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Influence of high-power nonlinear consumers on electric energy losses in mining high-voltage power line

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Influence of high-power nonlinear consumers on electric energy losses in mining high-voltage power line

M A Averbukh, D A Prasol

Belgorod State Technological University named after V.G. Shoukhov, Russia, 308012, Belgorod, Kostyukov St., 46

E-mail: dapras@mail.ru

Abstract The article elucidates the influence of high-power nonlinear consumers on electric energy losses in a mining high-voltage power line. The object of the study was a fragment of a power supply system of a mining enterprise with hoists. The investigation has assessed the electric energy losses conditioned by nonsinusoidal currents and voltages of the power line over a single hoist operation cycle. Also, the total electric energy losses in a high-voltage power line of a mining enterprise was calculated. The energy losses due to nonsinusoidal currents and voltages over single operation cycle of the cage hoist amount to 36.358 kWh. The presence of such losses increases total technological power and energy losses in the mining high-voltage power line by approximately 5-15%. The total energy losses in the components of the mining enterprise high-voltage power line caused by nonsinusoidal voltage are significant and lead to additional expenses of the company.

1. Introduction

At modern mining enterprises, a large number of consumers with nonlinear current-voltage characteristics are connected to power supply buses. For instance, they are represented by a controlled electric drive of hoists, main fans, main pumping stations. Moreover, the consumers with non-linear current-voltage characteristics can work in different dynamic modes. As an example, skip and cage hoists operate on intermittent duty of vehicle trips according to set motion tachograms. The movement tachograms of vehicles is followed by a controlled electric drive, which scheme includes thyristor converter, separately excited DC motor, which in its turn is a consumer with non-linear current-voltage characteristics.

Such consumers use nonsinusoidal current, i.e. they are generators of higher harmonic components of currents and voltages in a power line. Higher harmonic components of voltage and current in power supply systems of mining enterprises cause a range of negative phenomena [3]; the majority of them are additional losses of electrical energy in power line components [3, 4].

One of the main objectives of modern power generation industry in general is reduction of power and energy losses in power line components. As a rule, the major number of losses occurs in power lines and transformers. In mining power lines, the electric energy losses also depend on the composition of electric equipment used and on its operation modes.

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2. Materials and Methods

The object of study was a fragment of a power supply system of a mining enterprise depicted in Fig. 1. The electric drives of cage and skip hoist are powered by two sections of 6-kV distributor buses via matching transformers TDTP-8000 and TSZP-4000. As controlled rectifiers, twelve-pulse thyristor converters UKTESh-6300/930-211-500UKhL4 and UKTESh-6300/825-211-500UKhL4 were used for cage and skip hoists, correspondingly. Thus, the represented power supply scheme contains two high-power non-linear consumers.

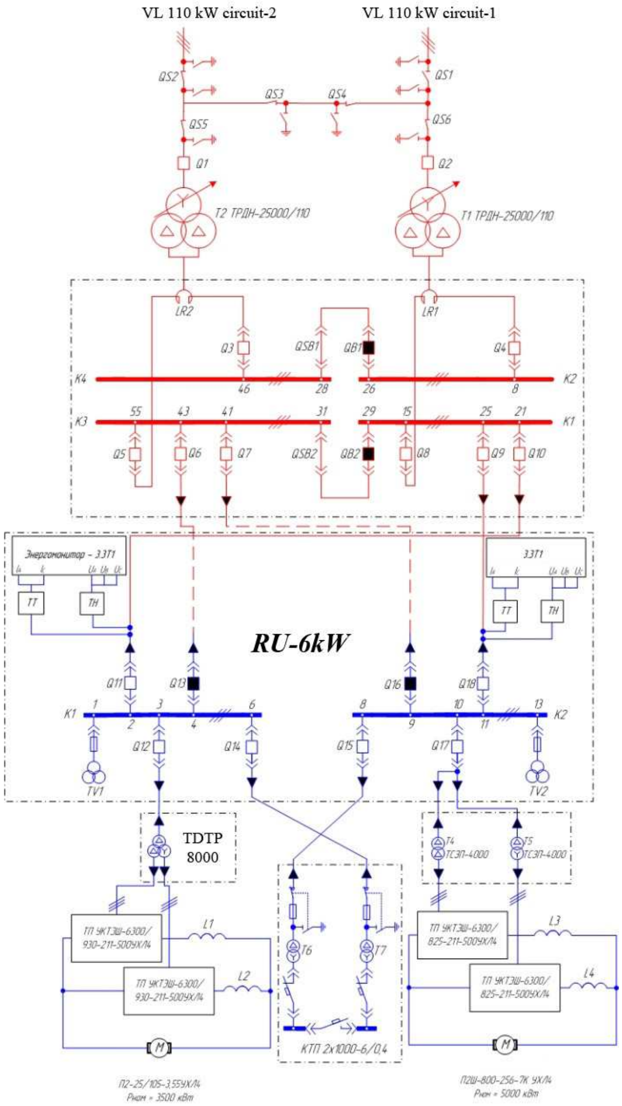

Figure 1. A fragment of the mining enterprise power supply scheme.

Electric energy losses in such power line are appreciably dependent on the hoist operation regime. This object is specific due to the presence of dynamic processes in the hoist operation cycle that take about 50-60% of the total cycle time. The cage movement time is 170 s, for skips it is 160 s. For instance, the movement tachogram of a cage hoist as well as the experimental values of main electrical parameters of the high-voltage power line are given in Fig. 2.

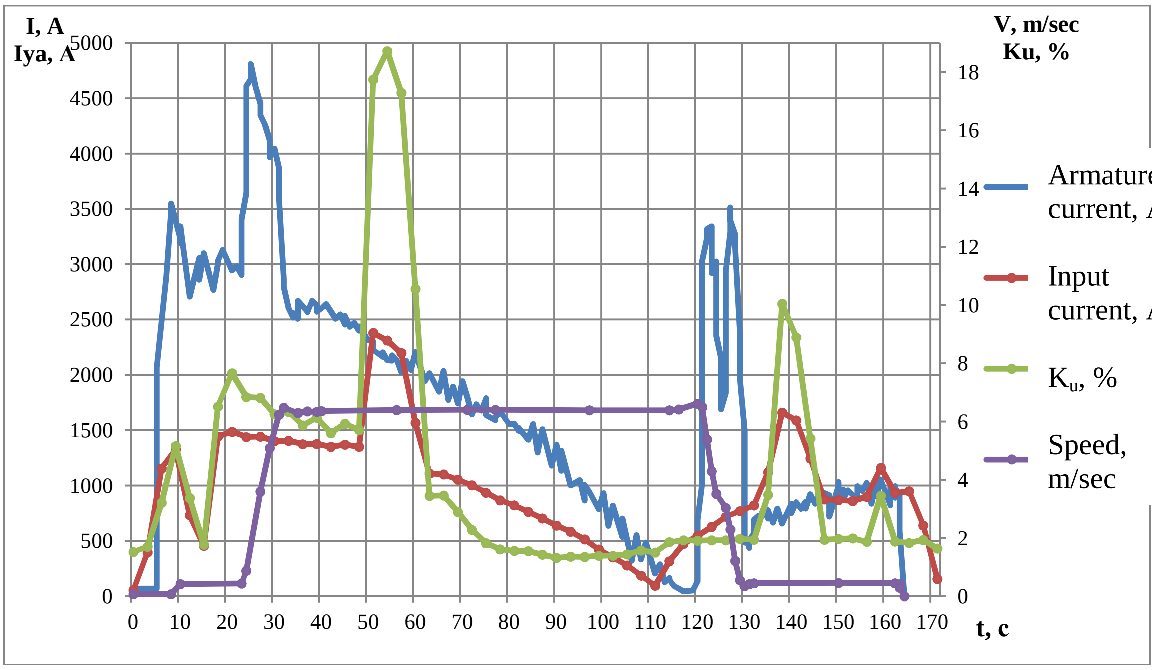

Figure 2. A diagram of vehicle speed alteration, armature current and input current, total harmonic components of the voltage over a cage hoist lift cycle.

During the switching of controlled rectifier thyristors, the signal is distorted by a specific set of higher harmonics determined as follows [2]:

$$\nu = m \cdot k \pm 1,$$

where *m* is the number of rectification phases; *k* =1, 2, 3, 4… is the sequence of natural numbers.

3. Evaluation of electric energy losses caused by nonsinusoidal current and voltage

The electric energy losses caused by nonsinusoidal consumed current and voltage are evaluated as [4]:

$$\Delta W_{\Sigma\nu} = \Delta W_{\Sigma TL\nu} + \Delta W_{\Sigma TP\nu},$$

where $\Delta W_{\Sigma pl\nu}$ is losses of active power in the power line caused by higher harmonics current; $\Delta W_{\Sigma TP\nu}$ is losses of active power in a transformer caused by higher harmonics current.

Losses in a power line caused by nonsinusoidal current are determined as [4]:

$$\Delta W_{TL\Sigma\nu} = 3\tau \sum_{\nu=2}^{40} I_\nu^2 R k_{r\nu},$$

where *R* is active resistance of the power line at elementary frequency, Ohm; ν is harmonic number; I_ν is current of ν-th harmonic, A; τ is considered time period, h; $k_{r\nu}$ is the coefficient factoring in the surface effect, usually it is taken as $k_{r\nu} = 0.47\sqrt{\nu}$.

Losses caused by nonsinusoidal voltage in a transformer are determined as [4]:

$$\Delta W_{TP\Sigma\nu} = \Delta P_{o.c.} \cdot \tau \sum_{\nu=2}^{40} K_{u\nu}^2 + 0.607 \frac{\Delta P_{s.c.}}{u_{s.c.}^2} \cdot \tau \sum_{\nu=2}^{40} \frac{1 + 0.05 \cdot \nu^2}{\nu \cdot \sqrt{\nu}} K_{u\nu}^2,$$

where $K_{u\nu}$ is the coefficient of ν-th harmonic component of voltage; $\Delta P_{o.c.}$, $\Delta P_{s.c.}$, $u_{s.c.}$ are transformer parameters.

The analysis of cage and skip hoist operation, as well as the calculation of electric energy losses, were performed on the basis of experimental studies carried out in the active power supply system of a mining enterprise at the voltage side of a 6-kV supply line through the circuits of measuring current and voltage transformers during the operation of hoist electric drives [1].

The results of electric energy loss estimation over a single operation cycle of the hoist caused by nonsinusoidal current and voltage in the power line are presented in Table 1.

Table 1. Results of electric energy loss estimation over a hoist operation cycle

Time interval	Losses [kWh]	Time interval	Losses [kWh]	Time interval	Losses [kWh]
17:43:42-17:43:51	0.04672	17:44:36-17:44:45	0.82655	17:45:30-17:45:39	0.71012
17:43:51-17:44:00	2.94097	17:44:45-17:44:54	0.22867	17:45:39-17:45:48	0.68289
17:44:00-17:44:09	3.67207	17:44:54-17:45:03	0.06620	17:45:48-17:45:57	0.10392
17:44:09-17:44:18	14.5596	17:45:03-17:45:12	0.04787	17:45:57-17:46:06	0.10855
17:44:18-17:44:27	10.249	17:45:12-17:45:21	0.05298	17:46:06-17:46:15	0.07488
17:44:27-17:44:36	1.9386	17:45:21-17:45:30	0.04527	17:46:15-17:46:21	0.03055

The plot of electric energy losses in the high-voltage power line of the mining enterprise caused by nonsinusoidal current and voltage over an operation cycle of the cage hoist is depicted in Fig. 3.

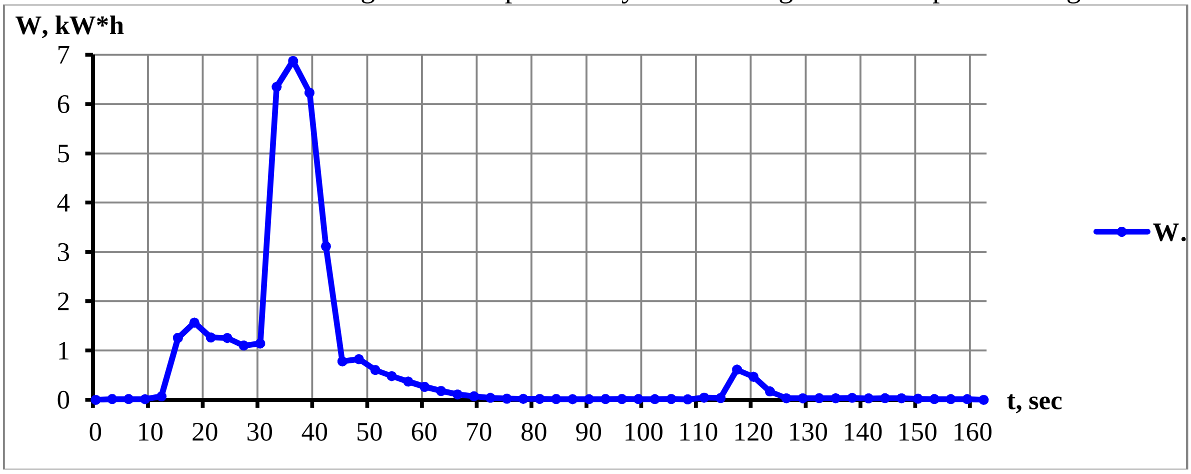

Figure 3. The electric energy losses conditioned by nonsinusoidal currents and voltages of the power line over a single hoist operation cycle.

Obviously (Fig. 3), the electric energy losses increase at acceleration and deceleration of the cage hoist. There losses are conditioned by both increasing power line current and considerable distortion of current and voltage curves. Total energy losses due to nonsinusoidal currents and voltages over single operation cycle of the cage hoist amount to 36.358 kWh.

The total electric energy losses in the mining enterprise high-voltage power line were calculated on the basis of obtained experimental results with due consideration of the most prominent odd harmonic components of voltage and current (Table. 2).

Table 2. The measurement results of the most prominent odd harmonic components of current

Harmonic number [n]	11	13	23	25	35	37
$K_{I\,(n)}$ [%] (cage hoist)	7.18	2.83	2.92	1.08	1.35	0.81
$K_{I\,(n)}$ [%] (skip hoist)	6.17	3.94	2.43	1.77	1.22	0.89

The power losses in power line were calculated similarly to electric energy losses. The power losses in the transformer were calculated as [4]:

$$\Delta P_{\Sigma n} = 3 \cdot \sum_{N=2}^{p} I_n^2 \cdot R_{k1} \cdot k_{nm},$$

where $R_{к1}$ is the transformer short-circuit resistance at elementary frequency; k_{nm} is coefficient factoring in the increase of short-circuit resistance for higher harmonics due to surface effect and proximity effect. For 11-th and 13-th harmonics, this coefficient is 3.2 and 3.7, respectively [4].

The results of calculation of total power and electric energy losses over a shift (8 hours) are presented in Table 3. Total additional power losses in power supply system components due to nonsinusoidality amounted to $\Delta P_{\Sigma n\text{total}}$ = 612.83 kW.

Table 3. Calculation results of total power and electric energy losses

Losses type	ΔP [kW]							
	11	13	23	25	35	37	Σ	$\Delta P_{\Sigma n}$
Cage hoist								
Losses in power line	1.222	0.754	0.232	0.244	0.061	0.087	2.602	7.805
Losses in transformer	53.961	35.426	2.218	2.239	0.472	0.656	94.972	284.916
Total losses	55.183	36.180	2.450	2.483	0.533	0.743	97.574	292.721
Electric energy losses ΔW_{Σ} [kWh]								2341.77
Skip hoist								
Losses in power line	1.503	0.666	0.337	0.186	0.105	0.057	2.856	8.567
Losses in transformer	66.381	31.298	3.218	1.708	0.811	0.432	103.846	311.539
Total losses	67.884	31.964	3.555	1.894	0.916	0.489	106.702	320.106
Electric energy losses ΔW_{Σ} [kWh]								2560.85
Total electric energy losses $\Delta W_{\Sigma total}$ [kWh]								4902.62

Total additional electric energy losses in the 6-kV high-voltage power line of the mining enterprise over a shift in the case of operation of hoists without taking into consideration of other consumers amounted to $\Delta W_{\Sigma total}$ = 4902.62 kWh. These losses cause additional heating of conductors, influence negatively transformers and lower the efficacy of power supply to mining enterprise consumers.

Additional financial expenses of the mining enterprise due to negative impact of higher harmonic components of current and voltage in the 6-kV power line of the mining enterprise, with the electricity tariff β = 3.15 RUB/kWh, can amount to 15443.25 RUB per shift. If the mining enterprise works with double shifts, additional expenses for electric energy losses caused by higher harmonic components in high-voltage power line can amount to 7 628 965.5 RUB (for 247 working days).

4. Conclusions

The electric energy losses due to nonsinusoidal currents and voltages over single operation cycle of the cage hoist amount to 36.358 kWh, notably the energy losses increase at acceleration and deceleration of the cage hoist.

The presence of electric energy losses due to nonsinusoidal current and voltage over a single operation cycle of each hoist increase total technological power and energy losses in the high-voltage mining power line by approximately 5-15%.

The electric energy losses in the elements of the mining enterprise high-voltage power line due to nonsinusoidal voltage over a single shift amount to 4902.62, while the additional expenses of the mining enterprise due to improper electromagnetic compatibility indicators can amount to more than 15 thousand RUB per shift or more than 7 628 965.5 RUB per year.

5. Acknowledgments

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