ABSTRACT AND REFERENCES

ENERGY-SAVING TECHNOLOGIES AND EQUIPMENT

DOI: 10.15587/1729-4061.2019.174112

IMPROVING ENERGY CHARACTERISTICS OF AC ELECTRIC ROLLING STOCK BY USING THE THREE-LEVEL ACTIVE FOUR-QUADRANT RECTIFIERS (p. 6–14)

Oleksandr Plakhtii
Limited Liability Company «VO OVEN», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-1535-8991

Volodymyr Nerubatskyi
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-4309-601X

Dmytro Sushko
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-9747-3263

Igor Ryshchenko
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-9859-4510

Vladyslav Tsybulnyk
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-9895-6662

Denys Hordiienko
Private JSC «ELAKS», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-0347-5656

In order to minimize the reactive power and higher harmonics of currents, as well as to improve the electromagnetic compatibility of electrical traction networks and systems of railroad automation, modern electric rolling stock of alternating current employ active four-quadrant rectifiers. The classical topology of a given converter is the two-level full-bridge active rectifier that ensures a power factor close to unity and the recuperation of energy to a power network. However, the high switching frequency predetermines high dynamic losses in power transistors and a low value for efficiency.

It appears promising to use the three-level active four-quadrant rectifiers with a power factor correction. It has been proposed in the current work to apply a system of control over a three-level active rectifier with the two-channel equal-shifted sinusoidal PWM. The advantage of the proposed algorithm, as compared with known, is the improvement of quality of the input current and a decrease in the frequency of switching power switches, which leads to a decrease in power losses and an increase in the rectifier efficiency. The paper reports results of comparative analysis of dependences of power losses and efficiency on the switching frequency of power switches for the two-level and three-level active rectifier with the proposed control system, which confirmed the feasibility of the proposed control system. The software package MATLAB 2017b was used for simulation modeling of the two-level and three-level active rectifier, based on which we analyzed the quality parameters of electric energy, established the dependence of a harmonic distortion coefficient of the input current of an active rectifier on the switching frequency of power switches. Our study has proven the technical and economic expediency of using a circuit of the three-level active rectifier with a control system based on the two-level equal-shifted sinusoidal PWM.

Keywords: three-level active rectifier, pulse-width modulation, switching frequency, power factor, energy efficiency.

References

1. Plakhtii, O., Nerubatskyi, V., Ryshchenko, I., Zinchenko, O., Tykhonravov, S., Hordiienko, D. (2019). Determining additional power losses in the electricity supply systems due to current's higher harmonics. Eastern-European Journal of Enterprise Technologies, 1 (8 (97)), 6–13. doi: https://doi.org/10.15587/1729-4061.2019.155672
2. Zhezhelenko, I. V. (2010). Vysshie garmoniki v sistemah elektrosnabzheniya promyshlennyh predpriyatiy. Moscow: Energoatomizdat, 375.
3. Lyutarevich, A. G., Vyrva, A. A., Dolinger, S. Yu., Osipov, D. S., Chetverik, I. N. (2009). Estimation of additional power losses due to higher harmonics in elements of power system. Omskiy nauchnyy vestnik, 1, 109–113.
4. Zhezhelenko, I. V., Shidlovskiy, A. K., Pivnyak, G. G. (2012). Elektromagnitnaya sovmestimost' potrebiteley. Moscow: Mashinostroenie, 351.
5. Bader, M. P. (2014). The analysis and the synthesis of the electromagnetic compatibility of the traction power supply system and infrastructure in the districts with the high-speed traffic. Elektryfikatsiya transportu, 7, 78–83.
6. Nerubatskyi, V. P., Plakhtiy, A. A., Gladka, A. V. (2018). EMC improvment research of three-phase active rectifiers with power factor correction in regenerative mode. Collected scientific works of Ukrainian State University of Railway Transport, 178, 21–28. doi: https://doi.org/10.18664/1994-7852.178.2018.138906
7. Blahnik, V., Talla, J. (2016). Single-phase synchronization for traction active rectifier. 2016 International Conference on Applied Electronics (AE). doi: https://doi.org/10.1109/ae.2016.7577233
8. Scherback, Y. V., Plakhtiy, O. A., Nerubatskiy, V. P. (2017). Control characteristics of active four-quadrant converter in rectifier and recovery mode. Tekhnichna Elektrodynamika, 2017 (6), 26–31. doi: https://doi.org/10.15407/techned2017.06.026
9. Fomin, O. V., Lovska, A. O., Plakhtii, O. A., Nerubatskyi, V. P. (2017). The influence of implementation of circular pipes in load-bearing structures of bodies of freight cars on their physico-mechanical properties. Scientific bulletin of National mining university, 6, 89–96.
10. Kolmakov, N. M., Bahovtsev, I. A., Garganeev, A. G. (2016). Analiz gisterezisnogo upravleniya po napryazheniyu avtonomnogo invertora napryazheniya. Doklady Tomskogo gosudarstvennogo universiteta sistem upravleniya i radioelektroniki, 19 (2), 84–89.
11. Yakupov, D. V., Kazachkovskiy, N. N. (2010). Control principles for PWM-based active rectifier under perturbations from the load. Vestnik KDU imeni Mihaila Ostrogradskogo, 4 (63), 16–19.
12. Oleksandr, P., Volodymyr, N. (2018). Analyses of Energy Efficiency of Interleaving in Active Voltage-Source Rectifier. 2018 IEEE 3rd International Conference on Intelligent Energy and Power Systems (IEPS). doi: https://doi.org/10.1109/ieps.2018.8559514
13. Gervasio, F., Mastromauro, R. A., Liserre, M. (2015). Power losses analysis of two-levels and three-levels PWM inverters handling reactive power. 2015 IEEE International Conference on Industrial Technology (ICIT). doi: https://doi.org/10.1109/icit.2015.7125248
14. Zhao, L., Wang, Q., Li, G., Chen, Q., Hu, C. (2014). Analyze and compare the efficiency of two-level and three-level inverter in SVPWM. 2014 9th IEEE Conference on Industrial Electronics and Applications. doi: https://doi.org/10.1109/iciea.2014.6931488
15. Vintrih, A., Ul'rih, N., Kolpakov, A. I., Mysak, T. V., Polischuk, S. I. (2017). Analiz dinamicheskih poter' moschnyh IGBT. Vestnik Natsional'nogo tekhnicheskogo universiteta «Kharkivskiy politekhnicheskiy institut», 27, 191–196.
16. Wu, R., Wen, J., Wu, J., Chen, Z., Peng, C., Wang, Y. (2012). Analysis of power losses in voltage source converter with new generation

IGBTs. 2012 IEEE International Conference on Computer Science and Automation Engineering (CSAE). doi: https://doi.org/10.1109/csae.2012.6272683

17. Dai, P., Guo, G., Gong, Z. (2016). A Selection Precharge Method for Modular Multilevel Converter. International Journal of Control and Automation, 9 (4), 161–170. doi: https://doi.org/10.14257/ijca.2016.9.4.16

DOI: 10.15587/1729-4061.2019.174629

ANALYTICAL AND EXPERIMENTAL STUDIES INTO THE PROCESSES OF HYDRODYNAMICS AND HEAT EXCHANGE IN THE CHANNELS OF DISK PULSE DEVICES (p. 15–23)

Valeriy Nikolsky
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0001-6069-169X

Ivan Kuzyayev
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-7073-1197

Oleksandr Alieksandrov
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-0442-0008

Ved Viktor
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-2391-6463

Andrii Pugach
Dnipro State Agrarian and Economic University, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-5586-424X

Vadim Yaris
LLC Soyuztechnoprom Production Co., Dnipro, Ukraine
ORCID: http://orcid.org/0000-0001-8162-5122

Serhiy Ptitsyn
Ukrainian-Turkmen educational center «Erkin», Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-4584-6291

Valerii Lopatin
Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0003-2448-0857

The paper reports an analytical study into the influence of basic parameters of channels in the pulse disk devices on the efficiency of processes of heat exchange and hydrodynamics under the pulse effect on a heat-carrier. A procedure has been proposed for determining basic parameters for the processes of heat exchange and hydrodynamics (flow rate, pressure, a heat-carrier's temperature) when a liquid is exposed to the pulse effect. Mathematical models have been constructed for the influence of structural and technological parameters of channels in the disk pulse devices on the efficiency of processes of heat exchange and hydrodynamics. Adequacy of the mathematical models has been confirmed by a series of experimental studies involving devices with a single- and multi-step system of the pulse treatment of a heat-carrier. Based on this, we have designed, tested, and implemented industrial structures of the pulse disk heat generators for decentralized heating of buildings for industrial and residential purposes with the single- and two-step pulse influence. The constructed method for a multi-step pulse influence, taking into consideration the results from mathematical modeling, experimentally confirmed and implemented in the structural design of a working chamber in a disk pulse heat generator, has made it possible to improve its energy efficiency by 12 %. We have defined the most efficient geometry for a disk pulse heat generator aimed at its further integration into the system of decentralized heating.

A series of experimental studies has been performed, which confirm energy efficiency of the designed devices. One of the designed heat generators with a multistep pulse influence on a heat-carrier has been integrated into a heating system for a shopping mall. Indicators of the heat generator operation meet modern standards of energy efficiency at the level of 0.86–0.9.

Keywords: disk pulse device, optimization, energy efficiency, heat generator design, rotor, working chamber geometry.

References

1. Promtov, M. A. (2001). Pul'satsionnye apparaty rotornogo tipa: teoriya i praktika. Moscow, 260.
2. Ved, V., Nikolsky, V., Oliynyk, O., Lipeev, A. (2017). Examining a cavitation heat generator and the control method over the efficiency of its operation. Eastern-European Journal of Enterprise Technologies, 4 (8 (88)), 22–28. doi: https://doi.org/10.15587/1729-4061.2017.108580
3. Nikolsky, V., Oliynyk, O., Ved, V., Svietkina, O., Pugach, A., Shvachka, A. (2018). Design and study of the energyefficient unified apparatuses for energytechnological manufacturing. Eastern-European Journal of Enterprise Technologies, 3 (8 (93)), 59–65. doi: https://doi.org/10.15587/1729-4061.2018.132572
4. Pivnyak, G., Dychkovskyi, R., Bobyliov, O., Cabana, E. C., Smoliński, A. (2018). Mathematical and Geomechanical Model in Physical and Chemical Processes of Underground Coal Gasification. Solid State Phenomena, 277, 1–16. doi: https://doi.org/10.4028/www.scientific.net/ssp.277.1
5. Nikolsky, V., Yariz, V., Reshetnyak, I. (2017). Improvement of energy efficiency in the operation of a thermal reactor with submerged combustion apparatus through the cyclic input of energy. Eastern-European Journal of Enterprise Technologies, 2 (8 (86)), 39–44. doi: https://doi.org/10.15587/1729-4061.2017.97914
6. Park, J. T., Cutbirth, J. M., Brewer, W. H. (2003). Hydrodynamic Performance of the Large Cavitation Channel (LCC). Volume 2: Symposia, Parts A, B, and C. doi: https://doi.org/10.1115/fedsm2003-45599
7. Lin, J., Lin, B.-L., Sun, J., Chen, Y.-L. (2016). Modelling hydrodynamic processes in tidal stream energy extraction. Journal of Hydrodynamics, 28 (6), 1058–1064. doi: https://doi.org/10.1016/s1001-6058(16)60711-4
8. Dealy, J. M., Wissbrun, K. F. (2012). Melt rheology and its role in plastics processing: theory and applications. Springer Science & Business Media, 680.
9. Tadmor, Z., Gogos, C. G. (2013). Principles of polymer processing. John Wiley & Sons, 962.
10. Kuziaiev, I. M. (2008). Modeliuvannia roboty ta proektuvannia ekstruziynykh ahrehativ z rozrobkoiu elementiv SAPR. Dnipropetrovsk: DVNZ UDKhTU, 474.
11. Kuzyaev, I. M., Sviderskiy, V. A., Petuhov, A. D. (2016). Modelirovanie ekstruzii i ekstruderov pri pererabotke polimerov. Ch. 1. Kyiv: NTUU «KPI» Izd-vo «Politekhnika», 412.
12. Momani, S., Odibat, Z. (2006). Analytical solution of a time-fractional Navier-Stokes equation by Adomian decomposition method. Applied Mathematics and Computation, 177 (2), 488–494. doi: https://doi.org/10.1016/j.amc.2005.11.025
13. Girimaji, S. S. (2006). Partially-Averaged Navier-Stokes Model for Turbulence: A Reynolds-Averaged Navier-Stokes to Direct Numerical Simulation Bridging Method. Journal of Applied Mechanics, 73 (3), 413–421. doi: https://doi.org/10.1115/1.2151207

14. Hirsch, C. (2007). Numerical computation of internal and external flows: The fundamentals of computational fluid dynamics. Elsevier, 680. doi: https://doi.org/10.1016/b978-0-7506-6594-0.x5037-1
15. Vetchanin, E. V., Kilin, A. A. (2016). Controlled motion of a rigid body with internal mechanisms in an ideal incompressible fluid. Proceedings of the Steklov Institute of Mathematics, 295 (1), 302–332. doi: https://doi.org/10.1134/s0081543816080186
16. Ma, Y., Liu, H., Zhu, Y., Wang, F., Luo, Z. (2017). The NARX Model-Based System Identification on Nonlinear, Rotor-Bearing Systems. Applied Sciences, 7 (9), 911. doi: https://doi.org/10.3390/app7090911
17. Shevchuk, I. V. (2009). Convective heat and mass transfer in rotating disk systems. Springer, 236. doi: https://doi.org/10.1007/978-3-642-00718-7
18. Sheikholeslami, M., Ganji, D. D. (2013). Heat transfer of Cu-water nanofluid flow between parallel plates. Powder Technology, 235, 873–879. doi: https://doi.org/10.1016/j.powtec.2012.11.030
19. Liu, C., Walkington, N. J. (2007). Convergence of Numerical Approximations of the Incompressible Navier–Stokes Equations with Variable Density and Viscosity. SIAM Journal on Numerical Analysis, 45 (3), 1287–1304. doi: https://doi.org/10.1137/050629008
20. Escudier, M. P., Oliveira, P. J., Pinho, F. T. (2002). Fully developed laminar flow of purely viscous non-Newtonian liquids through annuli, including the effects of eccentricity and inner-cylinder rotation. International Journal of Heat and Fluid Flow, 23 (1), 52–73. doi: https://doi.org/10.1016/s0142-727x(01)00135-7
21. Rayher, Yu. L., Rusakov, V. V. (2008). Vraschatel'naya vyazkost' vyazkouprugoy magnitnoy zhidkosti. Kolloidnyy zhurnal, 70 (1), 85–92.
22. Lavrent'ev, M. A., Shabat, B. V. (1973). Metody teorii funktsiy kompleksnogo peremennogo. Moscow: Nauka, 736.
23. Kuziaiev, I. M. (2002). Modeliuvannia neizotermichnykh protsesiv v robochomu obiemi cherviachnykh nasosiv dlia anomalno viazkykh ridyn. Voprosy himii i himicheskoy tekhnologii, 2, 107–112.
24. Kamke, E. (1976). Spravochnik po obyknovennym differentsial'nym uravneniyam. Moscow: Nauka, 576.
25. Antsiferov, S. S., Rusanov, K. E., Afanas'ev, M. S. (2014). Obrabotka rezul'tatov izmereniy. Moscow, 228.
26. Promtov, M. A., Akulin, V. V. (2006). Mechanisms of Heat Generating in the Rotor Impulse Apparatus. Vestnik Tambovskogo gosudarstvennogo tekhnicheskogo universiteta, 12 (2A), 364–369.

DOI: 10.15587/1729-4061.2019.173986

BOWL BLADED HYDROKINETIC TURBINE WITH ADDITIONAL STEERING BLADE NUMERICAL MODELING (p. 24–36)

Rudy Soenoko
Brawijaya University, Malang, Indonesia
ORCID: http://orcid.org/0000-0002-0537-4189

Purnami
Brawijaya University, Malang, Indonesia
ORCID: http://orcid.org/0000-0002-3771-7094

Bowl bladed kinetic turbine has a low performance. This is a simple turbine, easy to make, easy to install and inexpensive. Kinetic turbines are made specifically for rural areas which may be far from technology facilities. The reason why this kind of turbine is still being used is to meet the electric needs of rural areas. Research on this bowl bladed kinetic turbine is still often done, although not too much. There have been many efforts made to improve turbine kinetic performance. This simulation study was conducted to compare the conventional bowl bladed kinetic turbine with the bowl bladed kinetic turbine with an additional steering blade, to see whether there is an increase in turbine performance.

The performance of a kinetic turbine can be seen from the amount of pressure or momentum that occurs between two blades.

The simulation carried out is to review the pressure that occurs in four sequential blades that experience an initial jet water flow. A review of this pressure is carried out at every 5° movement of the turbine wheel, starts from $\alpha=45°$ to $\alpha=45°$, so there will be nine pairs comparison result of the bowl bladed kinetic turbine performance.

On the conventional bowl bladed kinetic turbine, it can be seen that the water flow enters the turbine area, after pushing the first blade, flows straight out to the turbine outlet area. So it is estimated that there is potential water energy lost.

From the bowl bladed kinetic turbine simulation with the steering blade, it can be seen that there is an increase in pressure on the blades. The water flow that had left the turbine area can provide an additional pressure on the rest of the turbine blade. By plotting the pressure value of the simulation result, it is clear that there is an increase of turbine performance after attached with a steering blade.

Keywords: bowl blade, kinetic turbine, rural area, steering blade, momentum, performance.

References

1. Rispiningtati, Soenoko, R. (2015). Regulation of sutami reservoir to have a maximal electrical energy. International Journal of Applied Engineering Research, 10 (12), 31641–31648.
2. Indonesia Energy Outlook (2016). Agency for the Assessment and Application of Technology.
3. Yang, B., Lawn, C. (2011). Fluid dynamic performance of a vertical axis turbine for tidal currents. Renewable Energy, 36 (12), 3355–3366. doi: https://doi.org/10.1016/j.renene.2011.05.014
4. Yang, B., Lawn, C. (2013). Three-dimensional effects on the performance of a vertical axis tidal turbine. Ocean Engineering, 58, 1–10. doi: https://doi.org/10.1016/j.oceaneng.2012.09.020
5. Golecha, K., Eldho, T. I., Prabhu, S. V. (2011). Investigation on the Performance of a Modified Savonius Water Turbine with Single and Two deflector Plates. The 11th Asian International Conference on Fluid Machinery and Fluid Power Technology.
6. Sinagra, M., Sammartano, V., Aricò, C., Collura, A., Tucciarelli, T. (2014). Cross-flow Turbine Design for Variable Operating Conditions. Procedia Engineering, 70, 1539–1548. doi: https://doi.org/10.1016/j.proeng.2014.02.170
7. Sammartano, V., Aricò, C., Sinagra, M., Tucciarelli, T. (2015). Cross-Flow Turbine Design for Energy Production and Discharge Regulation. Journal of Hydraulic Engineering, 141 (3), 04014083. doi: https://doi.org/10.1061/(asce)hy.1943-7900.0000977
8. Lopes, J. J. A., Vaz, J. R. P., Mesquita, A. L. A., Mesquita, A. L. A., Blanco, C. J. C. (2015). An Approach for the Dynamic Behavior of Hydrokinetic Turbines. Energy Procedia, 75, 271–276. doi: https://doi.org/10.1016/j.egypro.2015.07.334
9. Tian, W., Mao, Z., Ding, H. (2018). Design, test and numerical simulation of a low-speed horizontal axis hydrokinetic turbine. International Journal of Naval Architecture and Ocean Engineering, 10 (6), 782–793. doi: https://doi.org/10.1016/j.ijnaoe.2017.10.006
10. Sukmawaty, S., Firdaus, N., Putra, G. M. D., Ajeng, S. D. (2018). Effect of Blade number and Directional Plate Angle on Kinetic Turbine Performances. International Journal of Mechanical Engineering and Technology (IJMET), 9 (13), 395–402.
11. Jaini, Kaprawi, Santoso, D. (2015). Darrieus Water Turbine Performance Configuration of Blade. Journal of Mechanical Science and Engineering, 2 (1), 7–11.
12. Hantoro, R., Septyaningrum, E. (2018). Novel Design of a Vertical Axis Hydrokinetic Turbine – Straight-Blade Cascaded (VAHT-SBC): Experimental and Numerical Simulation. Journal of Engineering and Technological Sciences, 50 (1), 73–86. doi: https://doi.org/10.5614/j.eng.technol.sci.2018.50.1.5

13. Zanforlin, S., Burchi, F., Bitossi, N. (2016). Hydrodynamic Interactions Between Three Closely-spaced Vertical Axis Tidal Turbines. Energy Procedia, 101, 520–527. doi: https://doi.org/10.1016/j.egypro.2016.11.066
14. Góralczyk, A., Adamkowski, A. (2018). Model of a Ducted Axial-Flow Hydrokinetic Turbine – Results of Experimental and Numerical Examination. Polish Maritime Research, 25 (3), 113–122. doi: https://doi.org/10.2478/pomr-2018-0102
15. Anyi, M., Kirke, B. (2010). Evaluation of small axial flow hydrokinetic turbines for remote communities. Energy for Sustainable Development, 14 (2), 110–116. doi: https://doi.org/10.1016/j.esd.2010.02.003
16. Boedi, S. D., Soenoko, R., Wahyudi, S., Choiron, M. A. (2015). An Outer Movable Blade Vertical Shaft Kinetic Turbine Performance. International Journal of Applied Engineering Research, 10 (4), 8565–8573.
17. Soenoko, R., Setyarini, P. H., Gapsari, F. (2018). Bowl Bladed Hydro Kinetic Turbine Performance. ARPN Journal of Engineering and Applied Sciences, 13 (20), 8242–8250.
18. Kumar, A., Nikhade, A. (2014). Hybrid Kinetic Turbine Rotors: A Review, International Journal of Engineering Science & Advanced Technology, 4 (6), 453–463.
19. Streeter, V. L., Wylie E. B., Bedford, K. W. (1997). Fluid Mechanics. McGraw-Hill College.
20. Soenoko, R., Setyarini, P. H., Gapsari, F. (2018). Numerical modeling and investigation of hydrokinetic turbine with additional steering blade using CFD. ARPN Journal of Engineering and Applied Sciences, 13 (22), 8589–8598.

DOI: 10.15587/1729-4061.2019.174203

ASSESSMENT OF EFFICIENCY OF ELECTRIC DRIVE OF STOP VALVES (p. 36–44)

Heorhii Kulinchenko
Sumy State University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0002-8501-5636

Andrii Masliennikov
National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-1174-0322

Viktor Bahuta
Ltd «Zodiak», Shostka, Ukraine
ORCID: http://orcid.org/0000-0001-6685-5683

Vladymir Chervyakov
Sumy State University, Sumy, Ukraine
ORCID: http://orcid.org/0000-0002-2903-4779

The operation features of the stop valve electric drive are analyzed. It is found that the drive of stop valves, implemented on the basis of induction motors, is characterized by low energy efficiency. For the purposeful improvement of the energy efficiency of the electric drive, a method is developed for estimating the energy efficiency of the valve module. The need to develop the method is due to the fact that energy efficiency estimates based on international standards are valid for steady-state operating conditions, provided that the time of transient processes is neglected.

Unlike traditional types of actuators, the stop valve actuator is characterized by low speeds. The use of mechanical gearboxes does not significantly reduce the drive speed, so you have to carry out pulse control of the engine or switch to a gearless drive.

The efficiency of alternative engine types is estimated using the proposed method, which is based on valve positioning modeling. The trajectory of movement is formed in accordance with the control pulses applied to the windings of the motor, which is part of the mechatronic module.

Testing of the method is carried out on the basis of the passport data of the 120 W AIR56A4 induction motor, which is part of a serial single-turn mechatronic module. For comparison of energy indicators, a 3-phase synchronous rolling rotor motor was chosen, whose parameters of the stator winding are similar to those of the AIR56A4 motor winding.

Comparison of energy efficiency estimates showed the advantage and prospects of using gearless synchronous motors in the valve drive.

The developed models allow to investigate and optimize the characteristics of the electric drive based on the tested engines, as well as to formulate the requirements for the engine design and technological parameters based on the obtained energy efficiency estimates.

The proposed method of energy efficiency assessment is the basis for the implementation of a set of technical tools to assess the drive energy efficiency in real industrial conditions when performing a specific technological task.

Keywords: induction motor, gearless electric drive, valve module energy efficiency, synchronous reluctance motor.

References

1. Agamloh, E. B. (2018). On Efficiency Measurement of Motor-Drive Systems. Proceedings of the 10th international conference on energy efficiency in motor driven system (EEMODS' 2017). Publications Office of the European Union, 652–667.
2. Paszota, Z. (2013). Losses and energy efficiency of drive motors and systems. Polish Maritime Research, 20 (1), 3–10. doi: https://doi.org/10.2478/pomr-2013-0001
3. Vanhooydonck, D., Symens, W., Deprez, W., Lemmens, J., Stockman, K., Dereyne, S. (2010). Calculating energy consumption of motor systems with varying load using iso efficiency contours. The XIX International Conference on Electrical Machines – ICEM 2010. doi: https://doi.org/10.1109/icelmach.2010.5607992
4. Usynin, Y. S., Shishkov, A. N., Sychev, D. A., Savosteenko, N. V., Khayatov, E. S. (2015). Improving the energy efficiency of electric drives of reciprocating rolling mills. Russian Electrical Engineering, 86 (12), 709–711. doi: https://doi.org/10.3103/s1068371215120159
5. Hansen, C., Kotlarski, J., Ortmaier, T. (2016). A concurrent optimization approach for energy efficient multiple axis positioning tasks. Journal of Control and Decision, 3 (4), 223–247. doi: https://doi.org/10.1080/23307706.2016.1208548
6. Smirnov, Y. S., Yurasova, E. V., Funk, T. A. (2015). Energoinformatics of a Gearless Mechatronic Systems. Procedia Engineering, 129, 992–996. doi: https://doi.org/10.1016/j.proeng.2015.12.160
7. Kulinchenko, H. V., Masliennikov, A. M., Bahuta, V. A., Duniev, O. O. (2015). Electric drive dynamic performance providing based on a rolling rotor motor. Visnyk NTU «KhPI». Seriya: Problemy udoskonalennia elektrychnykh mashyn i aparativ. Teoriya i praktyka, 42 (1151), 34–38.
8. Gieras, J. F., Gieras, I. A. (2014). Recent developments in electrical motors and drives. Available at: https://www.researchgate.net/publication/228960734
9. Sarac, V., Cvetkovski, G. (2013). Transient Analysis of Induction Motor Using Different Simulation Models. Acta Technica Jaurinensis, 6 (1), 65–75.
10. Albarbarawi, O., Al-Rawashdeh, A. Y., Qaryouti, Gh. (2017). Simulink modelling of the transient cases of three phase induction motors. International Journal of Electrical & Computer Sciences, 17 (04), 6–15.
11. Tsybikov, B., Beyerleyn, E., Tyuteva, P. (2016). Comparison of energy efficiency determination methods for the induction motors. MATEC Web of Conferences, 91, 01034. doi: https://doi.org/10.1051/matecconf/20179101034

12. Ostroverkhov, M., Reutskyi, M., Trinchuk, D. (2018). Study of the induction motor electric drive efficiency in transients during their acceleration. Technology Audit and Production Reserves, 5 (1 (43)), 23–27. doi: https://doi.org/10.15587/2312-8372.2018.144612
13. Kulinchenko, G. V., Maslennikov, A. M., Baguta, V. A. (2016). Research of dynamic parameters of the electric drive on the basis of rolling rotor motor. Electrical Engineering & Electromechanics, 6, 9–14. doi: https://doi.org/10.20998/2074-272x.2016.6.02
14. Krishna, V., Prasad, E. Sh. (2018). Control Strategy of Switched Reluctance Motor. International Journal of Applied Engineering Research, 13 (10), 136–140.
15. Fabianski, B. (2016). Simplified model of Switched Reluctance Motor for real-time calculations. PRZEGLĄD ELEKTROTECHNICZNY, 1 (7), 21–25. doi: https://doi.org/10.15199/48.2016.07.03
16. Ungureanu, C., Rata, M., Graur, A. (2015). PLC control of an electromechanical converter with rolling rotor and axial air-gap. ACTA Electrotehnica, 56 (4), 137–142.
17. Yehorov, A. V., Masliennikov, A. M., Duniev, A. A., Yuhimchuk, V. D. (2017). Influence of the stator coils scheme connection in the motor with a rolling rotor on its energy performance. Bulletin of NTU «KhPI». Series: Electric machines and electromechanical energy conversion, 1 (1223), 106–113.

DOI: 10.15587/1729-4061.2019.175679

DEVELOPMENT OF A VACUUM-EVAPORATIVE THERMOTRANSFORMER FOR THE COOLING SYSTEM AT A NUCLEAR POWER PLANT (p. 45–56)

Victoria Tarasova
A. Pidgorny Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-3252-7619

Mikhail Kuznetsov
A. Pidgorny Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-5180-8830

Dionis Kharlampidi
A. Pidgorny Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-4337-6238

Andrey Kostikov
A. Pidgorny Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-6076-1942

The study addresses the development of a method for the optimal design of vacuum-evaporative heat pump plants (HPP) for a cooling system of technological equipment of the second circuit at a nuclear power plant (NPP) using modern methods of thermodynamic analysis and thermoeconomic optimization.

We have proposed two circuits for inclusion of a vacuum-evaporative HPP into a cooling system of the second circuit at NPP. The first circuit implies the use of HPP in combination with an existing cooling tower. It makes it possible to cool water additionally from 30 °C to 25 °C after a cooling tower. Only HPP cools water to the required parameters in the second circuit.

A thermodynamic model to forecast static characteristics of HPP has been developed. We analyzed thermodynamic properties of water as a refrigerant and evaluated their influence on mode parameters and energy efficiency of a vapor compression cycle. It was established that water fully complies with all environmental safety requirements for operation substances of heat pumps. Its use makes it possible to provide high energy performance of a cycle in comparison with synthetic refrigerants. The problematic aspects of water use include high temperature, which is characteristic of a vapor-water cycle at the end of the compression process. However, it is possible to level the influence of temperature on energy and operational parameters of a plant by using a two-section condenser with utilization of heat from vapor overheating.

We selected rational circuit-cycle solutions for a vacuum-evaporative HPP using a graph-analytic apparatus for constructing C-curves. The rational circuit-cycle solutions ensure efficient operation of a plant for cooling of technological equipment of the second circuit at NPP. The system's capital capacity has been estimated as well.

We used modeling of thermohydraulic processes in a circulation circuit of a refrigerant, performed thermoeconomic optimization and determined mode-and-structural characteristics of a plant that correspond to the minimum of resulting costs during its operation.

Keywords: vacuum-evaporative heat pump plant, nuclear power plant, thermoeconomic model, resulting costs

References

1. Li, Q., Amibe, D. A., Müller, N. (2011). Using water vapor as refrigerant in multistage variable speed turbo compressor to improve seasonal energy efficiency ratio of air conditioning. International Journal of Air-Conditioning and Refrigeration, 19 (02), 131–140. doi: https://doi.org/10.1142/s2010132511000491
2. Li, Q., Piechna, J., Müller, N. (2011). Numerical simulation of novel axial impeller patterns to compress water vapor as refrigerant. Energy, 36 (5), 2773–2781. doi: https://doi.org/10.1016/j.energy.2011.02.017
3. Patil, M., Müller, N. (2013). Structural analysis of continuous fiber wound composite impellers of a multistage high-speed counter rotating axial compressor for compressing water vapor (R-718) as refrigerant using Finite Element Analysis. Materials & Design, 50, 683–693. doi: https://doi.org/10.1016/j.matdes.2013.03.004
4. Chamoun, M., Rulliere, R., Haberschill, P., Berail, J. F. (2012). Dynamic model of an industrial heat pump using water as refrigerant. International Journal of Refrigeration, 35 (4), 1080–1091. doi: https://doi.org/10.1016/j.ijrefrig.2011.12.007
5. Chamoun, M., Rulliere, R., Haberschill, P., Peureux, J.-L. (2014). Experimental and numerical investigations of a new high temperature heat pump for industrial heat recovery using water as refrigerant. International Journal of Refrigeration, 44, 177–188. doi: https://doi.org/10.1016/j.ijrefrig.2014.04.019
6. Chamoun, M., Rulliere, R., Haberschill, P., Berail, J. F. (2012). Water vapour as refrigerant for a new high temperature heat pump. Holodil'naya tehnika, 12, 30–35.
7. Šarevski, M. N., Šarevski, V. N. (2014). Preliminary study of a novel R718 refrigeration cycle with single stage centrifugal compressor and two-phase ejector. International Journal of Refrigeration, 40, 435–449. doi: https://doi.org/10.1016/j.ijrefrig.2013.12.005
8. Marinyuk, B. T., Krysanov, K. S. (2014). Vacuum-evaporating refrigerating installation with air-cooled condenser. Holodil'naya tehnika, 3, 32–34.
9. Chistyakov, F. M., Poltaraus, V. B. (1986). Pat. No. SU 1204891 A. F 25 B 29/00, 11/00. Teplovoy nasos. published: 15.01.1986, Bul. No. 2.
10. Šarevski, M. N., Šarevski, V. N. (2016). Water (R718) Turbo Compressor and Ejector Refrigeration / Heat Pump Technology. Elsevier, 304. doi: https://doi.org/10.1016/c2015-0-01782-8
11. Yuan, Q. S., Blaise, J. C. (1988). Water – a working fluid for CFC replacement. International Journal of Refrigeration, 11 (4), 243–247. doi: https://doi.org/10.1016/0140-7007(88)90081-3
12. Koshkin, N. N., Sakun, I. A., Bambushek, E. M. et. al.; Sakun, I. A. (Ed.) (1985). Holodil'nye mashiny. Leningrad: Mashinostroenie, 510.
13. Mayake, V., Ehkkert, Yu., Koshpen, Zh. L. (1998). Uchebnik po holodil'noy tehnike. Mosow: Moskovskiy universitet, 1138.

14. Adler, Yu. P., Markova, E. V., Granovskiy, Yu. V. (1976). Planirovanie ehksperimenta pri poiske optimal'nyh usloviy. Moscow: Nauka, 280.
15. Lachner, B. F., Nellis, G. F., Reindl, D. T. (2007). The commercial feasibility of the use of water vapor as a refrigerant. International Journal of Refrigeration, 30 (4), 699–708. doi: https://doi.org/10.1016/j.ijrefrig.2006.09.009
16. Kharlampidi, D., Tarasova, V., Kuznetsov, M., Omelichkin, S. (2016). Application of graphic apparatus of c-curves for the analysis and optimization of supercritical cycles of thermotransformers. Eastern-European Journal of Enterprise Technologies, 5 (8 (83)), 20–25. doi: https://doi.org/10.15587/1729-4061.2016.79988
17. Matsevitiy, Yu. M., Harlampidi, D. H., Tarasova, V. A., Kuznetsov, M. A. (2018). Innovatsionnye sistemy termotransformatsii. Analiz. Sintez. Optimizatsiya. Kharkiv: ChP «Tehnologicheskiy Tsentr»,192.
18. Morandin, M., Mercangöz, M., Hemrle, J., Maréchal, F., Favrat, D. (2013). Thermoeconomic design optimization of a thermo-electric energy storage system based on transcritical CO2 cycles. Energy, 58, 571–587. doi: https://doi.org/10.1016/j.energy.2013.05.038
19. Wall, G. (1991). Optimization of refrigeration machinery. International Journal of Refrigeration, 14 (6), 336–340. doi: https://doi.org/10.1016/0140-7007(91)90029-g
20. Yantovskiy, E. I. (1988). Potoki ehnergii i ehksergii. Moscow: Nauka, 144.
21. Kuznetsov, M., Tarasova, V., Kharlampidi, D. (2019). Method for the Optimal Design of Vacuum-Evaporative Heat Pumps. Journal of Mechanical Engineering, 22 (2), 21–31. doi: https://doi.org/10.15407/pmach2019.02.021

DOI: 10.15587/1729-4061.2019.174099

DEVELOPMENT OF ENERGY-SAVING TECHNOLOGY TO MAINTAIN THE FUNCTIONING OF A WIND-SOLAR ELECTRICAL SYSTEM (p. 57–68)

Eugene Chaikovskaya
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0002-5663-2707

An integrated system to support the functioning of a wind-solar electric system has been designed, based on predicting a change in the capacity of a rechargeable battery when measuring voltage at the input to a hybrid charge controller, voltage at the output from an inverter and the frequency of voltage. Taking preliminary decisions to support the capacity of a rechargeable battery related to a change in the capacity of a thermoelectric battery is based on establishing the ratio of voltage at the input to a hybrid charge controller to voltage at the output from the inverter, which are measured. A change in the rotational speed of the electric motor of the circulating pump has been ensured in terms of changes in consumption and the temperature of heated water by reducing charge duration by up to 30 %. An integrated mathematical and logical modelling of a wind-solar electric system has been performed, based on the mathematical substantiation of the architecture of a technological system and the mathematical substantiation to support the operation of a wind-solar electrical system. The basis for the proposed technological system is a dynamic subsystem that includes the following components: a wind-energy installation, a photoelectrical electrical module, a hybrid charge controller, and an inverter, an array of rechargeable batteries, a thermoelectric battery. The time constants and the coefficients for mathematical models of the dynamics have been determined related to a change in the capacity of a rechargeable battery, the rotational speed of the electric motor of the circulating pump, and consumption of local water. A functional assessment has been derived for a change in the capacity of a rechargeable battery, the rotational speed of the electric motor of the circulating pump, consumption of local water related to a change in the temperature of local water in the range of 30–70 °C. Defining the resulting functional information on forecasting a change in the capacity of a rechargeable battery makes it possible to take the following preliminary decisions: about changing the rotational speed of the electric motor of the circulating pump, about changing the consumption of local water. Maintaining the capacity of a rechargeable battery is carried out based on adjusting the generation and consumption of energy.

Keywords: wind-solar electrical system, rechargeable battery, thermoelectric battery, hybrid charge controller, inverter.

References

1. Chaikovskaya, E. (2017). Development of energy-saving technology to support functioning of the lead-acid batteries. Eastern-European Journal of Enterprise Technologies, 4 (8 (88)), 56–64. doi: https://doi.org/10.15587/1729-4061.2017.108578
2. Al-Dhaifallah, M., Nassef, A. M., Rezk, H., Nisar, K. S. (2018). Optimal parameter design of fractional order control based INC-MPPT for PV system. Solar Energy, 159, 650–664. doi: https://doi.org/10.1016/j.solener.2017.11.040
3. Shahriari, M., Blumsack, S. (2018). The capacity value of optimal wind and solar portfolios. Energy, 148, 992–1005. doi: https://doi.org/10.1016/j.energy.2017.12.121
4. Fathabadi, H. (2017). Novel standalone hybrid solar/wind/fuel cell power generation system for remote areas. Solar Energy, 146, 30–43. doi: https://doi.org/10.1016/j.solener.2017.01.071
5. Chandra, M., Naiki, S., Anush, D. (2017). Design of solar PV-Wind Hibrid Power generation system. International Journal of Recent Trends in Engineering and Research, 3 (10), 89–93.
6. Cao, Z., O'Rourke, F., Lyons, W. (2017). Performance modelling of a small-scale wind and solar energy hybrid system. 2017 28th Irish Signals and Systems Conference (ISSC). doi: https://doi.org/10.1109/issc.2017.7983616
7. Vasant, L. G., Pawar, V. R. (2017). Solar-wind hybrid energy system using MPPT. 2017 International Conference on Intelligent Computing and Control Systems (ICICCS). doi: https://doi.org/10.1109/iccons.2017.8250531
8. Derrouazin, A., Aillerie, M., Mekkakia-Maaza, N., Charles, J.-P. (2017). Multi input-output fuzzy logic smart controller for a residential hybrid solar-wind-storage energy system. Energy Conversion and Management, 148, 238–250. doi: https://doi.org/10.1016/j.enconman.2017.05.046
9. Jia, Y., Liu, X. J. (2014). Distributed model predictive control of wind and solar generation system. Proceedings of the 33rd Chinese Control Conference. doi: https://doi.org/10.1109/chicc.2014.6896301
10. Saidi, A., Chellali, B. (2017). Simulation and control of Solar Wind hybrid renewable power system. 2017 6th International Conference on Systems and Control (ICSC). doi: https://doi.org/10.1109/icosc.2017.7958647
11. Maleki, A., Hafeznia, H., Rosen, M. A., Pourfayaz, F. (2017). Optimization of a grid-connected hybrid solar-wind-hydrogen CHP system for residential applications by efficient metaheuristic approaches. Applied Thermal Engineering, 123, 1263–1277. doi: https://doi.org/10.1016/j.applthermaleng.2017.05.100
12. Chaykovskaya, E. E. (2016). Soglasovanie proizvodstva i potrebleniya energii na osnove intellektual'nogo upravleniya teplomassobmennymi protsessami. XV Minskiy mezhdunarodnyy forum po teplomassobmenu: materialy XV Minsk. mezhd. foruma po teplomassobmenu. Sektsiya 8. Teplomassoperenos v energeticheskih protsessah i oborudovanii. Energosberezhenie. Minsk, 1–12.
13. Chaikovska, Ye. Ye. (2016). Informatsiyni tekhnolohiyi pidtrymky funktsionuvannia enerhetychnykh system na rivni pryiniattia rishen. Informatyka. Kultura. Tekhnika: zb. tez dop. IV ukr.-nim. konf. Odessa, 32–33.

14. Chaikovskaya, E. (2018). Development of energy-saving technology for maintaining the functioning of heat pump power supply. Eastern-European Journal of Enterprise Technologies, 4 (8 (94)), 13–24. doi: https://doi.org/10.15587/1729-4061.2018.139473

DOI: 10.15587/1729-4061.2019.174502

STUDY INTO PREDICTED EFFICIENCY OF THE APPLICATION OF HYBRID SOLAR COLLECTORS TO SUPPLY ENERGY TO MULTI-APARTMENT BUILDINGS (p. 69–77)

Anatolii Bondarchuk
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0003-1232-5403

This paper reports a study into efficiency of the application of hybrid solar collectors, which can simultaneously generate both electricity and thermal energy to supply power to multi-storey buildings. The novelty of the work is that efficiency was predicted taking into consideration the dynamics over recent years and by extrapolating trends in prices up to the year 2045 in the market of renewable energy, in contrast to existing approaches that disregard their likely change over the considered period. The results of calculations were used to model a predicted market value of the equipment, taking into consideration a reduction in its price due to the improved technology for manufacturing the collectors, their installation, and operating costs, over a specified period. In this case, the dynamics in the «basic» and «green» tariffs for solar electric and thermal energy were considered. Values for the coefficients of determination have confirmed sufficient adequacy of the derived models. An example has been provided for determining the electric and thermal loading on a multi-apartment building equipped with gas stoves; the proper equipment for a hybrid solar collector has been selected. The structures and procedures have been proposed for connecting a hybrid collector to the systems the supply electricity and heat to the building. The collector's modules the type of ATMOSFERA F2PV are arranged at the roof of the building, whose electric components are connected, through an inverter, to the inlet-distributor device in a building or to the low-voltage buses at a power substation with a voltage of 10/0.4 kV, which powers the building. A heat-carrier is fed from the collector, through storage capacities, to a thermal unit into the system of hot water supply and heating of the building. The obtained results of the study have made it possible to predict a probable energy efficiency (the amount of saved conventional fuel), economic (net discounted profit) and environmental efficiency (reduction in emissions that contribute to the global climate warming). The payback period has been determined by consistent calculation of net income for each year over the entire period of realization of investments provided the specified trend in market prices does not change. The paper presents the results from calculating the magnitude of investments and income for inhabitants per each apartment in the building from the implementation of the investment project.

Keywords: hybrid solar collectors, electrical energy, thermal energy, multi-apartment building, market prices

References

1. Khelifa, A., Touafek, K., Moussa, H. B., Tabet, I., hocine, H. B. cheikh E., Haloui, H. (2015). Analysis of a Hybrid Solar Collector Photovoltaic Thermal (PVT). Energy Procedia, 74, 835–843. doi: https://doi.org/10.1016/j.egypro.2015.07.819
2. Yahyaui, I., Stephanie, V. (2016). On the modeling and management of a hybrid energy system based on photovoltaic fuel cells. Advances in Renewable Energy and Energy Technologies, 2, 151–171.
3. Chow, T. T., Tiwari, G. N., Menezo, C. (2012). Hybrid Solar: A Review on Photovoltaic and Thermal Power Integration. International Journal of Photoenergy, 2012, 1–17. doi: https://doi.org/10.1155/2012/307287
4. Santos, J., Palacio, J., Barone, A. (2016). Advances in renewable energy and energy technologies. Concentrating Solar Energy, 12, 373–402.
5. Kwan, T. H., Shen, Y., Yao, Q. (2019). An energy management strategy for supplying combined heat and power by the fuel cell thermoelectric hybrid system. Applied Energy, 251, 113318. doi: https://doi.org/10.1016/j.apenergy.2019.113318
6. Mezzai, N., Rekioua, D., Rekioua, T., Mohammedi, A., Idjdarane, K., Bacha, S. (2014). Modeling of hybrid photovoltaic/wind/fuel cells power system. International Journal of Hydrogen Energy, 39 (27), 15158–15168. doi: https://doi.org/10.1016/j.ijhydene.2014.06.015
7. Salim, R. D. (2018). Manufacturing Procedure of a Hybrid Design of Solar Collector (Sterilization and Water Heating) By Solar and Electrical Energy. 2018 International Conference on Advanced Science and Engineering (ICOASE). doi: https://doi.org/10.1109/icoase.2018.8548807
8. Kumar, M., Natarajan, P., Jerin, R. A., Jayakumar, A. (2019). Impact of Performance Degradation and Capital Subsidy on the Revenue of Rooftop PV System. International Journal of Renewable Energy Research, 9 (1), 128–136.
9. Anwar, K., Deshmih, S., Mishra, O., Agraval, V. (2019). Hybrid CSP in India: Technological and Economic Aspects. International Journal of Renewable Energy Research, 9 (1), 137–146.
10. Fortuin, S., Hermann, M., Stryi-Hipp, G., Nitz, P., Platzer, W. (2014). Hybrid PV-thermal Collector Development: Concepts, Experiences, Results and Research Needs. Energy Procedia, 48, 37–47. doi: https://doi.org/10.1016/j.egypro.2014.02.006
11. Eabueldahab, Y., Zekry, A., Saad. N. H. (2019). Enhancing the Optimization of Hybrid Renewable Energy Systems by Using Statistical Calculations and Data Mining Analysis. International Journal of Renewable Energy Research, 9 (2), 868–886.
12. Ladide, S., El Fathi, A., Bendaoud, M., Hihi, H., Faitah, K. (2019). Hybrid Renewable Power Supply for Typical Public Facilities in Six Various Climate Zones in Morocco. International Journal of Renewable Energy Research, 9 (2), 893–912.
13. Prokopiv, V. V., Nykyrui, L. I., Vozniak, O. M., Dzundza, B. S., Horichok, I. V. et. al. (2017). Soniachnyi termoelektrychnyi henerator. Fizyka i khimiia tverdoho tila, 18 (3), 372–375.
14. Razumnyi, Yu. T., Rukhlov, A. V., Prokuda, V. M., Rukhlova, N. Yu. (2014). Efektyvne vykorystannia elektroenerhiyi ta palyva. Dnipro: Natsionalnyi hirnychyi universytet, 223.
15. Bondarchuk, A. S. (2015). Vnutrishno budynkove elektropostachannia. Kursove proektuvannia. Kyiv: Osvita Ukrainy, 480.