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Non Sinusoidal Modes of Traction Power Supply Systems Equipped with Reactive Power Compensation

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***Abstract*—Rectifier electric locomotives create essential harmonic distortions in tractive electric power supply systems. Because of the higher harmonics, overloads on capacitor banks are possible. Capacitors are a basic element of reactive power sources applied in power supply systems. In case of harmonic increased levels such overloads can lead to out of reactive sources operation. Therefore the task of possible overload prediction has the practical significance. It acquires special relevance when planning the pass of increased mass trains. In article the computer simulation technique allowing to define an capacitor batteries overload in the presence of higher harmonics currents is described. It is shown that the task of overload prediction can be solved by means of non-sinusoidal mode simulation for the schedulable amount of train movement by the methods and means developed at the Irkutsk state transport university. Simulation was carried out by the program Fazonord complex for the tractive power supply system including five inter substation zones of 27.5 kV two-way tractive network section. The received results showed that overloads of capacitor banks can be lowered to acceptable values by means of the protective reactor. In case of reactor switch-off an overload coefficients become unacceptably big. The offered computer simulation technique gives the chance to define capacitor batteries overloads in the presence of a non-sinusoidal curve currents and voltage. Technique application in practice will allow avoiding emergency situations which can lead to failure of the expensive equipment.**

Keywords*—railroad, tractive electric power supply system, alternating current, capacitor batteries, high harmonics, overload

I. INTRODUCTION

Capacitor-based reactive power sources (RPS) are an effective means to enhance electrical energy quality in traction power supply systems (TPSS) of AC railroads [1–10]. Capacitors overloads by higher harmonics (HH) currents are possible due to the presence of significant harmonic distortions in TPSS which are generated by rectifying electromotives. When unsinusoidality levels are high, such overloads can result in RPS going out of order [7, 11], therefore, the problem of possible overloads forecasting is of practical significance. It is of special urgency for scheduling increased weight trains operation [12–14].

II. MODELING METHODS

RPS in AC traction network are used for reactive power compensation. The problem of RPS condensers overload forecasting can be resolved using TPSS nonsinusoidal modes simulation for traffic amounts scheduled based on methods and means developed in the IrGUPS.

The ways of TPSS adequate modeling, considering electromagnetic interinfluences and allowing for combining TPSS and external network into a single system, are suggested in works [15, 16]. Transition to simulation modeling required development of some instant diagrams, determined by trains motion and development of integral modeling characteristics. Simulation method is implemented in software application Fazonord PSW which is designed to determine a combination of modes for AC TPSS instant schemes corresponding to trains location in space in discrete instants in time. Using the PSW, TPSS modes can be simulated on the basic frequency and higher harmonics frequencies, which are generated by electromotives and unsinusoidality stationary sources. To create design models, visual components are used complying with TPSS and electrical power supply system elements. Such elements are known as cable and OPL, traction networks, transformers with different windings connections, load nodes, etc.

Using the software application, the following operations can be performed:

- elements models generation using built-in editor, and models saving in the database;

- compiling nodalization diagrams using the generated elements and graphical interface;
- specifying elements of a relevant overhead system and generation of trains operation routes based on it;
- generation of instant schemes sets corresponding to a pre-set train diagram;
- determining power values for moving loads based on train performance;
- determining modes for a number of instant schemes for a train diagram under consideration;
- calculations of induced voltages occurring on power supply and communication lines, laid along the railway route; in this case, it is possible to perform simulation of railroad and lines constant-bearing and canted approach;
- representation of modeling results as graphs, tables and vector diagrams.

The main difference of Fazonord PSW from similar software applications is that using it, makes it possible to perform full-functional TPSS and electrical energy systems modeling in phase coordinates with due regard to inductive couplings. In addition, based on this PSW, it is possible to analyze the dynamics of mode change in the combined system of external and traction power supply, and to determine the quality of electrical energy indicators during the trains operation.

The article analyses the use of Fazonord PSW for purposes of TPSS nonsinusoidal modes modeling in order to determine possible capacitors overloading by higher harmonics currents.

Based on nonsinusoidal modes modeling results, coefficients of RPS overloads are calculated

$$k_P = \frac{1}{I_{\text{HOM}}} \sqrt{\sum_{k=1}^{40} (I_k)^2},$$

where I_k – harmonics current with k number. Value k_P, exceeding 1.3, as a rule, corresponds to prohibitive overload [3].

III. MODELING RESULTS

Modeling was carried out for AC real railroad power supply scheme, containing 366 junction points, 1382 branches and five inter-substation zones (ISZ) of double-track road section's 27.5 kW traction network. Inter-substation zones (ISZ) length was in the range 38 to 55 km. Inter-substation zones was supplied by TDTNZh transformers-40000/230/27.5. A capacitor with impedance coil is installed on one of inter-substation zones' sectioning point. Capacitor's rated current – 75 A, basic frequency resistance – j385 Ohm, impedance coil resistance – j23 Ohm, resonance frequency – 205 Hz. The parameters provided correspond to a real power factor correction installation with resonance adjustment leading to capacitive currents on the third harmonics. Operation of 15 even and 15 odd trains weighing 6,000 t each was considered; the trains operation intervals were 30 minutes (fig. 1). The trains current profiles are shown in fig. 2.

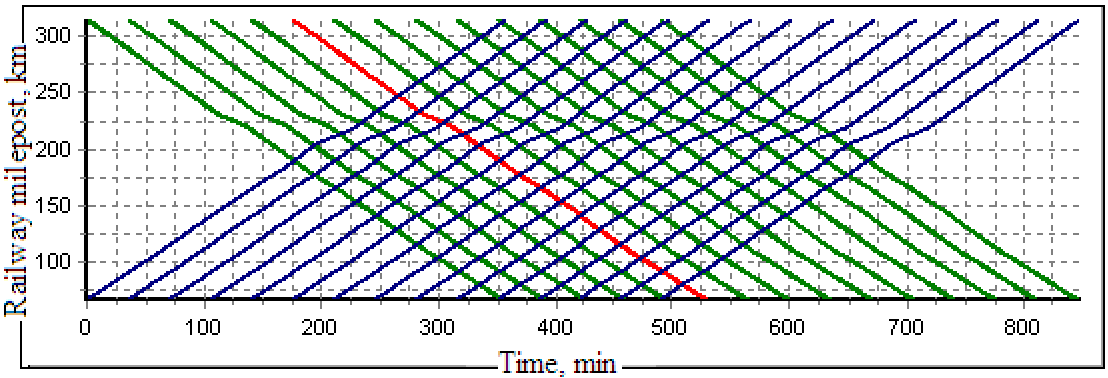
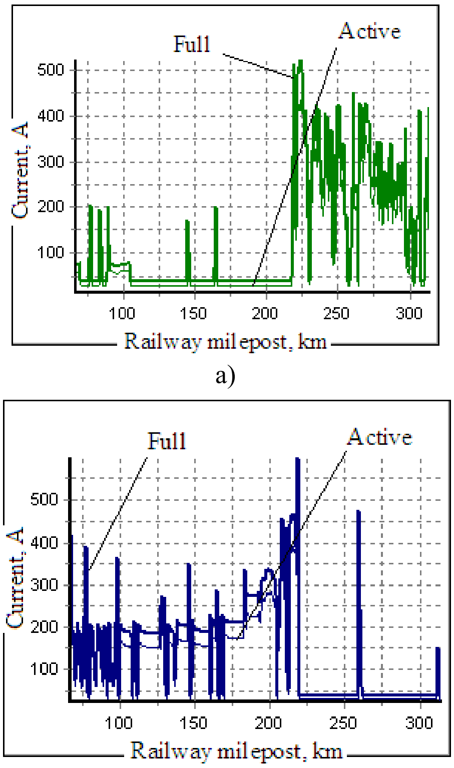


Fig. 1. Train schedule

A fragment of nodalization diagram with inter-substation zones (ISZ) and reactive power source is provided in fig. 3 where node 233 has virtually zero potential due to the presence of the earth high conductivity shunt. The electromotive harmonic current composition is provided in fig. 4. The modeling was carried out for two options:

- for a switched on impedance coil represented by RL-elements with resistance on basic frequency of 0.43 + j23 Ohm;
- for a shut down (shunted) impedance coil.

Modeling results are represented in fig. 5-12 and in table 1 as factors' time dependences characterizing reactive power sources and the value of their overload.



a)

b)

Fig. 2. The current profile of the odd train (a) and the even train (b)

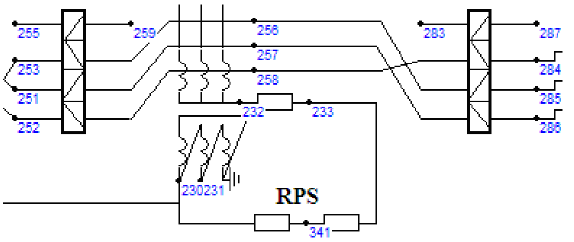


Fig. 3. A fragment of the nodalization diagram

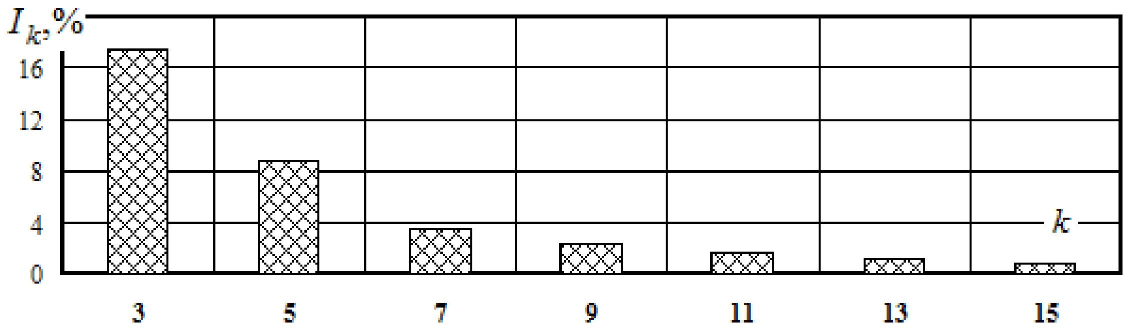


Fig. 4. Electromotive harmonics spectrum

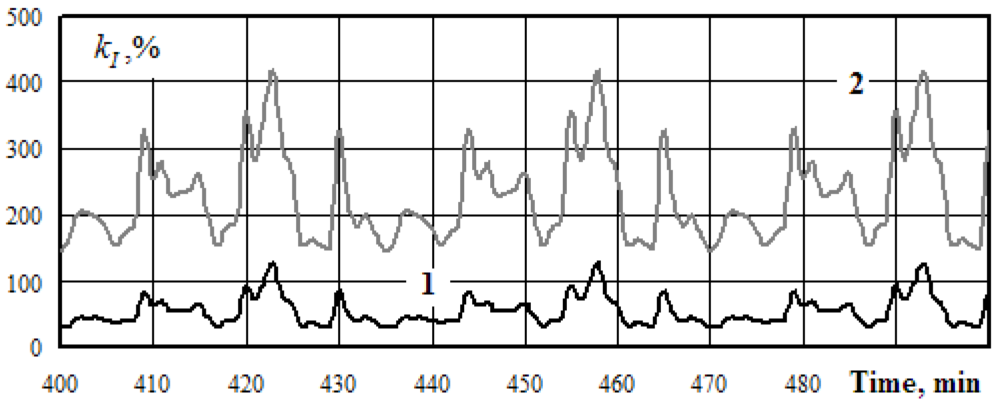


Fig. 5. Total coefficients of RPS current harmonics: 1 – impedance coil is on; 2 – impedance coil is off

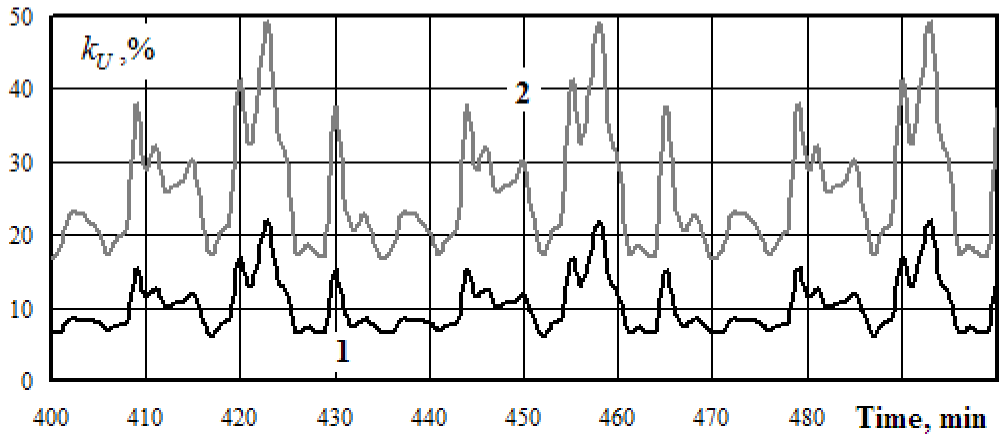


Fig. 6. Total coefficients of RPS voltage harmonics: 1 – impedance coil is on; 2 – impedance coil is off

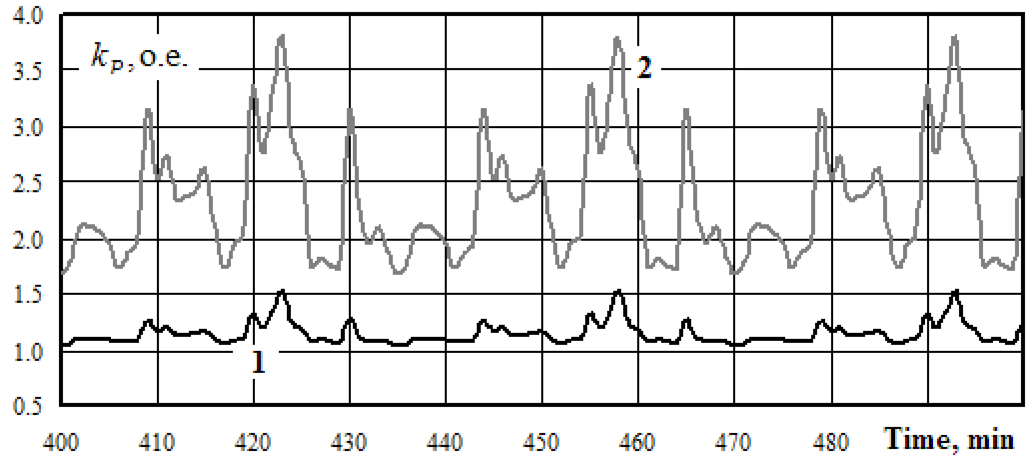
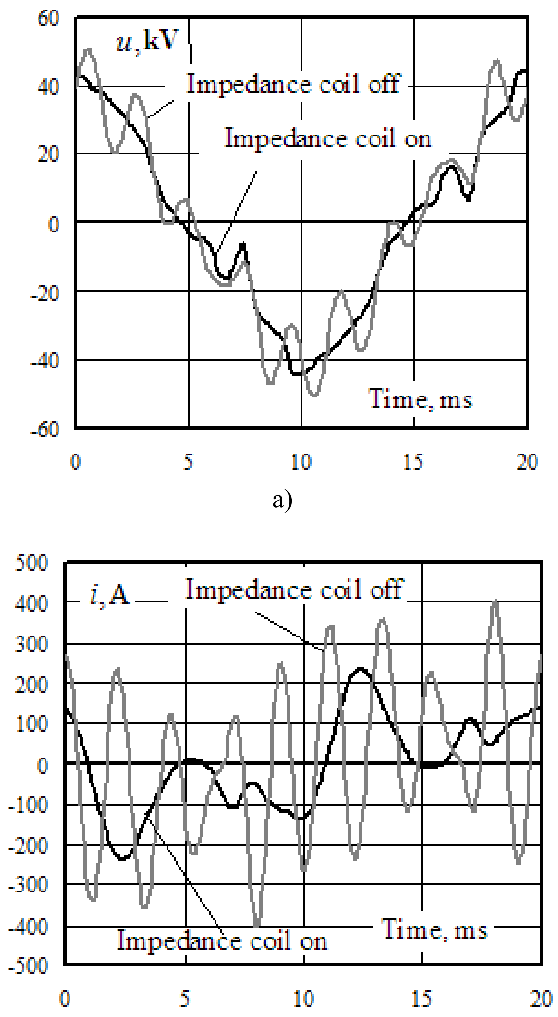


Fig. 7. Capacitor overload coefficients: 1 – impedance coil is on; 2 – impedance coil is off

TABLE I. SUMMARIZED DATA FOR COMPENSATION INSTALLATION MODE

Parameter	**Factor**	**Mode**		**Ratio**
		Impedance coil on	***Impedance coil off***	
I_1, A	Maximum	78.7	73.9	0.94
	Average value	76.2	71.6	0.94
I_Σ, A	Maximum	114	285	2.49
	Average value	82.0	127	1.55
k_P, p.u.	Maximum	1.52	3.80	2.49
	Average value	1.09	1.70	1.55
k_I, %	Maximum	127	417	3.28
	Average value	33.3	137	4.11
k_U, %	Maximum	21.8	49.1	2.25
	Average value	6.30	15.7	2.49

a. Notes: I_1 – basic frequency current; I_Σ, A – harmonic effective current value; k_P – overload factor; k_I , k_U – current and voltage harmonic coefficients



a)

b)

Fig. 8. Capacitor current and voltage curves on the 355-th min.: a – voltage; b – current

Results obtained indicate that when impedance coil is on, overload coefficient is comparatively low in average, but in maximum, it exceeds the permissible value. When it is shut down, resonance phenomena occur on the 9-11-th harmonics with condensers' prohibitive overload. Voltage and RPS current curves significantly differ from sinusoid, whereas for shut down impedance coil current curve is represented by the two sinusoids overlapping with frequencies 50 and 450 Hz.

The following time dependences are represented in fig. 9 – 11 in order to study capacitors overloads with higher harmonics currents:

$$I_1 = I_1(t)$$

$$I_{ef}^{(hg)} = I_{ef}^{(hg)}(t)$$

$$I_\Sigma = I_\Sigma(t)$$

where $I_{ef}^{(hg)} = \sqrt{\sum_{h=3}^{40} I_h^2}$ – higher harmonics effective current.

Values included in expressions (1) are associated with the following relations:

$$I_{ef}^{(hg)} = k_I I_1$$

$$I_\Sigma = I_1\sqrt{1 + k_I^2}$$

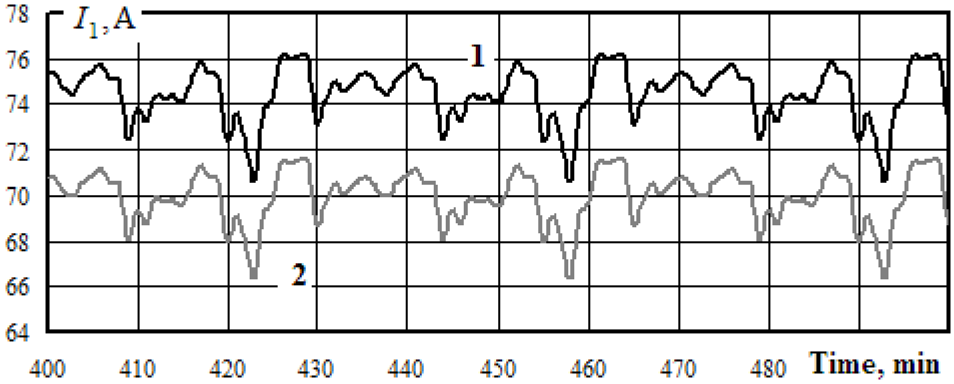


Fig. 9. Basic frequency current flowing in RPS circuit: 1 – impedance coil is on; 2 – impedance coil is off

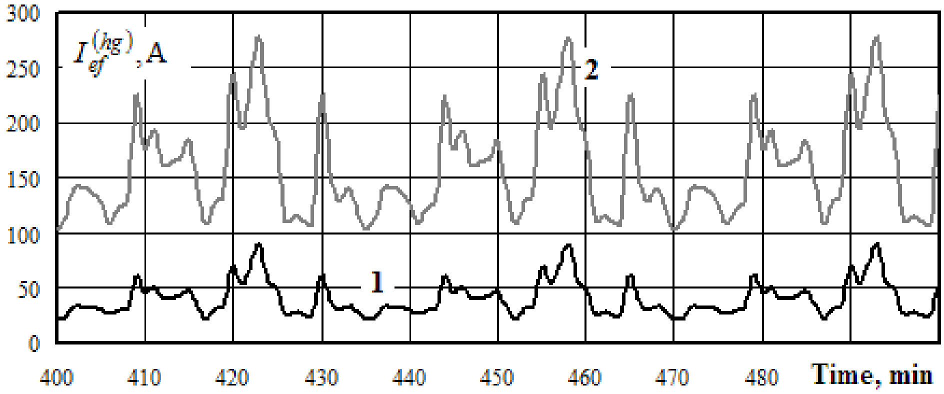


Fig. 10. HH Basic frequency current flowing in RPS circuit: 1 – impedance coil is on; 2 – impedance coil is off

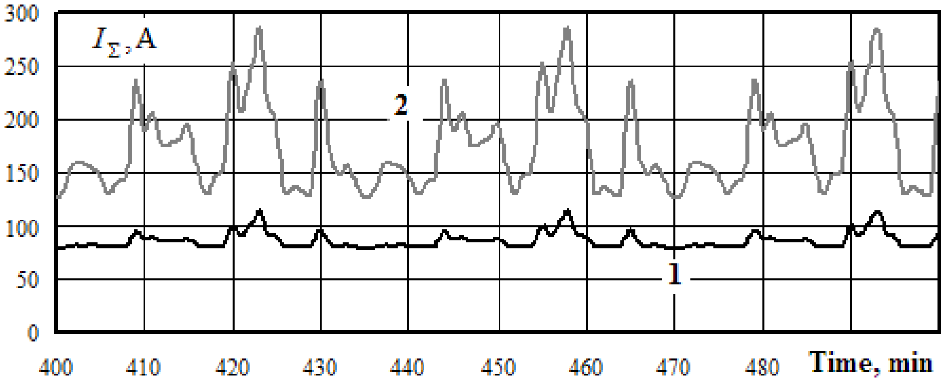


Fig. 11. Resulting effective current: 1 – impedance coil is on; 2 – impedance coil is off

In fig. 9 – 11 it is seen that basic frequency currents increase approximately by 6% due to drop in RPS circuit resulting resistance, when the impedance coil is on. HH effective current flowing in RPS circuit with impedance coil is sufficiently lower than current without the impedance coil which is determined by the increase in RPS full resistance when frequency is increased. Reduction in currents $I_{ef}^{(hg)}$ results in to pronounced decrease in effective currents I_Σ; in this case, capacitors overload coefficients virtually do not exceed the permissible limits.

IV. CONCLUSION

The proposed computer modeling method allows one to determine capacitors overloading by higher harmonics currents. The application of this method in operation would help to avoid accidents that may cause costly equipment failure.

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