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MODELING AND SIMULATION OF RESONANCE FREQUENCIES AND COEFFICIENT OF INCREASE IN CURRENT IN 25 KV AC RAILWAY TRACTION SYSTEM USING PSB/SIMULINK SOFTWARE PACKEGE

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Abstract: *This paper presents the modeling and simulation of resonaces in the traction circuit AC 25 kV;50 Hz using Power System Block set (PSB) / SIMULINK software package. The three-phase system with substations, track section with rectifier-fed DC locomotives and a detailed traction load are included in the model. The model has been used to study the effect of loading and fault conditions in 25 kV AC traction. has been used to study the effect of loading and fault conditions in 25 kV AC traction. The last part presents results of calculations of real cases from the Serbien Railways´s traffic.* ***(****Font Size – 11 pi, bold) - text – 11 pt. Italic, Justified*

Key words: *PSB/SIMULINK, coefficient of increase in traction current.*

1. INTRODUCTION

The supply to the OHE can be switched ON/OFF through interruptors. Normally power supply from the traction substation extends upto the sectioning post (SP) on either side of the substation, but in case of an emergency necessitating total shut down of the substation, it can be extended upto the failed substation by closing the bridging interruptors at the two SPs.

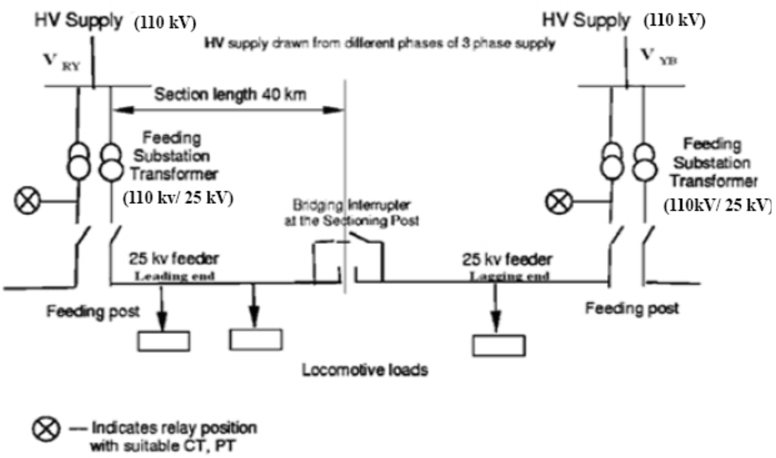

Fig. 1. Typical feeding arrangement of 25 kV traction system of Indian Railways

Fault on the OHE can be of two types (i) Earth faults (ii) Phase-to-phase faults. The second fault can occur by accidental closure of the bridging interruptor at the SP during normal feeding condition or by a short circuit at the insulated overlap opposite a traction substation at times of emergency feed conditions. This is termed as Wrong phase coupling (WPC) fault.

The harmonic currents drawn by the dc motor locomotives degrade the power quality of the traction supply [3]. The excessive voltage drop due to the flow of lagging reactive current makes the performance of the system even worse. Voltage regulation with shunt compensation allows overcoming these drawbacks. Static VAR Compensators (SVCs), Thyristor controlled reactors (TCRs) and Thyristor Switched Capacitors (TSCs) can be used to provide such compensation.

2. RAILWAY TRACTION SYSTEM MODEL

In order to investigate the performance of faults and loading conditions, the OHE of a typical 25 kV traction system of the Indian Railways has been considered. The Power System Block set (PSB) of MATLAB/SIMULINK is a modern design tool used to build the simulation models for electric power system as well as its interactions with other systems [4]-[6]. The basic function blocks of the individual subsystems are developed initially and are interconnected to form the full system model. Each system element is modeled based on its specifications [7].

2.1 THREE-PHASE AC SUPPLY SYSTEM

A three phase 110 kV, 50 Hz AC supply system with the 110 kV single circuit transmission line has been modeled as shown in Fig. 2. The power received from the supply authority grid network is transmitted to the railway's own transmission lines by a series of transformer and line sectioning facilities. The substations have been modeled as subsystems. A bridging interruptor modeled as a switch connected between Substation 1 (Sub1) and Substation 2 (Sub2) facilitates the simulation of WPC faults.

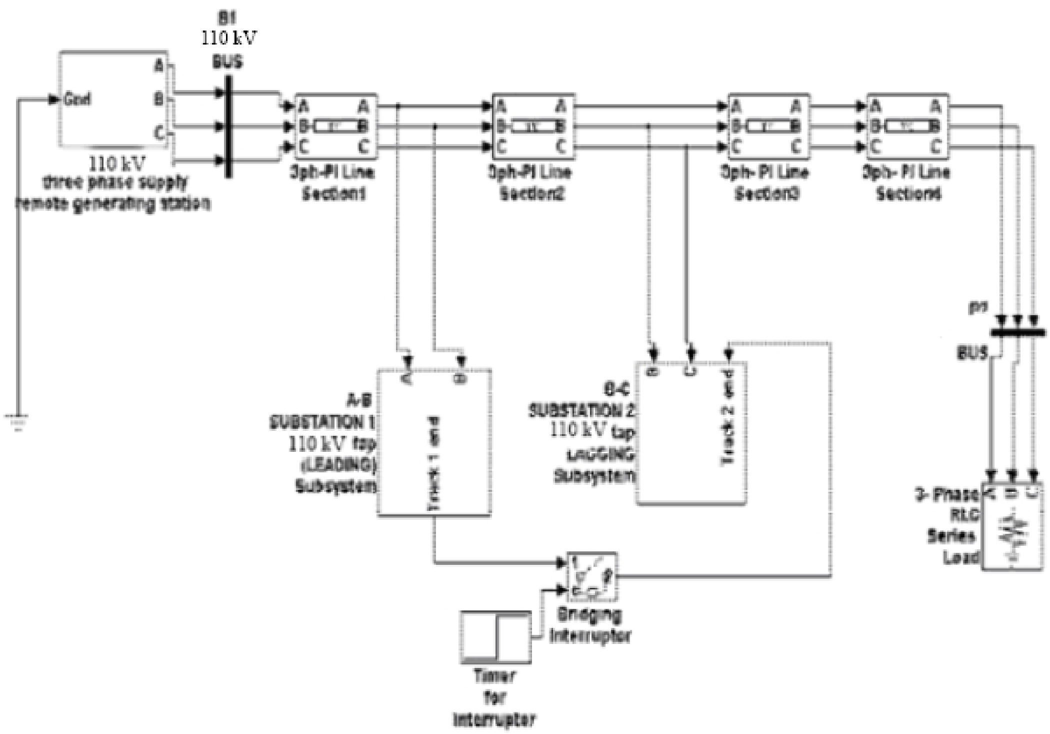

Fig. 2. Model of three-phase supply grid with substations

Traction contact system : 100 mm^2 Cu + 50 mm^2 bronze

R_K = 0,26 Ω/km, L_K = 1,43 mH/km, C_K=20,5 nF/km

2.2 SUBSTATION, TRACK SECTION AND LOCOMOTIVES MODEL

Fig. 3 shows the modeling of Substation 1. The modeling of Substation 2 is identical to that of Substation 1. The 25 kV supply for traction system is drawn through a single phase step down transformer. This is modeled as a 25 MVA, 110 kV/25kV, two winding single phase transformer with impedance of 12% at 7,5 MVA base. The average length of the catenary to be protected during normal feed conditions is 40 km. This feeder is modeled as ten 4 km pi sections, each having a longitudinal impedance of 0.26+j1,43 Ω/km at 50 Hz and shunt capacitance of 20,5 nF/km [8]. This facilitates the simulation of earth faults from 10% to 90% of the line. The TSC is modeled appropriately by choosing reactor and capacitor values tuned to a particular frequency (i.e. the third harmonic) and can reduce the harmonic pollution. In order to simulate earth faults, an ideal switch block with a small fault resistance has been used. The timing of the fault is provided by a timer block that goes high at the fault instant, thus closing the switch and providing a path to the ground.

The locomotives are assumed to be of the conventional diode type with a total locomotive rating of 5,1 MW (ZS 461). They are modeled as two halfcontrolled thyristor-diode bridge rectifiers with each rectifier having parameters of ON state resistance Ron = 1mΩ, forward voltage = 0.8 V, snubber resistance = 100 Ω. The upper and lower half-bridge convertersconvert AC voltage to a controlled DC voltage. AC voltage from the 25 kV feeder is reduced to the required voltage of the power converters. Each diode bridge is fed from a 25 kV/ 2 X 400 V three winding single phase transformer having 8% impedance and saturable characteristics

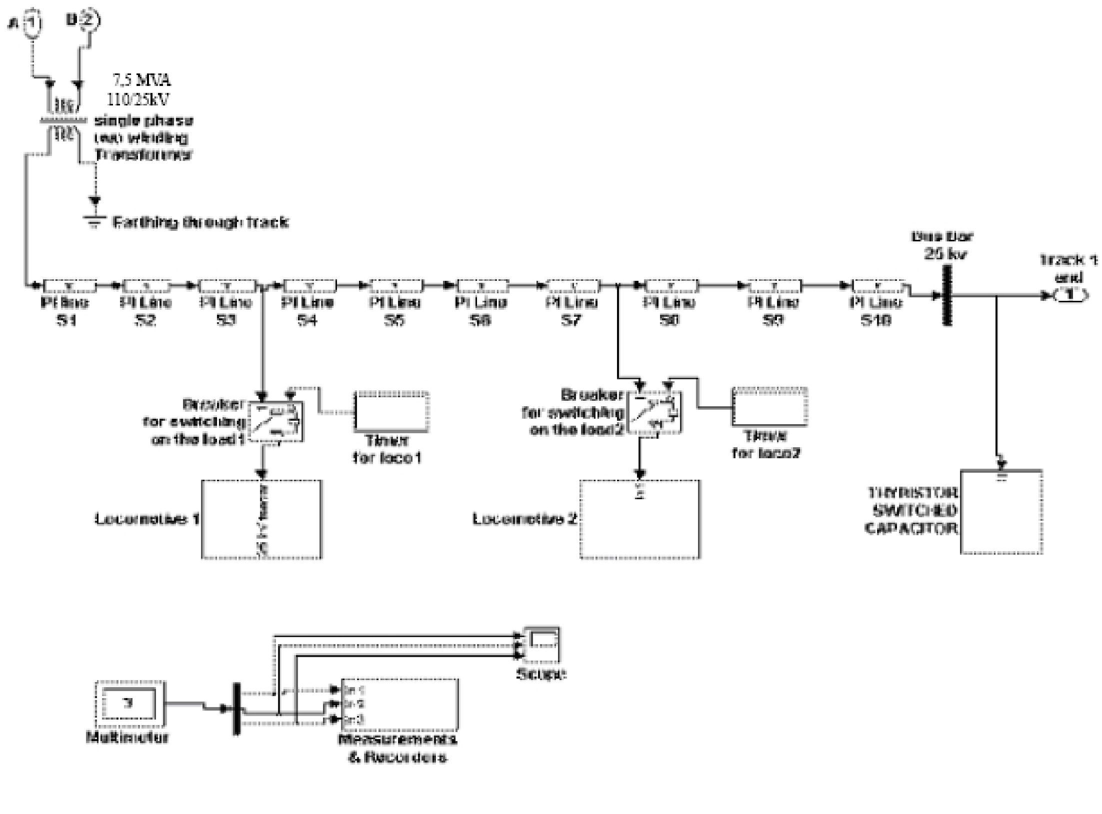

Fig. 3. Model of Substation 1 with traction feeder and loads

3. RESONANCE FREQUENCIES AND COEFFICIENT OF INCREASE IN CURRENT K

Under influence of resonance in the traction circuit of AC traction system current harmonics in the traction transformer substation increase or decrease, especially those that are similar to resonance frequencies. This phenomenon is quantified by the relation:

$$I2n = Kn.I1n$$

where I2n is value of the n-th current harmonic in the output of the traction transformer substation (A)

I1n value of n-th current harmonic generated by electric vehicle (A)

Kn coefficient of increase in current of n-th current harmonic (-)

4. RESULTS

Using Power System Block set (PSB) / SIMULINK software package were calculated values of coefficient of increase in current K in dependence on multiple (n) of the basic frequency 50 Hz for these cases:

1. **(generating) electric vehicle in the traction supplying section**
   - generating electric vehicle is in the end of the traction supplying section,
   - generating electric vehicle is by the traction transformer substation,

2. **electric vehicles in the traction supplying section úseku**
   - generating electric vehicle is in the end of the traction supplying section, the second electric vehicle is by the traction transformer substation,
   - both generating and the second electric vehicle are by the traction transformer substation,

3. **electric vehicles in the traction supplying section**
   - generating electric vehicle is in the end of the traction supplying section, the second electric vehicle is by the traction transformer substation, the third electric vehicle is in the middle of the traction supplying section,
   - generating electric vehicle is close to the traction transformer substation, the second electric vehicle is close to the traction transformer substation, the third electric vehicle is in the middle of the traction supplying section.

Examples of the calculated dependencies for three various lengths of the traction supplying section (30, 40, 50 km) are shown in Fig.5 a Fig.6. Fig.5 represents dependence of the absolute value of coefficient K for one generating electric vehicle in the traction supplying section. Fig.6 shows identical dependence for two electric vehicles in the traction supplying section. Peak values of the coefficient K arise when there is parallel resonance in the traction supplying section. In surroundings of resonance frequencies the values of coefficient K are bigger than one. This means that current harmonics in this frequencies are in the traction transformer substation bigger than in current of the generating vehicle.

With use of this methodology were calculated values of coefficient of increase in current in dependence on multiple (n) of the basic frequency 50 Hz for various combinations of number and localisation of electric vehicles. Value of the coefficient K increases to its maximum from the initial value which is almost equal to value 1. Maximum, as it was already said, corresponds to parallel resonance of the electric circuit and in this frequency the character is converted from inductance to capacitance. From this point value of the coefficient K starts to fall to its minimum value, which represents series resonance o the electric circuit and where capacitance character converts back to inductance. Afterwards increase in value of the coefficient K starts and resonances repeat. If series resonance in the electric circuit arises, value K is lower than 1 which means that relevant harmonics are damped. While vehicles move from the end of the traction supplying section to its start, value of K decreases but resonance frequency stays unchanged. Fig.7. shows dependence of resonance frequency and K on movement of all vehicles.

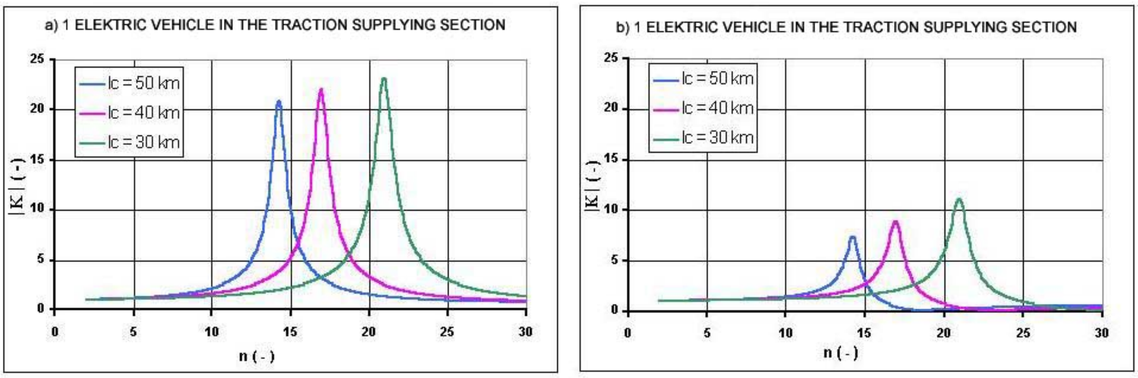

Fig.5. Dependence of the coefficient's K absolute value on frequency for one electric vehicle in supplaying section

a) vehicle in the end of the section

b) vehicle close to the traction transformer substation

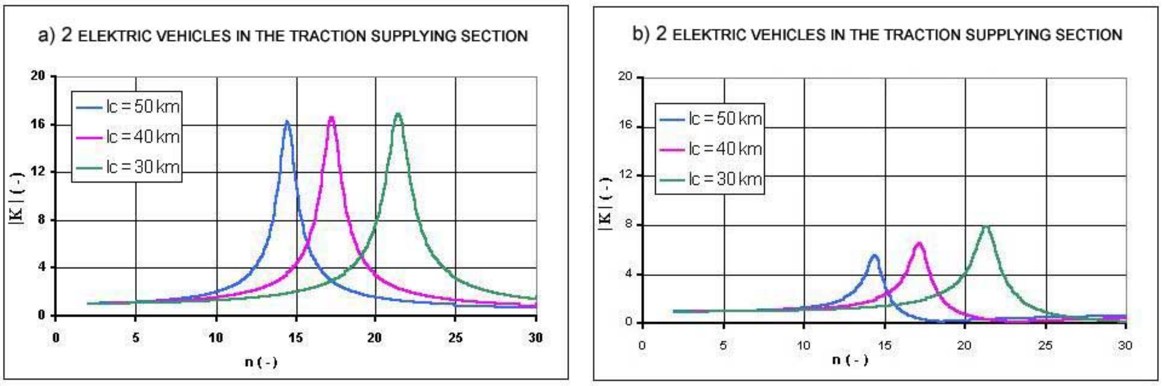

Fig.6. Dependence of the absolute value of the coefficient K on frequency for two electric vehicles in the section

a) generating vehicle in the end of the section and the second close to the traction transformer substation.

b) both generating vehicle and the second vehicle are close to the traction transformer substation.

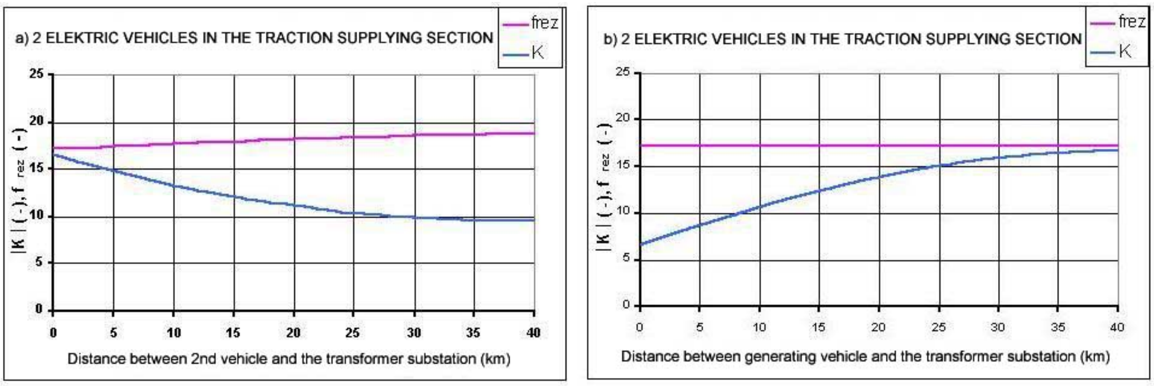

Fig.7. Dependence of K and resonance frequency on movement of 2nd vehicle in the traction supplying section (length of the section is 40 km)

a) generating electric vehicle in the end of the section

b) generating electric vehicle close to the traction transformer substation.

Table1. Results of the resonance frequency and results of the maximum value of the the coefficient K

Generating vehicle by the end of traction supplying section (TSS)

Lenght of TSS		1 vehicle	2 vehicles 2nd vehicle by TS	3 vehicles 2nd vehicle by TS 3rd vehicle in the half of TSS
50 km	n (-)	14,28	14,48	15,62
	frez (Hz)	714	724	781
	Kmax (-)	20,865	16,274	8,73
40 km	n (-)	16,97	17,25	18,48
	frez (Hz)	848,5	862,5	924
	Kmax (-)	21,979	16,673	9,498
30 km	n (-)	20,99	21,4	22,76
	frez (Hz)	1049,5	1070	1138
	Kmax (-)	23,168	16,998	10,381

Generating vehicle by the transformer substation (TS)

Lenght of TSS		1 vehicle	2 vehicles 2nd vehicle by TS	3 vehicles 2nd vehicle by TS 3rd vehicle in the half of TSS
50 km	n (-)	14,24	14,41	15,42
	frez (Hz)	712	720,5	771
	Kmax (-)	7,373	5,51	2,481
40 km	n (-)	16,94	17,19	18,33
	frez (Hz)	847	859,5	916,5
	Kmax (-)	8,957	6,521	3,747
30 km	n (-)	20,96	21,35	22,63
	frez (Hz)	1048	1067,5	1131,5
	Kmax (-)	11,156	7,883	4,826

In the calculation are used followings paramethers of traction curcuit:
Traction transformer EJER 7491/75 :   S = 7,5 MVA, uk = 12,5 %,
Traction contact system : 100 mm2 Cu + 50 mm2 bronze (RK = 0,26 □/km, LK = 1,43 mH/km, CK=20,5 nF/km)

5. CONCLUSION

For value of parallel resonance frequency of the traction supplying circuit we can deduce:
a) Value of resonance frequency decreases with length of the traction supplying section. See Fig.5 a Fig.6
b) Value of resonance frequency is independent of vehicle's location. See Fig.7.
c) 2nd and 3rd elektric vehicle cause slightly increase of the resonance frequency.
For value of the coefficient *K* we can deduce:
a) Maximum value of *K* decreases with increasing length of the section. See Fig.5 and Fig.6
b) With movement of generating electric vehicle due to the end of the section it increases. See Fig.7.
c) 2nd and 3rd electric vehicle cause huge decrease of value of coefficient *K*.

6. REFERENCE

[1] R. P. Maheshwari, H. K. Verma, “Adaptive Digital relay for comprehensive distance protection of traction overhead equipment”, Developments in Power system protection, Conference Publication No. 434, IEE, 25-27th March 1997, pp. 331-337.

[2] Gao Shibin, He Weijun, Chen Xiaochuan, “Study on microprocessor based adaptive protection relay for heavy duty electric traction system”, Developments in Power System Protection, Sixth Intl. Conf., Pub. No. 434, IEE, 25th-27th March 1997, pp. 319-322.

[3] G. Celli, F. Pilo, S.B. Tennakoon, “Voltage Regulation on 25 kV AC railway systems by using Thyristor switched capacitor”, Proceedings of 9th Intl. Conference on Harmonics and Quality of Power, Vol. 2, Oct. 2000, pp. 633-638.

[4] “Power System Blockset User’s Guide”, The Mathworks Inc., Natick, MA, January 1999.

[5] “Using Simulink”, the Mathworks Inc., Natick, MA, January 1999.

[6] “Using MATLAB”, The Mathworks Inc., Natick, MA, January 1999.

[7] “Static distance protection relay with parallelogram characteristic for 25 kV AC single phase, 50 Hz traction Overhead equipment”, Specification No. ETI/PSI/141 (10/90), Research Designs and Standards organization, Ministry of Railways, India.

[8] Pee-Chin Tan, Robert E. Morrison, Donald Grahame Holmes, “Voltage form factor control and reactive power compensation in a 25 kV Electrified railway system using shunt active filter based on voltage detection”, IEEE Transactions on Industry Applications, Vol. 39, No. 2, March/April 2003, pp. 575-581.

[9] M.J.Domzalski, K.P.Nickerson, P.R.Rosen, “Application of mho and quadrilateral distance characteristics in power systems”, Developments in Power System Protection, Seventh Intl. Conf., Pub. No. 479, 9-12 April 2001, pp. 555-558.

[10] Palecek, J : Napájení jednofázové vozby Ceských drah z hlediska elektromagnetické kompatibility, VSB-TU, Ostrava, 2000.

МОДЕЛИРАНЕ И СИМУЛАЦИЯ НА РЕЗОНАНСНИТЕ ЧЕСТОТИ И КОЕФИЦИЕНТ НА УВЕЛИЧЕНИЕ В ДЕЙСТВАЩАТА ЖЕЛЕЗОПЪТНА ТЯГОВА СИСТЕМА С ПРОМЕНЛИВ ТОК 25 KV ЧРЕЗ СОФТУЕРЕН ПАКЕТ PSB / SIMULINK

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***Ключови думи**: PSB / SIMULINK, коефициент на увеличение на тяговия ток*

***Резюме:** Тази статия представя моделиране и симулация на резонанса в тяговата верига с променлив ток 25 kV; 50 Hz чрез софтуерен пакет Power System Block set (PSB) / SIMULINK. В модела са включени трифазна система с подстанции, релсов участък с локомотиви, захранвани с токоизправител за постоянен ток, и теглещо натоварване. Моделът е използван за проучване на ефекта в условия на натоварване и повреди при тяга с променлив ток 25 kV. В последната част са представени резултатите от изчисленията в реални случаи от трафика на Сръбските железници.*

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