DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Averbukh, Mikhail A.; Zhukov, Nikolay A.; Khvorostenko, Stanislav V. et al.

Article

Reducing electric power losses in the system of power supply due to compensation of higher harmonics of currents : economic and energy efficiency outcomes

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Averbukh, Mikhail A./Zhukov, Nikolay A. et. al. (2019). Reducing electric power losses in the system of power supply due to compensation of higher harmonics of currents : economic and energy efficiency outcomes. In: International Journal of Energy Economics and Policy 9 (4), S. 396 - 403.
http://econjournals.com/index.php/ijeep/article/download/7693/4472.
doi:10.32479/ijeep.7693.

This Version is available at:
http://hdl.handle.net/11159/5074

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte.

https://zbw.eu/econis-archiv/termsofuse

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence.

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der
Leibniz-Gemeinschaft

IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2019, 9(4), 396-403.

EJ EconJournals

Reducing Electric Power Losses in the System of Power Supply Due to Compensation of Higher Harmonics of Currents: Economic and Energy Efficiency Outcomes

Mikhail A. Averbukh[1]*, Nikolay A. Zhukov[1], Stanislav V. Khvorostenko[1], Vasiliy I. Panteleev[2]

[1]Belgorod State Technological University Named After V. G. Shukhov, Belgorod, Russia, [2]Siberian Federal University, Krasnoyarsk, Russia. *Email: avers45@rambler.ru

Received: 14 Febuary 2019 **Accepted:** 18 May 2019 **DOI:** https://doi.org/10.32479/ijeep.7693

ABSTRACT

The issue of increasing energy efficiency and energy saving is of great importance for the countries with high energy intensity of the gross domestic product, including Russia and the rest of the Commonwealth of Independent States. The measures adopted in Russia on the federal and regional level as part of the State Program on Energy Efficiency and Energy Development are focused on reducing the energy intensity of Russia's gross domestic product and introduce sustainable practices on energy saving in Russia's commercial and budget sectors. This paper presents a case study describing the way to reduce electric power losses in a system of power supply (SPS) of an industrial enterprise. In particular, the case study determines the level of the higher harmonic components of current and voltage at the existing enterprise for the production of reinforced concrete products. The results of the experiment were reproduced using a simulation model of the power supply system in the Matlab/Simulink package. A comparative analysis of using a passive and hybrid filter compensating device to reduce the level of the higher harmonics of current and voltage was carried out by means of modeling. The active losses in the SPS from non-sinusoidal mode are calculated. In addition, the economic effect of using the proposed method is estimated.

Keywords: Energy Efficiency, Industry, Electric Power Losses, Higher Harmonics of Currents.
JEL Classifications: Q29, Q49, L94.

1. INTRODUCTION

The key role in improving economic performance, energy security, and environmental sustainability, as well as mitigating climate change, is played by energy efficiency (Fawcett and Killip, 2019; Foggia, 2018; Ingrao et al., 2018; Dadzie et al., 2018). There is a considerable body developed on energy efficiency of industry in general and in particular industrial enterprises (Malinauskaite et al., 2019; Zheng and Lin, 2018; Pusnik, 2017; Paulo de Lima, et al., 2018; Bhat et al., 2018; Lin and Zheng, 2017; Yanez et al., 2018; Xiong et al., 2019; Quiceno et al., 2019; Zuberia et al., 2017; Haraldsson and Johansson, 2018; Tanaka, 2011; Kohler, 2014; Hea and Wang, 2017). One of the most important factors contributing to energy efficiency is energy and recourse saving (Çay, 2018; Matraeva, et al., 2019; Feng, et al., 2018; Yang et al., 2018; Trotta, 2018). This is achieved through the implementation of energy saving measures, timely transition to new technical solutions, technological processes based on the introduction of the best available and innovative technologies, optimization forms of management, as well as improving product quality, using international experience and other measures. The modern research convincingly shows that the introduction of energy saving technologies not only leads to lower costs and increases product competitiveness, but it also contributes to improving the overall sustainability of the fuel and energy complex and the ecological situation, reducing the cost of introducing additional capacity, and removing barriers to economic development by reducing technological limitations (Kim, 2017; Aslani et al., 2019; Chowdhury et al., 2018).

One of the ways to increase energy efficiency in industrial enterprises is to reduce electricity losses in electrical networks. This is highly topical issue for the energy industry not only in Russia (Sadykova, 2014; Borodin et al., 2015; Savina and Myasoedov, 2017) but in other countries as well (Jamshidieini et al., 2019; Rozali, et al., 2018; Ward and Staffell, 2018). More than that, reducing electricity losses in electrical networks allows to: (1) Reduce the losses of the electric grid organizations due to the reduction of payment for excess losses and accumulate additional funds for a further reduction of losses; (2) unload the electrical networks from the additional power flows and, consequently, ensure the possibility of connecting additional power to the electrical networks; (3) reduce fuel consumption and harmful emissions at power plants by reducing power generation to compensate for losses; (4) reduce the volume of construction of generating capacity for reliable power supply to consumers with the apparent shortage of active capacity; (5) reduce tariffs for electricity transmission services on electric grids and electricity tariffs for end users (Liu et al., 2016; Abeysinghe et al., 2017; Innocent and Francois-Lecompte, 2018; Usman, 2018).

This paper presents a case study of how an industrial enterprise could reduce electric power losses in the system of power supply (SPS) and increase its energy efficiency. In particular, we calculate the level of the higher harmonic components of current and voltage at the existing enterprise for the production of reinforced concrete products (RCP). The results of the experiment were reproduced using a simulation model of the power supply system in the Matlab/Simulink package. A comparative analysis of using a passive and hybrid filter compensating device to reduce the level of the higher harmonics (HH) of current and voltage was carried out by means of modeling. The active losses in the SPS from non-sinusoidal mode are also determined, along with the economic effect of using the proposed method.

The presented case study contributes to the scholarly literature on energy saving and energy efficiency (Davidson, 2002). The model described and calculated in the paper is applicable at any industrial enterprise and demonstrates its effectiveness to reduce energy losses in electric power systems.

2. CASE STUDY

2.1. Introduction

At industrial enterprises, the production of RCP is carried out by a conveyor method in compliance with the requirements of the technological process. To ensure the necessary degree of compaction of concrete, mixture dosing, various vibration frequencies, speeds of belt conveyors and dispensers are used (Averbukh et al., 2016). For this purpose, a frequency-controlled electric drive is used based on a semiconductor frequency converter with an intermediate DC link – an asynchronous motor. Such receivers are the cause of the HH of current and voltage generated in the SPS of the enterprise. The negative influence of the HH is manifested in the violation of the operation of the monitoring and control means, leads to false alarms, to an increase in additional losses of electricity in the elements of the power supply system, etc.

2.2. Materials and Methods

The SPS of the industrial enterprise of the reinforced concrete industry is illustrated in Figure 1. It can be seen from the diagram that the main receivers with a non-linear voltage-voltage characteristic are variable frequency drives (VEDs) of various capacities connected to one section of the bus of the sub-station 630/6/0.4, where the transformer is used as a step-down and matching. To determine the degree of influence of the non-sinusoidal regime on the power supply system for such electric receivers, experimental studies (I_1-I_4) were carried out at the substation of RCP, which showed that the total coefficients of the harmonic current components K_I and the voltage K_U on the low side of the step-down transformer: K_I=22÷45%, K_U=2.5÷9% (Averbukh et al., 2017).

To develop recommendations for achieving the optimum level of electromagnetic compatibility (EMC), a simulation model in Figure 2 based on the actual SPS of the enterprise under investigation was built in the Simulink application of the Matlab software package. The basic elements are modeled in the same sequence as those included in the real scheme with numerical values of the parameters in accordance with the VED passport data. The role of the electric power source in the model is performed by a three-phase source of a sinusoidal voltage (Three-Phase Source). In the adjustment fields, the amplitude of the line voltage, the initial phase of the voltage in degrees, the frequency of the voltage in hertz and the internal parameters of the source (Chernykh, 2008). The cable line (CL) connecting the transformer to the voltage source is represented by the Three-Phase Series RL Branch and the input parameters for the unit is the active, inductive resistance of the CL. The step-down transformer is represented by the Three-phase Reduce Transformer (Two Windings), we indicate the connection schemes of the primary and secondary windings, the parameters of the rated total power and frequency, the voltage, the active and inductive resistance of the windings and the magnetizing circuit. Non-linear receivers are represented by units with VED subsystems connected to the secondary winding of the transformer using a CL unit.

The results of the experimental studies and modeling are shown in Figure 3, in the form of histograms of the fundamental and VG current and voltage with the indication of K_I and K_U.

2.3. Calculation of Electricity Losses in the SPS

The most significant effect due to non-sinusoidal operation is additional losses of active power in CLs and transformers from high-frequency current and voltage components (Averbukh and Zhilin, 2016; Averbukh et al., 2017; Abrokwa et al., 2017; Ahamed et al., 2019).

The total losses of active power in the elements of the SPS can be determined from expression:

$$\Delta P_{\Sigma}=\Delta P_{\Sigma T}+\Delta P_{\Sigma \text{КЛ}},$$

where $\Delta P_{\Sigma T}$ - total losses of active power in the transformer, $\Delta P_{\Sigma \text{КЛ}}$ - total active power losses in CLs.

The loss of electric power in the KL from non-sinusoidal operation is determined by the formula:

$$\Delta P_{\Sigma_{\ddot{E}\acute{Y}\ddot{E}}} = 3 \times \sum_{n=2}^{p} I_n^2 \times R_\Sigma \times k_{rn},$$

where R_Σ is the total active resistance of the transmission line at the fundamental frequency; n is the number of the harmonic; I_n is the current of the nth harmonic; k_{rn} is a coefficient that takes into account the effect of the surface effect, it is equal to $\sqrt{n}$.

Additional losses of active power in the transformer windings from non-sinusoidal operating modes can be expressed as the sum of losses of a short circuit and an idling (Costa-Campi et al., 2018; Hollas and Herren, 1982). In addition to additional transformers, there are additional losses due to eddy currents. In normal sinusoidal modes, these losses are small and amount to 5% of the nominal losses of short circuits. However, when the HH currents flow in the transformer, the additional losses increase sharply and can reach 30-50% ΔP_{nc} (Dolinger, 2013):

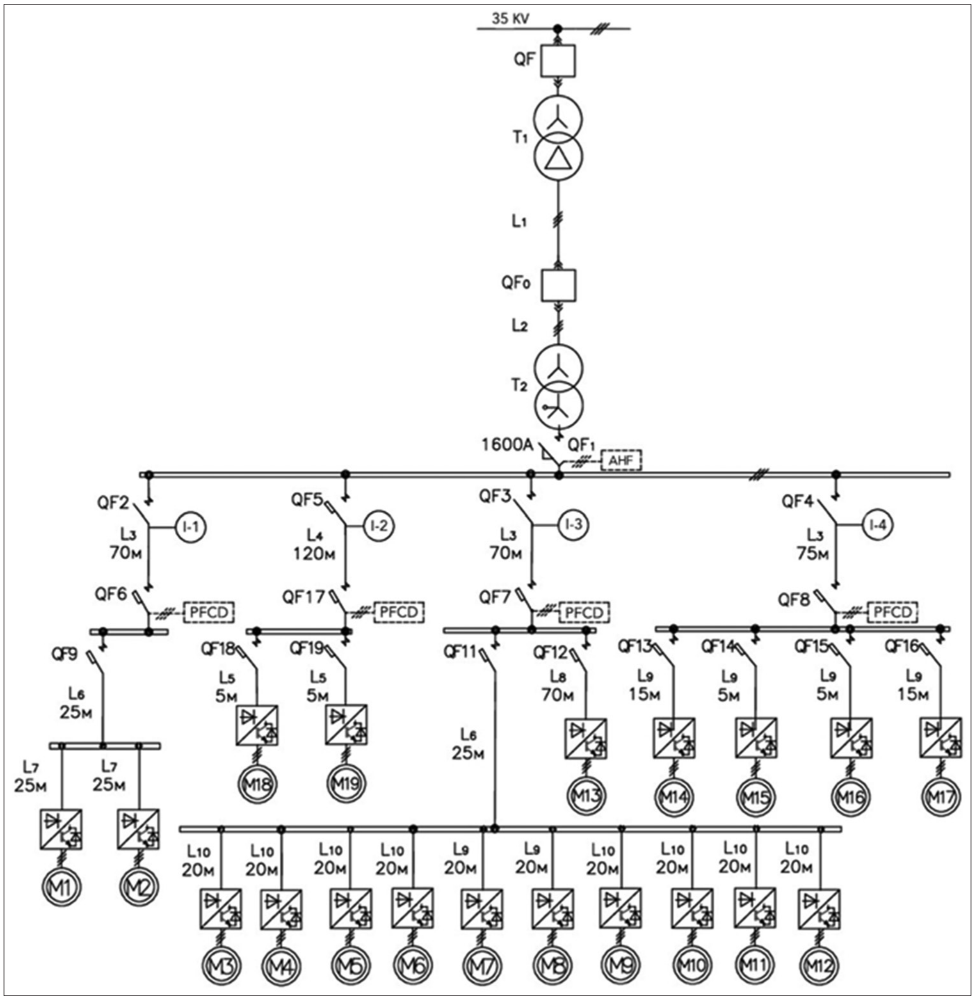
$$\Delta P_{\Sigma_T} = \Delta P_{nc} \times \sum_{n=2}^{p} U_n{}^2 + 0.607 \times \frac{\Delta P_{si}}{u_{si}^2} \times \sum_{n=2}^{p} \frac{1 + 0.05 \times n^2}{n \times \sqrt{n}} \times U_n{}^2.$$

Calculated losses of electricity based on the results of experimental studies in the SPS showed that the total active energy loss per shift (8 h) is 159.6 kWh. Taking into account the fact that the company operates an average of 6120 h a year, the annual power losses amount to 122.1 MWh, with a consumption of 957.44 MWh, hence the share of total additional losses from HH with 12.8%. Therefore, to reduce the influence, high-frequency components of current and voltage, the use of filter compensating devices (FCD) is necessary. In Figure 1, the dashed line indicates the proposed installation site for a passive and active FCD for EMC.

2.4. Passive Filter Compensating Device (PFCD) for Compensation of HH

The filter-feeding network system is a complex resonant voltage circuit caused by a current of frequency equal to or near the resonant frequency ω_p, overcurrent arises in a series circuit on its inductive and capacitive elements (7) (Kartashev, 2006). At the frequency $\omega > \omega p$, the impedance of the PFCD under consideration will be inductive, and if $\omega < \omega p$ it is capacitive, it follows that at the fundamental frequency, the filter generates reactive power; therefore, such devices are able not only to filter out the HH

Figure 1: A scheme of the power supply system



Source: QF-BP35HCM, T^1 – TMH 1000/35/6, L1-AC-70/11 3 × 70 7.5 km. QF^0 – BHA – 10/630 U2, L^2 – ABCbSHv 3 × 120 50 m, T^2 – TMG 630/6/0.4, L^3 – ABBG 4 × 95, L^4 – ABBG 4 × 120, L^5 – BBG 4 × 95, L^6 – ABBG 4 × 50, L^7 – ABBG 4 × 25, L^8 – ABBG 4 × 16, L^9 – BBG 4 × 16, L^{10} – BBG 4 × 4, PFCD – passive filter compensating device, AHF – active harmonic filter

Figure 2: Simulation model of the power supply system in Matlab/Simulink

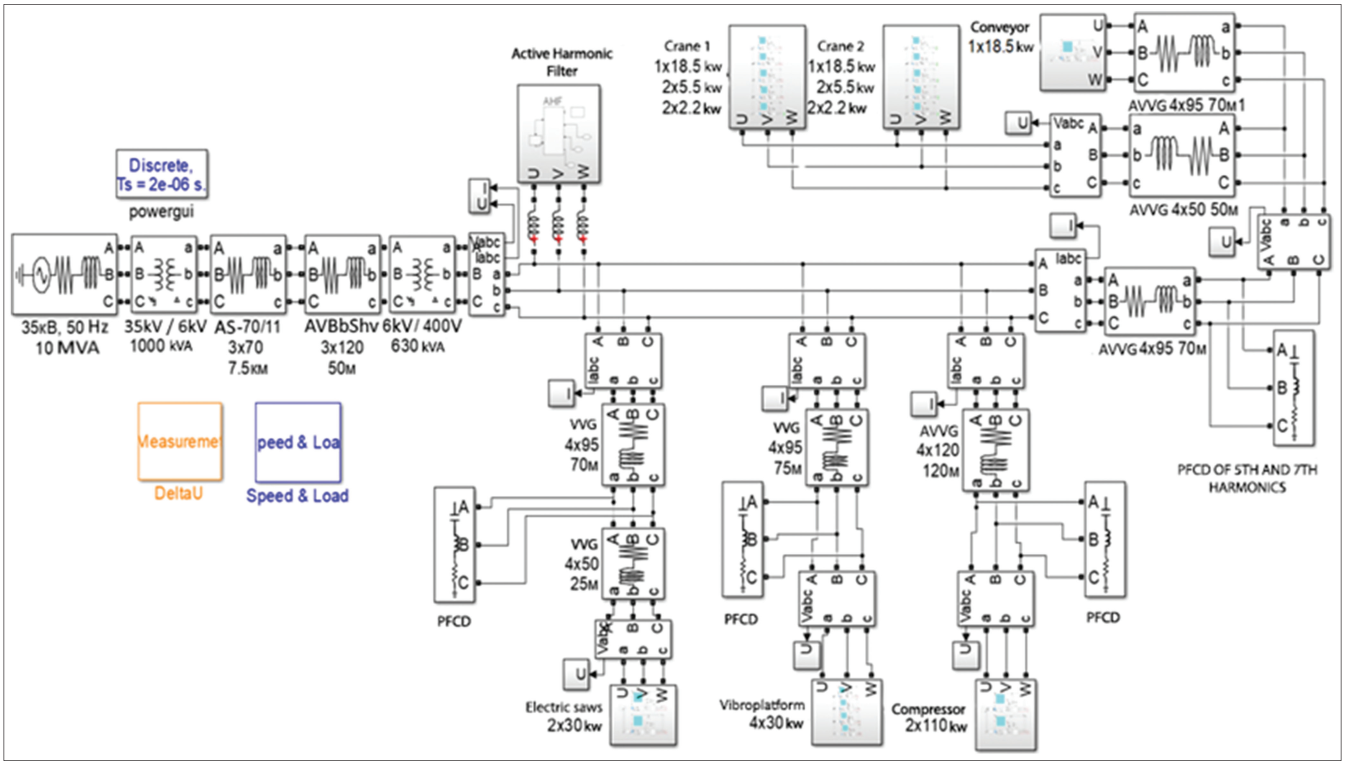
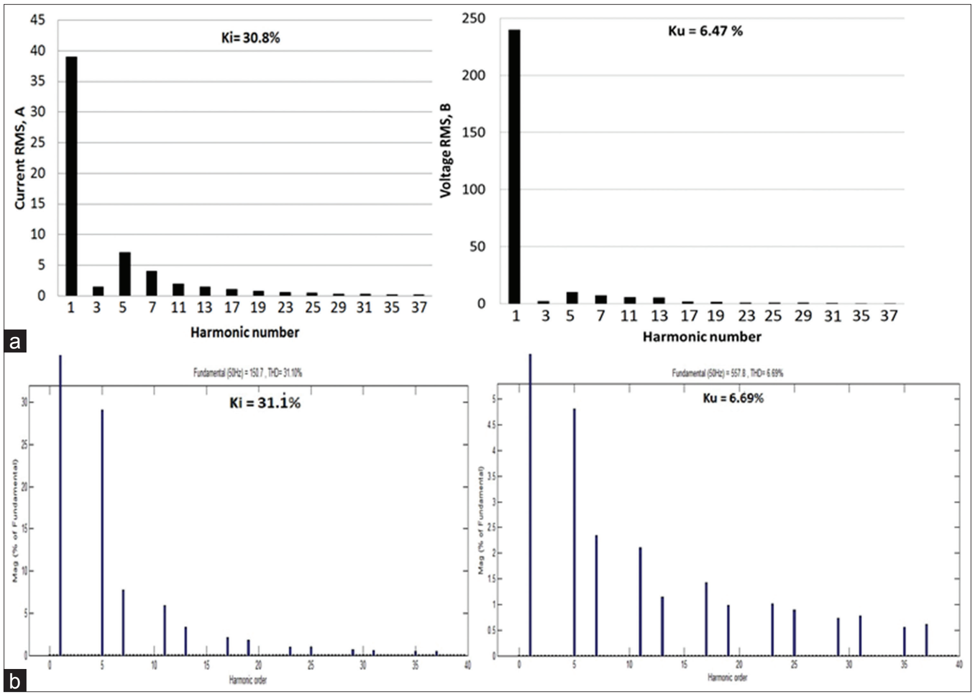


Figure 3: Current and voltage histograms obtained (a) experimentally and (b) in simulation



generated by the RE, but also compensate for the lack of reactive power at the connection point (Das, 2003; Arrilaga et al., 1985). Selecting the power of the capacitor bank that is part of the PFCD Q_n, if the PFCD performs the function of a filter and a reactive power compensator, is performed under the condition $cos\varphi = 0.94$ at the device connection point:

$$Q_n = Q_{m-}Q_d$$

where Q_m is the reactive power measured by the device during the investigation of the operating conditions of the substation users, Q_d is the design reactive power at which $cos\varphi = 0.94$

The qualitative difference in the characteristics of the UPF and the SPF is due to the fact that their filtering properties are provided by different techniques. If, in the first case, the phenomenon of series resonance is used to allow the main resistance of the filter to shunt the resistance of the system with a low-resistance circuit $R = 0$, thus creating a bypass path for the higher-order current, then in the second case, the shunt resistor $R \rightarrow \infty$ filter.

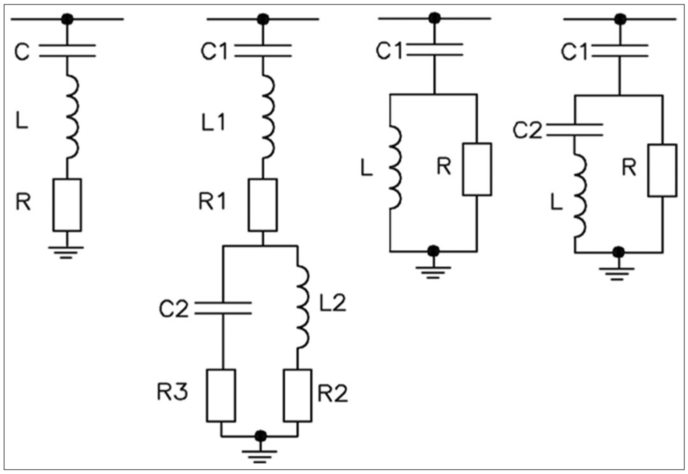
Figure 4 shows the four types of PFCD:

a. A narrowband filter tuned to the frequency of a single harmonic is, in practice, rarely tuned to the harmonic frequency due to a change in the temperature coefficient of capacitance, the frequency of the mains supply and the inductance of the reactor or the capacitance of the capacitor during operation;
b. The double-tuning filter allows to significantly reduce the losses at the fundamental frequency, and the large operating voltage associated with the decrease in the number of inductors under full line voltage is relatively expensive and complicated in tuning;
c. The broadband filter of the second order, are not sensitive to the deviation of temperature and frequency, so the quality factor (0.5 ÷ 5) is chosen from the condition of equi-efficient filtering of the harmonics of the entire band above the resonant one, from disadvantages - the loss in resistance and inductance is higher than in the UPF;
d. A wide-band C-type filter, due to the successively tuned C2 and L, smaller losses are achieved at the fundamental frequency, and the losses at high frequencies are comparable with the filter (c).

As a result of simulation using PFCD Schneider Electric of the Varset series of narrowband and broadband filters tuned to the frequencies of the 5th and 5th, the 7th harmonic respectively, installed on the outgoing sections of electric receivers with nonlinear CEC. The analysis of the total coefficient of harmonic current and voltage components on the secondary winding of the step-down transformer is presented in Table 1.

From the obtained modeling results it follows that the efficiency of HH decrease is greater for filter (b), but its higher cost and complexity of tuning for resonance make the filter (a) a practical-significant option for application, with its lower cost and simple tuning. The use of PFCD in the power supply system has reduced the level of the higher harmonic components, however, in order to completely reduce the HH current and voltage, it is necessary to include harmonics in the SPS of the active filter, which also reduces the losses in the step-down transformer and the 6 kV supply line.

Figure 4: Passive filter compensating devices



2.5. Hybrid FCD for Compensation of HH

Depending on the switching scheme of the active and passive parts, the following hybrid filter configurations exist:

- Serial connection of the active and passive parts, while the active harmonic filter (AHF) is considered as a voltage source;
- Parallel connection of the active and passive parts, while the active filter must have the characteristics of the current source.

It should be noted that PFCD type b (Table 1) sufficiently reduces the levels of harmonic current and voltage components at the point of connection of the most powerful TRE. However, in order to take into account the sharply variable nature of the load of the entire SPS for providing the best parameters of EMC, a simulation model of the system under study with an active filter connected in parallel on the low side of the step-down transformer.

An important element of the structure of the active filter is the block for calculating the reference signal. The accuracy of the calculation of this unit directly affects the efficiency of using the AHF. The existing methods for generating the active filter control signal can be divided into 2 groups:

- Methods for generating reference signals in the frequency domain;
- Methods for generating time-domain reference signals;

The methods for generating the reference signals in the frequency domain are based on the application of the discrete Fourier transform and its modifications, and thus have a long time delay, which is necessary for obtaining a sample of variables and calculating the Fourier coefficients. Despite the fact that these methods are widely used, the above features do not allow them to be used for the real-time control system operation in distribution networks with sharply variable load (Boyarskaya, 2014). Most methods for generating signals in the time domain (for example, the instantaneous power method or p-q theory) differ in the increased complexity of the algorithms (Akagi, 2005; JenoPaul and Raglend, 2010). However, the use of intelligent methods allows you to design a high-speed real-time management system.

Intellectual technologies distinguish, first of all, what exactly is the basis of the concept of intellectuality – either the ability to work with formalized human knowledge (expert systems, fuzzy logic), or the methods of learning and thinking peculiar to man (artificial neural networks and genetic algorithms) (Rubanov and Filatov, 2006; Viegas et al., 2017). The use of fuzzy inference systems allows the creation of high-speed and simple algorithms that can be used to replace objects with a complex mathematical description. Therefore, the use of fuzzy models in active filter management systems is quite effective. However, the structure of the fuzzy inference system does not imply the adjustment of the parameters, i.e., in the case under consideration, which is not envisaged at the design stage of the active filter control system, the load operation mode can negatively affect the level of harmonic current components in the network. Therefore, it becomes necessary to adapt the algorithm of the system for

Figure 5: Current and voltage histograms showing the total level of harmonic components obtained in the simulation of a system with passive filter compensating device

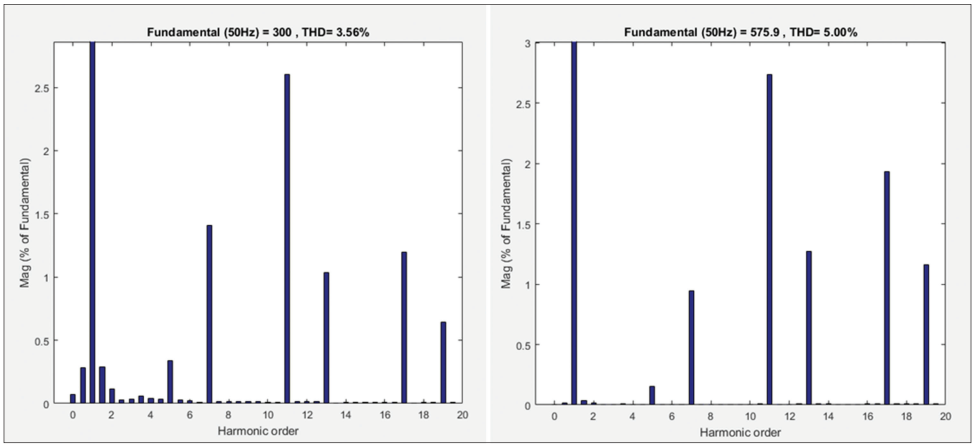


Figure 6: Current and voltage histograms showing the total level of harmonic components obtained during the simulation of a system with a hybrid filter compensating device

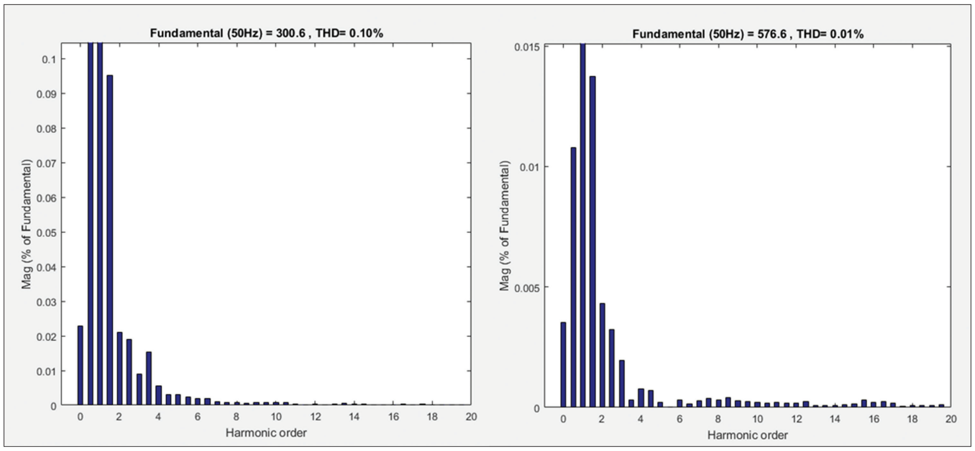


Table 1: Comparison of simulation results

Indicators (%)	Without PFCD	PFCD (a)	PFCD (b)	PFCD (c)	PFCD (d)
K_I	31.1	9.55	6.52	9.92	9.84
K_I (5)	22.1	0.24	0.28	3.4	3.14
K_I (7)	9.62	1.62	0.05	1.84	1.82
K_U	6.69	2.97	2.43	2.59	2.55
K_U (5)	3.74	0.07	0.08	1.04	0.96
K_U (7)	2.3	0.67	0.02	0.79	0.78

PFCD: Passive filter compensating device

Table 2: Results of hybrid FCD simulation

Indicators (%)	Without PFCD	PFCD	Hybrid PFCD
K_I	31.1	3.55	0.15
K_U	6.69	5	0.02

PFCD: Passive filter compensating device, FCD: Filter compensating device

calculating the reference signals. It is this advantage that a system that uses for neural inference a neural network. Among the set of neural-fuzzy algorithms, the Adaptive-Network-Based Fuzzy Inference System (ANFIS) system has become most widespread in real-time systems (Zhukov, 2016). ANFIS implements the fuzzy Takagi-Sugeno system and is a five-layer neural network of direct signal propagation (Andrievskaya et al., 2014). Within the framework of this work, an imitation model of the AHF was developed. In this case, the task signal generation subsystem is represented by a neural-fuzzy system designed in the Matlab Neuro-Fuzzy Designer editor and implemented as a simulation model in the Simulink environment using the Fuzzy Logic Controller block from the Fuzzy Logic Toolbox. This allowed us to investigate the use of an active filter with an intelligent control system in the simulation model of the power supply system of the plant.

The analysis of the total coefficient of harmonic current and voltage components on the low side of the step-down transformer in simulation of the investigated CEC using hybrid FCD is presented in Table 2.

Spectral compositions of currents and voltages on the low side of the step-down transformer, obtained as a result of simulation of the investigated power supply system using PFCD and hybrid FCD are shown in Figures 5 and 6.

3. CONCLUSION

On the basis of the conducted research, we would like to make the following conclusions:

1. The built simulation model in Matlab/Simulink based on the real SPS showed good convergence of the results of experimental research and modeling in the assessment of the main indicators of EMC, which served as the basis for applying FCD to reduce the level of HH current and voltage;
2. As a result of simulation of non-sinusoidal operating modes of electric receivers of an industrial enterprise using the example of CJSC "Belshpala" and the PFCD of Schneider Electric, Varset, it was possible to reduce the amount of active losses in the elements of the shop SPS and the supply line of 6 kV by 37.9 MWh/year or up to 3.96% (instead of 12.8%);
3. The use of an AHF with an intelligent reference signal generation system as part of a hybrid filter compensating device in the simulation model of the power supply system significantly reduced the level of higher harmonic components, which is a more efficient method of compensating HH of current and voltage than using a local PFCD.
4. As a result of using the hybrid FCD, the total active losses from the harmonic components of the SPS are <1%.

In sum, the proposed model is effective in reducing energy losses in electricity systems at an industrial enterprise and can be applied in other countries for increasing energy saving and, as a result, energy efficiency.

REFERENCES

Abeysinghe, S., Wu, J., Sooriyabandara, M. (2017), A statistical assessment tool for electricity distribution networks. Energy Procedia, 105, 2595-2600.

Abrokwa, K.K., Dramani, J.B., Bhattarai, K. (2017), The effect of electricity technical losses on Ghana's economy: A simulation evaluation. OPEC Energy Review, 41(4), 286-317.

Ahamed, M.S., Guo, H., Tanino, K. (2019), Energy saving techniques for reducing the heating cost of conventional greenhouses. Biosystems Engineering, 178, 9-33.

Akagi, H. (2005), Active harmonic filters. Proceedings of the IEEE, 93(12), 2128-2141.

Andrievskaya, N.V., Reznikov A.S., Cheranev A.A. (2014), Features of the use of neuro-fuzzy models for the problems of the synthesis of automatic control systems. Fundamental Research, 7, 342-352.

Arrilaga, J., Bradley, D., Bodger, P. (1985), Power Systems Harmonics. Chichester, USA: John Wiley and Sons.

Aslani, A., Bakhtiar, A., Akbarzadeh, M.H. (2019), Energy-efficiency technologies in the building envelope: Life cycle and adaptation assessment. Journal of Building Engineering, 21, 55-63.

Averbukh, M.A., Prasol, D.A., Khvorostenko, S.V. (2017), Experimental study of non-sinusoidal modes of the shop power supply system with dynamic vibration formation of concrete mixtures. MSTU JOURNAL-Electrotechnical Systems and Complexes, 1(34), 24-31.

Averbukh, M.A., Zhilin E.V., Roshchubkin P.V. (2017), Experimental analysis of the electrical and power supply system. Journal of Engineering and Applied Sciences, 12, 3446-3451.

Averbukh, M.A., Zhilin, E.V. (2016), About electricity losses in power supply systems of individual housing construction. Energetics, 6, 54-57.

Averbukh, M.A., Zhukov, N.A., Khvorostenko, S.V. (2016), Estimation of the level of higher harmonics of currents and voltages in electrical networks of concrete products plants. Scientific Review, 7, 79-86.

Bhat, J.A., Haider, S., Kamaiah, B. (2018), Interstate energy efficiency of Indian paper industry: A slack-based non-parametric approach. Energy, 161, 284-298.

Borodin, M.V., Volchenckov, Y.A., Vinogradov, A.V. (2015), Development of measures to reduce energy losses in the branches of "IDGC of Center" "Orelenergo" JSC. Herald NGIEI, 4, 10-11.

Boyarskaya, N.P (2014), Synthesis of Filter-Compensating Devices for Power Supply Systems. Krasnoyarsk, Russia: Siberian Federal University.

Çay, A. (2018), Energy consumption and energy saving potential in clothing industry. Energy, 159, 74-85.

Chernykh, I.V. (2008), Simulation of Electrical Devices in MATLAB, Sim Power System and Simulink. St. Petersburg, Russia: Peter: Moscow, Russia DMK Press.

Chowdhury, J.I., Hu, Y., Haltas, I., Balta-Ozkan, N., Matthew Jr., J., Varga, L. (2018), Reducing industrial energy demand in the UK: A review of energy efficiency technologies and energy saving potential in selected sectors. Renewable and Sustainable Energy Reviews, 94, 1153-1178.

Costa-Campi, M.T., Daví-Arderius, D., Trujillo-Baute, E. (2018), The economic impact of electricity losses. Energy Economics, 75, 309-322.

Dadzie, J., Runeson, G., Ding, G. (2018), Determinants of sustainable upgrade for energy efficiency the case of existing buildings in Australia. Energy Procedia, 153, 284-289.

Das, J. (2003), Passive filters-potentialities and limitations. IEEE Translation on Industry Applications, 40(1), 232-241.

Davidson, I.E. (2002), Evaluation and effective management of nontechnical losses in electrical power networks. IEEE AFRICON, 1, 473-477.

De Lima, L.P., de Deus Ribeiro, G.B., Perez, R. (2018), The energy mix and energy efficiency analysis for Brazilian dairy industry. Journal of Cleaner Production, 181, 209-216.

Dolinger, S.Yu. (2013), Estimation of additional power losses from the reduction of the quality of electrical energy in the elements of power supply systems. Omsk Scientific Herald, 2, 178-183.

Fawcett, T., Killip, G. (2019), Re-thinking energy efficiency in European policy: Practitioners' use of 'multiple benefits' arguments. Journal of Cleaner Production, 210, 1171-179.

Feng, C., Wang, M., Zhang, Y., Liu, C.G. (2018), Decomposition of energy efficiency and energy-saving potential in China: A three-hierarchy meta-frontier approach. Journal of Cleaner Production, 176, 1054-1064.

Foggia, G.D. (2018), Energy efficiency measures in buildings for achieving sustainable development goals. Heliyon, 4, e0095, 1-21.

Haraldsson, J., Johansson, M.T. (2018), Review of measures for improved energy efficiency in production-related processes in the aluminium industry from electrolysis to recycling. Renewable and Sustainable Energy Reviews, 93, 525-548.

Hea, K., Wang, L. (2017), A review of energy use and energy-efficient technologies for the iron and steel industry. Renewable and Sustainable Energy Reviews, 70, 1022-1039.

Hollas, D.R., Herren, R.S. (1982), An estimation of the deadweight and x-efficiency losses in the municipal electric industry. Journal of

Economics and Business, 34(3), 269-281.

Ingrao, C., Messineo, A., Beltramo, R., Yigitcanlar, T., Ioppolo, G. (2018), How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance. Journal of Cleaner Production, 201, 556-569.

Innocent, M., Francois-Lecompte, A. (2018), The values of electricity saving for consumers. Energy Policy, 123, 136-146.

Jamshidieini, B., Rezaie, K., Firuzabad, M.F. (2019), Cleaner distribution of electricity energy considering Personnel's attitudes toward waste generation. Journal of Cleaner Production, 209, 371-385.

Kartashev, I.I. (2006), Power quality management. Moscow, Russia: MEI Publishing House.

Kim, J.J. (2017), Economic analysis on energy saving technologies for complex manufacturing building. Resources, Conservation and Recycling, 123, 249-254.

Kohler, M. (2014), Differential electricity pricing and energy efficiency in South Africa. Energy, 64, 524-532.

Lin, B., Zheng, Q. (2017), Energy efficiency evolution of China's paper industry. Journal of Cleaner Production, 140, 1105-1117.

Liu, X., Wu, J., Jenkins, N., Bagdanavicius, A. (2016), Combined analysis of electricity and heat networks. Applied Energy, 162, 1238-1250.

Malinauskaite, J., Jouhara, H., Ahmad, L., Milani M., Montorsi, L., Venturelli, M. (2019), Energy efficiency in industry: EU and national policies in Italy and the UK. Energy, 172, 255-269.

Matraeva, L., Solodukha, P., Erokhin, S., Babenko, M. (2019), Improvement of Russian energy efficiency strategy within the framework of "green economy" concept (based on the analysis of experience of foreign countries). Energy Policy, 125, 478-486.

Paul, R.D.P., Raglend, J.L.C. (2010), Design and simulation of phase locked loop controller based three phase unified power quality conditioner for nonlinear and voltage sensitive loads. International Journal of Applied Engineering Research, 1(2), 234-243.

Pusnik, M., Al-Mansour, F., Sucic, B., Cesen, M. (2017), Trends and prospects of energy efficiency development in Slovenian industry. Energy, 136, 52-62.

Quiceno, G., Álvarez, C., Ávila, R., Fernández, Ó, Francoc, C.J., Kunce, M., Dyner, I. (2019), Scenario analysis for strategy design: A case study of the Colombian electricity industry. Energy Strategy Reviews, 23, 57-68.

Rozali, N.E.M., Ho, W.S., Alwi, S.R.W., Manan, Z.A., Klemes, J.J., Yunus, M.N.S., Zaki, S.A.A. (2018), Peak-off-peak load shifting for optimal storage sizing in hybrid power systems using power pinch analysis considering energy losses. Energy, 156, 299-310.

Rubanov, V.G., Filatov, A.G. (2006), System Modeling. Belgorod, Russia: BSTU.

Sadykova, F.M. (2014), Analysis of electric energy losses and ways of their reduction in city electric networks of Makhachkala: The setting of technological losses of electric energy. Systemniye Tekhnologii, 12, 1-6.

Savina, N.V., Myasoedov, Yu.V. (2017), Managing the level of electricity losses in distribution grid companies in market conditions. Available from: http://www.sei.irk.ru/symp2010/papers/RUS/S4-10r.pdf.

Tanaka, K. (2011), Review of policies and measures for energy efficiency in industry sector. Energy Policy, 39, 6532-6550.

Trotta, G. (2018), Factors affecting energy-saving behaviours and energy efficiency investments in British households. Energy Policy, 114, 529-539.

Usman, M., Coppo, M., Bignucolo, F., Turri, R. (2018), Losses management strategies in active distribution networks: A review. Electric Power Systems Research, 163, 116-132.

Viegas, J.L., Esteves, P.R.P., Melício, R., Mendes, V.M.F., Vieira, S.M. (2017), Solutions for detection of non-technical losses in the electricity grid: A review. Renewable and Sustainable Energy Reviews, 80, 1256-1268.

Ward, K.R., Staffell, I. (2018), Simulating price-aware electricity storage without linear optimisation. Journal of Energy Storage, 20, 78-91.

Xiong, S., Ma, X., Ji, J. (2019), The impact of industrial structure efficiency on provincial industrial energy efficiency in China. Journal of Cleaner Production, 215, 952-962.

Yanez, E., Ramírez, A., Uribe, A., Castillo, E., Faaij, A. (2018), Unravelling the potential of energy efficiency in the Colombian oil industry. Journal of Cleaner Production, 176, 604-628.

Yang, L., Wang, K.-L., Geng, J.C. (2018), China's regional ecological energy efficiency and energy saving and pollution abatement potentials: An empirical analysis using epsilon- based measure model. Journal of Cleaner Production, 194, 300-308.

Zheng, Q., Lin, B. (2018), Impact of industrial agglomeration on energy efficiency in China's paper industry. Journal of Cleaner Production, 184, 1072-1080.

Zhukov, N.A. (2016), Research of Control Systems of Active Filter-Compensating Devices. Belgorod, Russia: BGTU Publishing House.

Zuberia, M.J.S., Tijdink, A., Patel, M.K. (2017), Techno-economic analysis of energy efficiency improvement in electric motor driven systems in Swiss industry. Applied Energy, 205, 85-104.