ is the phase to ground voltage of the conductor k.

The voltage $\underline{U}_{BQ}$ in Fig. 1 is the result of the resistive-inductive coupling between the conductor under consideration and other conductors:

$$\underline{U}_{BQi} = \sum_{k=1;k\neq i}^{n} \underline{Z}_{ik} \cdot \underline{I}_k \tag{2}$$

where $\underline{Z}_{ik} = R_{ik} + j\omega \cdot L_{ik}$ is the impedance between conductors i and k, $\underline{I}_k$ is the current in the conductor k.

Taking into assumption the grounding of both ends of the conductor under consideration the prospective induced current in the conductor can be calculated:

$$\underline{I}_{BVi} = \frac{\underline{U}_{BQi}}{\underline{Z}_{ii}} \tag{3}$$

In normal operating states of transmission line the induced current is limited by network and load impedances.

For the close disposed HVDC transmission lines is one additional mechanism of the interaction with electrified railway must be considered. It is the possible injection of DC ion currents into the railway conductors. [16].

Last but not least is the possible interaction due to direct galvanic connection of grounded conductors and metallic parts. The following analysis is mainly based on the simulations using the MATLAB / Simulink software.

3. Main Cases of Investigation

A. EHV AC OHL on the common pylons with catenary

Fig. 2 presents an example of a network configuration containing EHV AC transmission line and catenary system on the same pylons over a distance of 125 km.

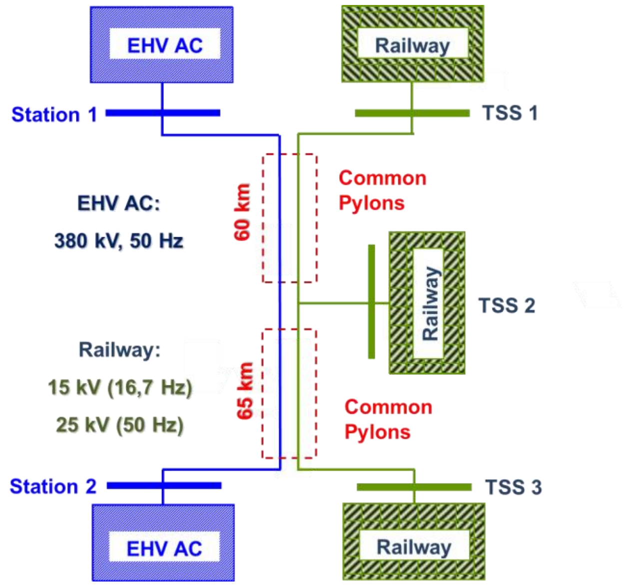

Fig. 2. Network configuration under study

The railway line in Fig. 2 is supplied by 3 traction substations (TSS) over distances of 60 km (TSS1 – TSS2) and 65 km (TSS2 – TSS3).

Fig. 3 shows schematically the prospective current induction in the catenary conductors due to the EHV AC line operation. The structure of the catenary system is shown in Fig. 3. Contact wire, catenary wire and reinforcing feeder wire can be supplied with line-to-ground voltage 15 kV (16.7 Hz) or 25 kV (50 Hz). The geometry of the catenary system can be the same for both voltages 15 kV and 25 kV. Rails and return wire are earthed.

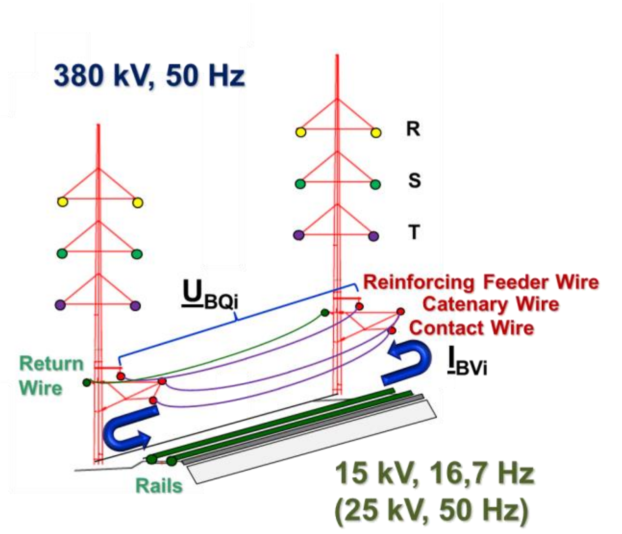

Fig. 3. Prospective current induction in the catenary conductors due to the EHV AC line operation

Fig. 4 and 5 illustrate the influence of the EHV AC line on the catenary voltage and current of 50 Hz railway line. It can be seen from the Fig. 4 that the induced current of over 300 A flows in the catenary conductors due to the influence of EHV AC line. It is about 50 % of the train operating current of 600 A. From the Fig. 4 can be seen that the induced current can increase or decrease the current load of different catenary segments. It can be explained by the influence of induced voltages $\underline{U}_{BQ}$. This effect depends on locations of trains and must be considered for correct energy metering.

In case of a fault at the 380 kV network induced currents will be higher.

It must be noted that capacitive currents $\underline{I}_{BQ}$ are small in comparison with induced currents. It is clearly seen from the Fig. 4 (case “non-loaded HVAC line”).

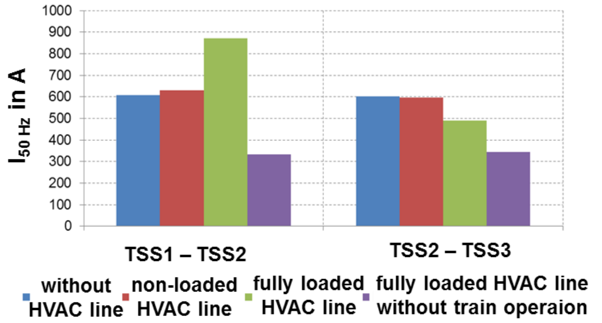

Fig. 4. Influence of the EHV AC line on the current in the catenary (50 Hz railway line, 2 trains at TSS2)

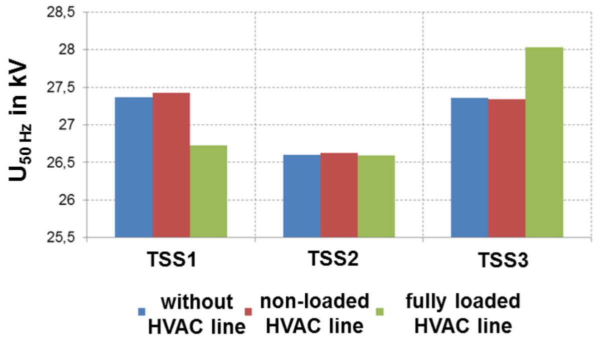

Fig. 5. Influence of the EHV AC line on the catenary voltage (50 Hz railway line, 2 trains at TSS2)

It can be seen from the Fig. 5 that the catenary voltage can exceed the limiting value of 27.5 kV [17] due to the influence of EHV AC line.

The other problem is the possible increase of touch voltage on the rails. The measured values of touch voltages on the rails under real operating conditions of railway lines can be 46 V and higher [18]. It means that the additional voltage of about 20 - 40 V on the rails caused by the EHV AC transmission line operation is enough in many practical cases for the violation of the requirements for electrical safety in AC traction systems. According to [19] the permissible effective touch voltages in AC traction systems are 75 V for the maximal duration of 1 s and 60 V for the duration over 300 s.

Fig. 6 - 8 illustrate the influence of the EHV AC line on the catenary voltage and current of 16.7 Hz railway line.

It can be seen from the Fig. 6 that the value of 50 Hz induced currents are similar to the values of induced currents in the 50 Hz catenary system (Fig. 4). It must be noted that the same values of induced 50 Hz currents cause smaller RMS values of conductor currents in the case of 16.7 Hz catenary system:

$$I_{RMS} = \sqrt{I^2_{16,7\ Hz} + I^2_{50\ Hz}} \qquad (4)$$

But the values of traction currents needed for the same rated power of locomotives in the catenary system 25 kV (50 Hz) are smaller in comparison with currents in the catenary system 15 kV (16.7 Hz). Because of it the continuous relative loading of 16.7 Hz catenary system due to the 50 Hz induced currents can be higher in comparison with the relative loading in the 50 Hz catenary system. Fig. 7 illustrates it.

The values of 50 Hz voltages are presented in the Fig. 8.

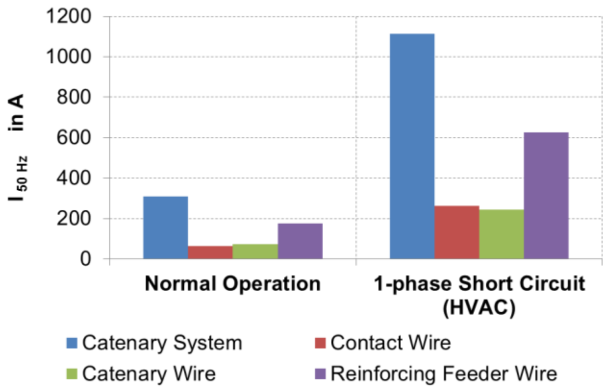

Fig. 6. 50 Hz currents induced in the catenary conductors of the 16.7 railway line due to the influence of the EHV AC line

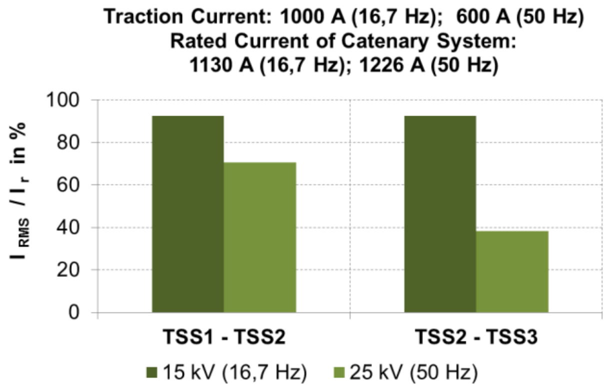

Fig. 7. Continuous relative loading of catenary system due to the influence of the EHV AC line

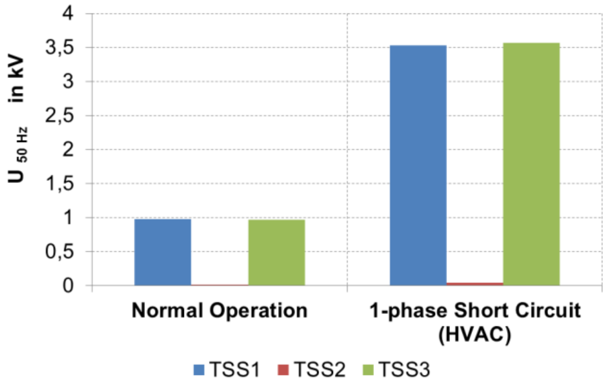

Fig. 8. 50 Hz voltages at the nodes of the 16.7 Hz catenary system caused by the influence of the EHV AC line

B. HVDC OHL on the common pylons with catenary

Fig. 9 shows the structure of HVDC transmission line containing one additional wire (neutral wire) for the redundancy of power transmission in case of failure of positive or negative wires.

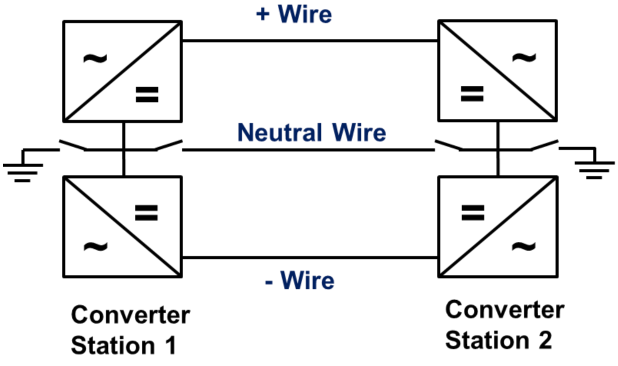

Fig. 9. HVDC transmission line with neutral wire

The positioning of HVDC line on the same pylons with AC catenary system causes the influence of the AC catenary conductors on the HVDC line. Fig. 10 illustrates schematically the prospective current induction in the conductors of HVDC line due to the 16.7 Hz railway line operation.

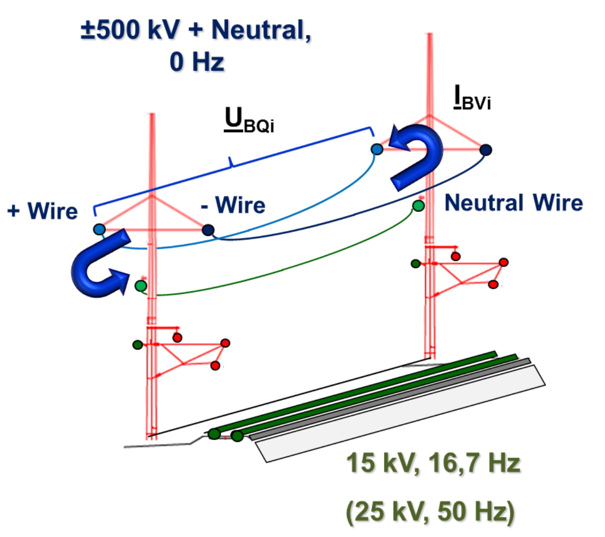

Fig. 10. Prospective current induction in the conductors of HVDC line due to the 16.7 Hz railway line operation

The AC currents induced in the HVDC line conductors must be estimated respectively the requirements for DC side harmonics to prevent telephone interference. In [21] is noted that the psophometrically weighted RMS value of the DC side harmonic current must be under the maximum threshold of 200 mA. The RMS value must be calculated as follows [22]:

$$I_{ps} = \frac{1}{p_{800}} \sqrt{\sum (p_f \cdot I_f)^2} \quad (5)$$

where I_f - harmonic current of frequency f,

p_f - weighting factor at frequency f

p_{800} = 1000- psophometric weight at frequency 800 Hz.

The weighting factors $p_f = 0.056$ at the frequency 16.7 Hz and $p_f = 0.71$ at the frequency 50 Hz [21].

Fig. 11 presents the values of psophometrically weighted harmonic currents in the HVDC line conductors induced by 16.7 Hz currents of catenary system. From the Fig. 11 can be seen that the induced currents are significantly dependent on the operating state of railway line. The directions of current flows in the catenary conductors are decisive for the magnitudes of induced currents.

Fig. 12 illustrates the simplified assumption about the dependence of directions of current flows in the catenary system on the location of trains.

Fig. 11. Psophometrically weighted harmonic currents in the HVDC line conductors induced by 16.7 Hz catenary system

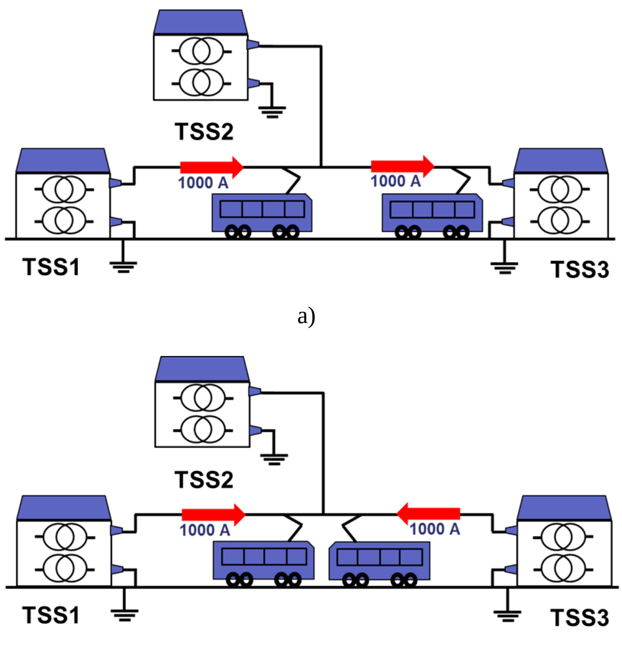

Fig. 12. Dependence of directions of current flows in the catenary system on the location of trains

a) Trains at TSS2 and TSS3
b) Trains at TSS2

From the Fig. 11 can be seen that the psophometrically weighted induced harmonic currents in the HVDC line conductors are very small in comparison with the maximum threshold of 200 mA.

Fig. 13 shows the neutral conductor voltage of HVDC line caused by the influence of the 16.7 Hz railway line operation. It can be seen from the Fig. 13 that the 16.7 Hz induced voltage in the neutral conductor of HVDC line can be up to several kV under normal operating conditions.

It must be noted that the 16.7 Hz current will be induced in the both sides grounded neutral conductor. The 16.7 Hz current of 334 A was calculated for normal operating conditions of the railway line in the network example under consideration.

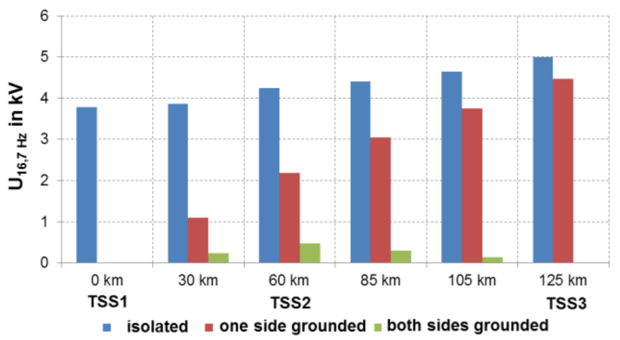

Fig. 13. 16.7 Hz line-to-earth voltage in the neutral conductor of HVDC line caused by the influence of the railway line operation

The DC currents of HVDC transmission line do not induce any currents in the catenary conductors. But the DC corona currents (ion currents) of HVDC line can be partly injected into the catenary system. In [16] was noted that direct currents can cause asymmetric saturation of the transformer cores and respectively some operating problems, including unacceptable generation of harmonics and transformer audible noise. An extensive analysis of HVDC corona and ion trajectories for the determination of direct currents injected into the catenary system requires sophisticated simulations using FEM software and specialized mathematical models. For the simplified estimation of DC corona currents it is enough to use semi-analytical methods based on empirical assumptions. According to [22] the DC corona current of 0.6 mA/km was estimated for the HVDC transmission line under study. The assumptions [22] were verified and confirmed using the ANYPOLE software developed by BPA [23].

The mathematical modelling of the ion current injection into the catenary system using standard MATLAB models of saturable power transformers has shown that the influence of injected DC currents on the additional saturation of transformer core is neglectable in the network example. Possible influence of injected DC currents on other devices in the railway network like measuring devices with saturable magnetic cores must be studied.

C. HVDC cable placed parallel to electrified railway line

Location of HVDC cable line close to an electrified railway line leads to similar interference effects which are well-known for metallic pipelines located close to AC power lines [24]. The cable conductors are good protected from the interferences by cable screens, but the cable screens are influenced by AC railway line like pipelines.

Fig. 14 shows schematically the prospective current induction in the screens of HVDC cable line due to the 16.7 Hz railway line operation.

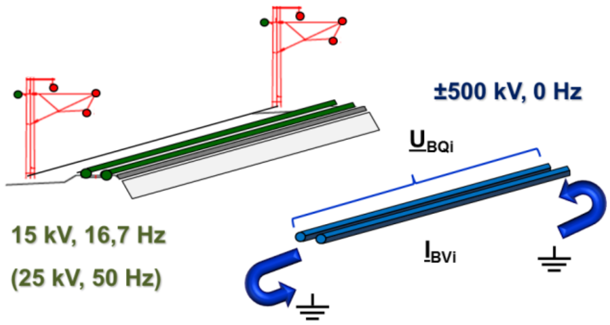

Fig. 14. Prospective current induction in the screens of HVDC cable line due to the 16.7 Hz railway line operation

Fig. 15 presents the calculated values of 16.7 Hz currents in the HVDC cable screens caused by the influence of the railway line operation. From the Fig. 15 can be clearly seen that the 16.7 Hz currents in the cable screens are mainly caused by induction from the catenary system and not by galvanic influence. Earthing of cable screens is necessary for the reducing of touch voltage on the screen.

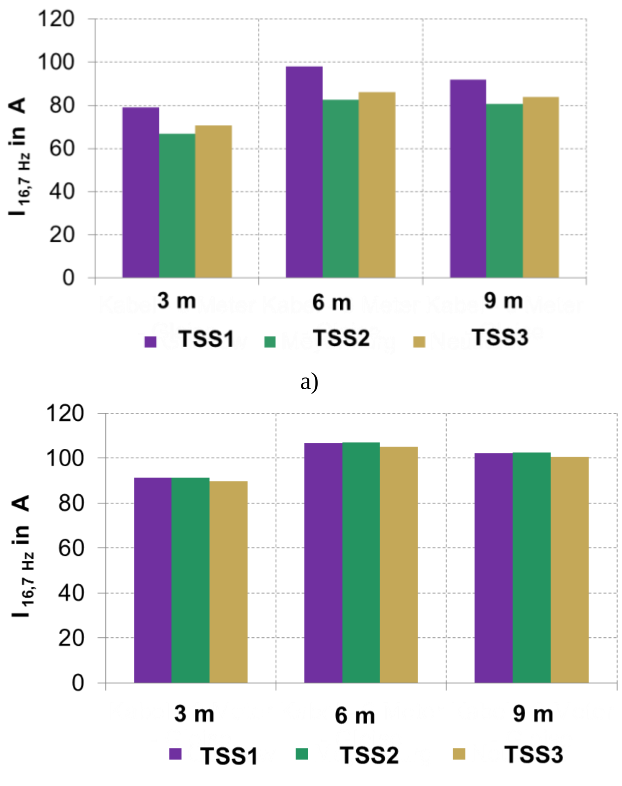

Fig. 15. 16.7 Hz current in the earthed screen of the HVDC cable placed parallel to the electrified railway line in dependence on the distance to the track axis

a) without galvanic connection to the rail earthing
b) with galvanic connection to the rail earthing

Requirements of corrosion protection must be considered in the design of the grounding for cable screens.
It must be noted that disconnection of the screen from the grounding can cause non-permissible values of the touch voltage on the screen (several hundred volts and more in the network example under consideration).

4. Summary

On the base of mathematical modelling of electromagnetic interferences between transmission lines and catenary the interaction between power circuits of both systems is considered in the paper.
Typical EMC problems caused by combinations of EHV AC or HVDC transmission lines and electrified railway lines of different frequencies are described.
It is shown that the electromagnetic interaction can disturb the operation of installed power lines.
Constraints of the use of combined EHV transmission lines and catenary caused by EMC problems are shown in the paper.

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