Development Simulation Model of Traction Network Alternating Current 25 kV

Alexander Onischenko[1(✉)] and Ilya Chernykh[2]

[1] Far Eastern State Transport University, Seryshev str. 47, Khabarovsk, Russia
a.a.onischenko@mail.ru
[2] Ural Federal University, Mira str. 19, Ekaterinburg, Russia

Abstract. Railway transport is the most important part of the country's transport system. Railway transport accounts for about 70% of domestic freight turnover and almost 60% of passenger traffic. More than 50% of cargo transportation is carried out by electric traction. Train safety devices connected to rail circuits are subject to constant interference from traction network power supply. The sources of influence are noise generators and the processes of summing them from several sources (including resonance in contact network). Interference arising in the contact network may appear at the input of the receivers of SCB devices galvanically or inductively. The article covers technical characteristics of electrified Russian Railways JSC "RZD", with particular emphasis given traction AC network of 25 kV, proposed and developed in MATLAB & Simulink a generalized mathematical model of the contact network, electric rolling stock and rail network designed to conduct a comprehensive study of processes resulting from operation of the traction network and interaction between different physical processes.

Keywords: Rail transport · Electrification · Traction network · Contact network · Electric rolling stock · Rail network · Simulation · MATLAB & simulink

1 Introduction

The railway complex is special strategic importance for Russia. It is link of the unified economic system, ensures stable activity of industrial enterprises, timely delivery of vital goods to most remote corners of the country and most affordable transport for citizens.

According 2018, the operational length Railways of Russia for more than 85.5 thousand km, length of electrified lines is approximately 43.7 thousand km. Over 19 thousand km of Railways were electrified by the 3 kV DC system. In recent years, preference has been given to electrification of lines to more advanced alternating current systems of 25 kV or 2 $\times$ 25 kV of 50 Hz power frequency.

Figure 1 shows a section of the railway length of 40–50 km electrified AC system 25 kV with two traction power substations (TPSS1, TPSS 2), located near stations A and B. To the power line (transmission line) three-phase alternating current 110/220 kV connected three-phase transformer (TphTr), which lowers the primary

Z. Popovic et al. (Eds.): TransSiberia 2019, AISC 1115, pp. 392–400, 2020.
https://doi.org/10.1007/978-3-030-37916-2_38

voltage 110 kV to 10, 25 or 35 kV. Voltage 25 kV is supplied to the bus (phase A, B, C) supply traction network (STN), voltage 35 or 10 kV - on the power bus adjacent to the substation area [1].

Uniform loading of phases power supply system is provided by delivery in TN at station A and section S1 voltage differing in phase from the voltage of TN S2, which is implemented by connection contact network (CN) of above section and stations to the different phases of tire 27.5 kV: CN of a section S2 through feeder (F3) and appropriate switch feeder contact network (SFCN) connected to the bus phase b; CN station A and section S1 to the bus phase a; rails through rail feeder (RF) to the bus phase c. This connection makes possible connection of the CN of section S1, station A and current collector (CC) of moving electric rolling stock (ERS) and impossible connection to CN station A and section S2 due to joining different phases a and b, which will lead to short circuit (SC) phases transformer (TphTr), so these areas of CN divided by air gaps (AG) and neutral insert (NI), which eliminates possibility of even short circuit phases a and b when passing site ERS. TN at section S2 receives the voltage from TPSS1 and TPSS2 through TphTr1, TphTr2 connected to the power lines according to special rules, enabling two-way power ERS and uniform loading phases of power lines.

After supplying voltage to the TN train driver raises CC and switch on switch (SA), providing AC voltage to the primary winding of step-down traction transformer (TV). On secondary winding of TV, voltage is converted by rectifier (VD) and through smoothing reactor (SR) is fed to the traction motors (TM), through which current begins to flow, driving ERS in motion. On auxiliary power lines from tires of traction voltage 27.5 kV power get and non-traction consumers, which is implemented by connection buses of phases a and b through power switch (PSNTC) two wires mounted on poles, fixed on CN supports from field side. Step-down transformers of consumers (SDTrC) and rail lines are connected to them on system of TWR (two wires – rail). To ensure uninterrupted power supply to consumers, a disconnector (QF) is provided in middle of TWR line, which provides a transition to power from one TN when other is disconnected.

From transformer of own needs (TrON) through buss (BON) get power to the load own needs TN (power control circuits, alarms, lighting, heating, motor loads and other), through a transformer of signalization, centralisation and blocking (TrSCB) voltage is applied to a high-voltage line (HVL SCB) to supply equipment signalling and communication, through using low-power step-down transformers (LPSDTr) and the device is in relay cabinets (RC) are powered traffic lights. Disconnecting switch (QS) enables to power supply the HVL SCB from any of TN (QS closed) or each half of his (open QS). Ensuring safety of train traffic and continuous power supply of SCB devices is achieved by presence of a backup power supply (BUPS), which receives power through step-down single-phase transformers (SDTr) from TWR line. As a reverse wire for passage of reverse traction currents (RTC) electro-technical complex of railway power supply used electrically combined elements: rail line (RL), choke-transformers (DT), microcline and throttle jumper, butt-traction connectors, and between line and between rail jumper, suction feeders (SF) traction substations.

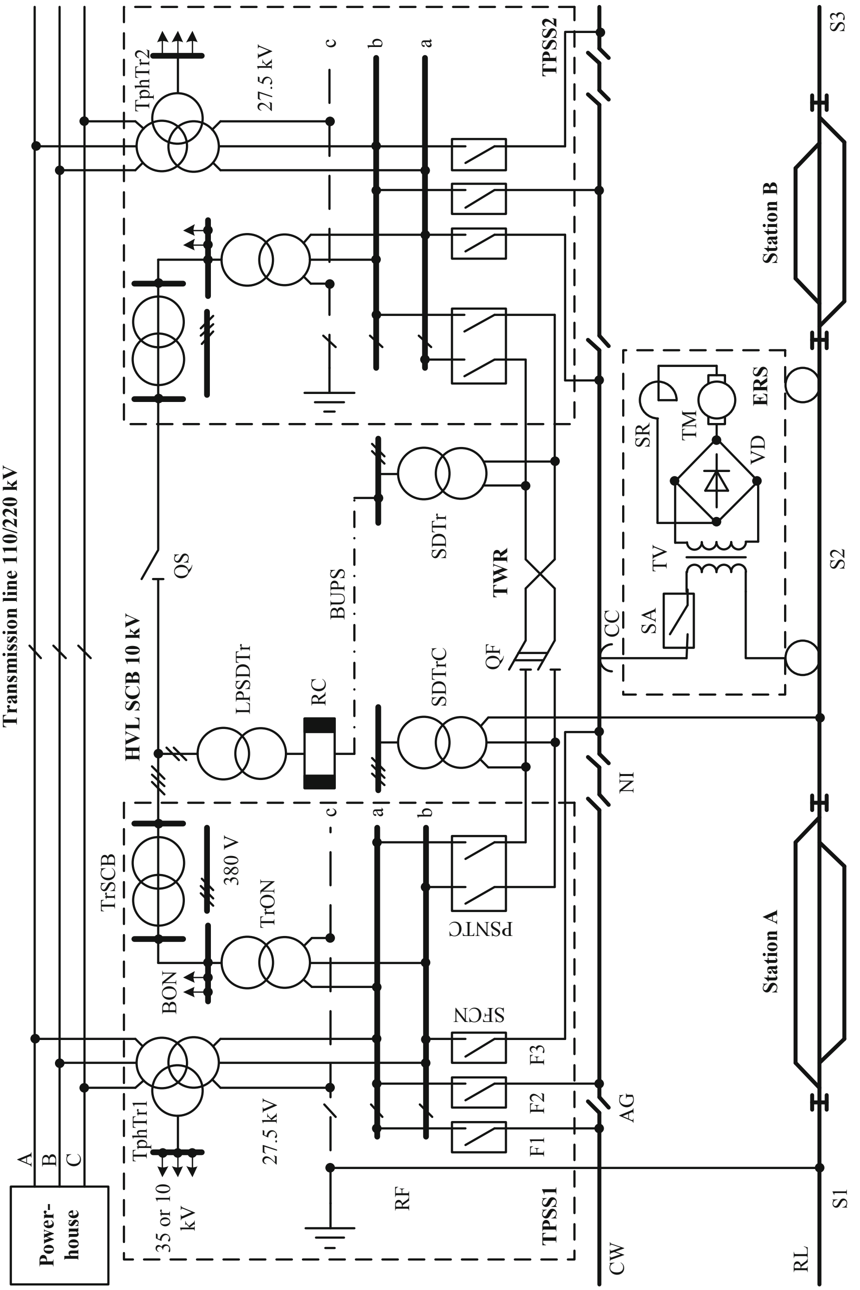

Fig. 1. Scheme of railway section, electrified by AC 25 kV

The advantages AC systems with voltage of 25 kV include higher voltage in the contact network (CN) and simple reduction possibility it by electric locomotive transformer. Electric locomotive with capacity of 6000 kW at direct current (DC) consumes from CN current of 2000 A, at an alternating current (AC) – 300 A, so the DC is more complex and has large number of wires (usually two copper contact wires with a cross section of 100 mm^2 each, a copper carrier cable with a cross section of 120 mm^2 and one or two reinforcing aluminium wires with a cross section of 185 mm^2 each), and at alternating current of CN is less complex and consists of one copper contact wire with a cross section of 100 mm^2 and a bimetallic wire carrying cable Sect. 95 mm^2. The design of AC substation compared to DC substation is simpler due to the absence of rectifying units. The number of substations on lines in the AC system is less, because they are located at long distances. The disadvantages of AC system are increased influence on the communication line (CL), since the alternating current creates an alternating electromagnetic field around the wires. CL passing along the railway must be executed cabling and not overhead cable, as a direct current, which leads to the increase in cost of railway electrification. In addition, there are problems asymmetry of currents and voltages due to the fact that electric locomotives consume single-phase current, transmission line are three-phase. There is a need for installation of neutral inserts at each substation, the presence of which increases the probability of burnout contact wire.

2 Materials and Methods

Figure 2 shows a simplified diagram flow of traction and reverse traction currents by elements of traction network AC 25 kV.

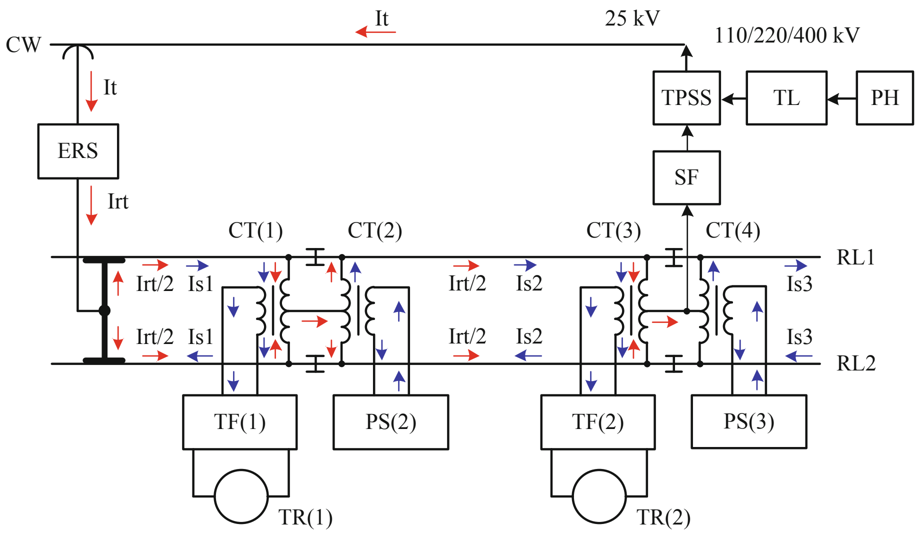

Fig. 2. Scheme of flow currents by elements traction network

The harmonic components of traction current affect rail circuit (RC) only if there is sufficiently large difference between RTC in different RL (asymmetry). Passing through two half-windings CT reverse traction currents (Irt/2) can induce in the secondary winding CT interfering EMF due to the fact that the primary half-windings are included counter for them and consonant to the signal currents (Is). In the presence of resistance asymmetry in RL components of traction current passing through semi-windings may not be equal, and with a large difference can lead to induction of interfering EMF on the secondary winding, on track relay (TR) and locomotive coils in presence ERS on the track section.

The presence of asymmetry of traction current changes resistance of main winding of the CT, which generally changes the input resistance at ends of RC and adversely affects main modes of its operation. Asymmetry can be longitudinal (due to breakage of butt connectors, rail breakage, run of insulating joints, inhomogeneity metal in rails, inequality of resistance throttle jumpers, etc.) or transverse (due to grounding of contact supports on right rail, shorting to ground of one RL, the difference of resistance of the ballast for RL, etc.). A large number of scientific papers have been devoted to study effect of reverse traction network (RTN) asymmetry, for example [2–7].

Figure 3 shows oscillograms, where pause of code signals automatic locomotive signalization continuous type action (ALSC) filled AC voltage with frequency of 50 Hz induced on receiving end of RC current asymmetry, while the pulse code signals are distorted.

3 Modeling

The problem of research in operation devices of a contact network (CN), electric rolling stock (ERS) and rail network (RN) difficult the experiment in context of multicriteria nature interference influencing the useful signals and the functioning of equipment of railway automation and telemechanic not always unambiguous.

A large number of factors affecting operation of traction network devices make it difficult to identify causes of breakdown or failures, their elimination in real time. To conduct experiments and establish interdependencies in practice, it is necessary to simultaneously use special measuring and recording equipment on the way and ERS to attract a large number of specialists, to create conditions under which breakdown or failure will be repeated [8–11].

The development of computer technology has created the preconditions for improving methodology of research work, allowed part of tasks to be assigned to the software, therefore, to simplify experiments, reduce number of staffs, to ensure the accumulation and possibility of mathematical processing of information [12, 13].

Therefore, this article proposes a new approach implemented in the form of data collection and centralized processing: the development of a simulation model of CN, ERS and RC for a comprehensive study of the processes arising from the operation of these systems and the interaction of various physical processes.

The process of modeling AC traction network 25 kV consisted implementation of model contact network of AC 25 kV; simplified circuit EPS AC type 2ES5K «Ermak»; model rail network (coded rail circuit 25 Hz, which is powered by a frequency converter FC-50/25 with track relay IMVSH-110, response voltage of which is 3–4.5 V. Figure 4 shows developed model of AC traction network 25 kV [14–16].

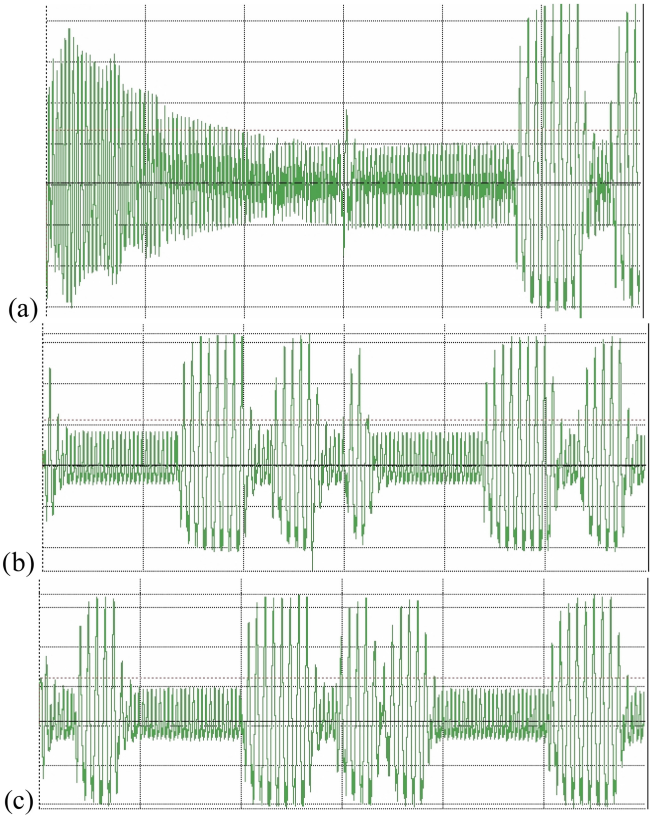

Fig. 3. Oscillograms of ALSN signals under the influence of OTT asymmetry

4 Findings from the Research

The mathematical model of traction AC 25 kV allows to conduct experimental researches on personal computer in laboratory to determine behaviour of various circuit elements during normal operation and during influence of destabilizing factors (disturbances) to develop and implement in simulation environment of MATLAB & Simulink of different designs to increase noise immunity and protection of this complex device, to simulate appearance of possible situations and make a digital processing of measurement results. Further improvement and development of simulation models' complex devices of railway automation and telemechanic (RAT), use of modern simulation environments will create a powerful apparatus for studying influence of interference on normal operation of individual nodes, development of algorithms for protection of distortion transmitted information, evaluation of noise immunity devices under influence of various destabilizing factors. In the future, improvement of simulation model, it is advisable to supplement it with blocks that simulate the influence of destabilizing factors and various disturbances [17].

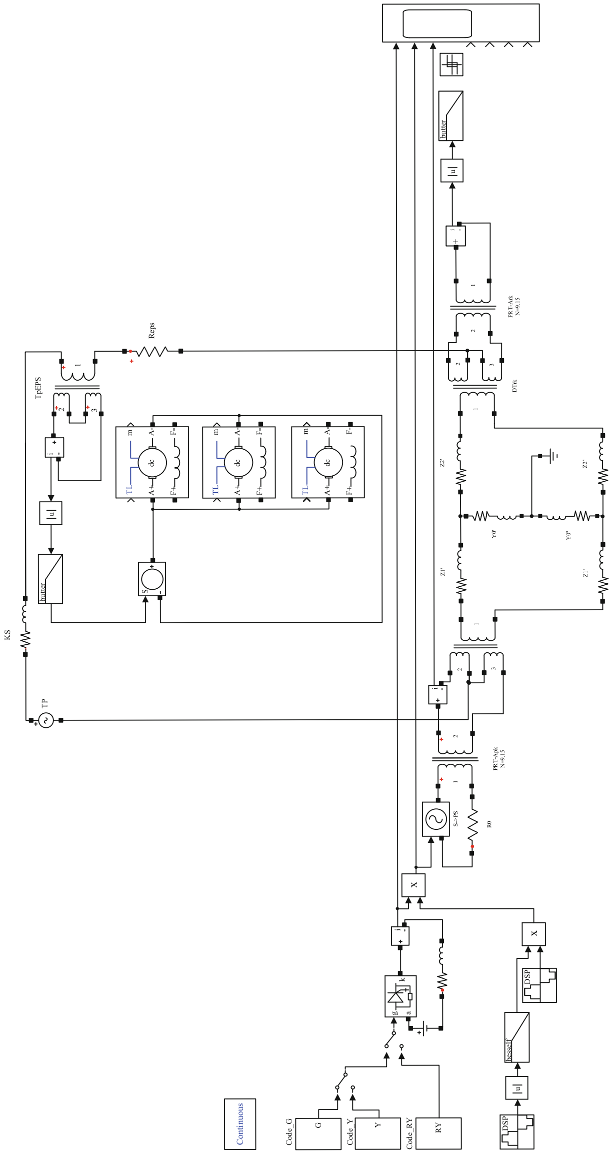

Fig. 4. Model of CNS, ERS, coded RC

Acknowledgment. We Express our deep gratitude to all our colleagues, authors of the works, familiarization with which greatly helped us in conducting research and obtaining relevant results, although they may not agree with all our interpretations and conclusions.

References

1. Grigor'ev, N., Klykov, M., Parfianovich, A., Shestukhina, V.: Increasing the power efficiency of a 25-kV alternating current traction power supply system. Russ. Electr. Eng. **87** (2), 113–115 (2016). https://doi.org/10.3103/S106837121602005X
2. Plakhova, M., Bassam, M., Arboleya P.: Static model of a 2 × 25 kV AC traction system. In: 2015 6th International Conference on Power Electronics Systems and Applications (PESA), pp. 1–5 (2015). https://doi.org/10.1109/pesa.2015.7398917
3. Godyaev, A., Onischenko, A.: Automated monitoring of level distortion coded signals transmitted on rail line. In: International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), 18393174 (2018). https://doi.org/10.1109/fareastcon.2018.8602696
4. German, L., Serebryakov, A., Osokin, V., Subkhanverdiev, K.: Equivalent scheme for calculating short-circuit current in an alternating-current electric traction network. Russ. Electr. Engin. **90**, 516 (2019). https://doi.org/10.3103/S1068371219070058A
5. Mariscotti, A.: Induced voltage calculation in electric traction systems: simplified methods, screening factors, and accuracy. IEEE Trans. Intell. Transp. Syst. **12**, 201–210 (2011). https://doi.org/10.1109/TITS.2010.2076327
6. Tryapkin, E., Ignatenko, I., Keino, M.: Development of "digital substation" technology for power supply of railways. In: Siberian Transport Forum – TransSiberia. MATEC Web Conference, vol. 239, p. 01051 (2018). https://doi.org/10.1051/matecconf/201823901051
7. Serdiuk, T.; Kuznetsov, V., Kuznetsova, Y.: About electromagnetic compatibility of rail circuits with the traction supply system of railway. In: IEEE 3rd International Conference on Intelligent Energy and Power Systems (IEPS), 18323445 (2018). https://doi.org/10.1109/ieps.2018.8559541
8. Buyakova, N., Zakaryukin, V., Kryukov, A., Nguyen, T.: Electromagnetic safety enhancing in railway electric supply systems. In: E3S Web of Conferences, vol. 58, p. 03003 (2018). https://doi.org/10.1051/e3sconf/20185803003
9. Apollonskiy, S.: Problems of electromagnetic safety on electrified railway. Electromagn. Saf. Railw. Altern. Curr. Tract. Power Netw. **58**(03003), 414 (2018). https://doi.org/10.1051/e3sconf/20185803003. In: E3S Web of Conferences, In 2 volumes. T. II
10. Zharkov, Y., Popova, N., Figurnov E.: Accounting power supply schemes for traction substations in the calculation of short circuits in the AC traction network. Vestnik of the Railway Research Institute, vol. 78, JSC Vniizht (2019). https://doi.org/10.21780/2223-9731-2019-78-1-10-18
11. Bellan, D.: Reconstruction of noisy electromagnetic fields by means of compressive sensing theory. Appl. Mech. Mater. **263–266**, 99–102 (2013). https://doi.org/10.4028/www.scientific.net/AMM.263-266.99
12. Figurnov, E., Zharkov, Y., Kharchevnikov, V.: Determination of long-term permissible currents in wires of power supply systems of railways. Vestnik of the Railway Research Institute, vol. 78, JSC Vniizht (2019). https://doi.org/10.21780/2223-9731-2019-78-2-90-95
13. Shamanov, V.: The process of traction-current asymmetry generation in rail lines. Russ. Electr. Eng. **85**(8), 34–37 (2014). https://doi.org/10.3103/S1068371214080124

14. Charalambous, C., Cotton, I., Aylott, P.: Modeling for preliminary stray current design assessments: the effect of crosstrack regeneration supply. IEEE Trans. Power Deliv. **28**, 13596015 (2013). https://doi.org/10.1109/TPWRD.2013.2259849
15. Baranovskii, A.: Computer simulation and experimental investigations of noise levels and spectra for railway transport. Autom. Control. Comput. Sci. **45**(5), 69–78 (2011). https://doi.org/10.3103/S0146411611050026
16. Belyaev, N., Korovkin, N., Frolov, O., Chudnyi, V.: Methods for optimization of power system operation modes. Russ. Electr. Eng. **85**(8), 541 (2014). https://doi.org/10.3103/S1068371214080136
17. Badyor, M., In'kov, Y.: Electromagnetic compatibility of a traction power-supply system and infrastructure elements in areas with high traffic. Russ. Electr. Eng. **85**(8), 488–492 (2014). https://doi.org/10.3103/s1068371214080021