Lighting Engineering & Power Engineering
2023, Vol. 62, No. 1, 17–22
https://doi.org/10.33042/2079-424X.2023.62.1.03

OPEN ACCESS

Design Features of the Screw Unit for Processing Bulk Substances

Mykola Zablodskiy[1], and Vladyslav Pliuhin[2]

[1] National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
[2] O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine

Article History
Received:
03 March 2023
Accepted:
17 March 2023
Published online:
29 April 2023

Keywords
Energy Converter; Electromechanical Unit; Screw Conveyor; Drying; Mixing; Bulk Material; Solid Rotor; Multifunctional

Abstract
This article is devoted to the description of the design of the multifunctional energy converter (MFEC) of the screw type. MFEC is an induction motor with an external hollow solid rotor. On the surface of the rotor, which is a steel pipe, the turns of the screw conveyer are welded. When supplying power to the stator winding (which visually resembles the wound rotor of an induction motor), the magnetic field not only causes the rotor to rotate, but also, due to the formation of eddy currents, heats the latter. Thus, the idea of combining several functional components is realized in one device: mixing, heating and transportation along the turns of the screw of bulk material. The specified operations are implemented without the use of an external electric drive, heaters, but only due to the principle of operation of the MFEC. Previously, the two-module design of the MFEC was investigated, but experimental studies indicated certain shortcomings of the chosen approach. In this work, an attempt is made to show an alternative configuration of the MFEC, based on the execution of independent single modules that can be combined into a continuous screw thanks to transitional fasteners. In addition, the approach to the power supply and module management system has been revised. This article is one of a series of works devoted to a detailed description of the design of the MFEC.

INTRODUCTION

The technology of processing loose substances, such as grain, coal slurry, mixtures for fuel briquettes, involves the performance of operations of mixing, drying to a certain percentage of moisture, and transportation to storage [1, 2].

In terms of functions and devices used, the following can be distinguished:

1) mixing: electric motor, mixer or screw conveyor [3, 4];
2) drying: electric motor, fan, lime, centrifuge, thermoelectric heater, boiler, boiler room for preparation of hot steam, etc. [5, 6];
3) transportation: electric motor, screw conveyor [7].

If mixing and transportation is a fairly simple process and requires only an electric motor and an screw conveyor/mixer, then drying is implemented in various ways. Installations for drying a large amount of loose material can occupy quite large areas of the production workshop, sometimes several floors. Drying is carried out in the following way:

- mixing of loose material with lime to absorb moisture with subsequent separation of lime and material and a vacuum separator, the drum of which rotates with the help of an electric motor;
- drying of the material using superheated steam; steam is prepared in a boiler, which is heated by a gas boiler room;
- drying of containers with loose material with the help of electric heaters, the material is mixed with a mixer or screw conveyor, which in turn is set in motion by an electric motor.

An alternative device that provides a reasonable compromise between the implementation of the functions of processing loose materials and the amount of equipment involved is a drying unit based on a multifunctional energy converter (MFEC). In the works that were published earlier, attention was paid to the design features of MFEC, issues of design, mathematical modeling and simulation of transient modes under load [8–11].

The main feature that distinguishes the MFEC from other devices for the processing of loose substances is the combination of several technological

Corresponding author: vladyslav.pliuhin@kname.edu.ua (Vladyslav Pliuhin)

Cite as: Zablodskiy, M., & Pliuhin, V. (2023). Design features of the screw unit for processing bulk substances. *Lighting Engineering & Power Engineering, 62*(1), 17–22. https://doi.org/10.33042/2079-424X.2023.62.1.03

operations due to their functional integration. It should be noted that the combination of several technological functions in one device is achieved in the MFEC not due to a simple summation of the component nodes, but due to the principle of operation of the MFEC itself.

The general efficiency factor (efficiency) of the MFEC is very high, which ensures the effective implementation of the principles of energy and resource conservation. The creation of MFEC and technologies based on them is based on the idea of combining in one electromechanical device simultaneously heating, transporting, mixing (turbulence-forming) functions, integration of thermal energy and the direction of the latter to the processing area of raw materials. The MFEC uses a design of a hollow ferromagnetic rotor (HFR), which simultaneously performs the functions of an induction motor (IM) rotor, a heater, an executive mechanism, and a protective case [12, 13]. At the same time, the HFR is cooled by the processed raw materials. Air and low-melting materials with high heat capacity and latent heat of fusion can act as an additional cooling agent in MFEC [14].

The significant advantages of technologies based on MFEC are not only a high value of efficiency, but also significant reductions in the production area, the number of equipment units, and its payback period. In this regard, an important scientific and applied problem of electromechanics is the creation of MFEC for the performance of new specific functions of technological purpose, including hot pressing of plastics and technical air conditioning in the casings of electric machines, autonomous heat-generating systems [15, 16].

The main condition for effective use of the dissipative energy of MFEC is the following [17, 18]: thermal gradients along the lines of connection of active parts with the processed material and additional cooling agent (for example, air) must have directions towards the active parts. During the drying processes of loose substances, temperature and humidity gradients in the MFEC-material system should not have the opposite direction, and in the path of movement of evaporated moisture in the volume of MFEC, cold zones should be excluded, i.e. surfaces with a temperature below the dew point.

MAIN PART

Since MFEC is a new class of electromechanical devices, its creation raises a complex of unsolved theoretical and practical problems. One of the main features of the classification of MFEC is the mode of conversion of electrical energy into thermal and mechanical energy [19]. Based on the invariance of the transformation, the duration of the process, the share distribution between thermal and mechanical energy, two possible modes of transformation can be proposed:

- binary conversion mode – a simultaneous continuous process of converting electrical energy into mechanical and thermal energy with the targeted use in the technological process of each of the received types of energy and, in the general case, with different weighting coefficients of conversion;
- discrete-invariant mode – the mode of alternation of the processes of converting electrical energy mainly into thermal or mechanical energy.

As an example of a discrete-invariant mode, the following can be given: the operation mode of an immersion heater with a solidified mass of low-melting material (“parking” under the current) with the receipt of only thermal energy with a gradual transition to the mode of mixing of the molten material (the majority of the mechanical energy at the output of the converter).

For consideration, we take two structural and technological schemes (Fig. 1 and Fig. 2), which most fully reflect the integral properties and technological orientation of the MFEC.

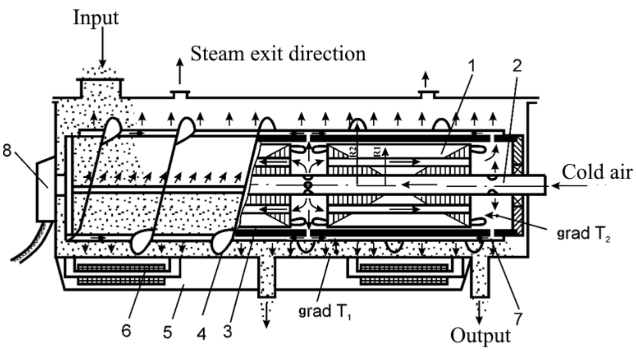

Figure 1. Structural and technological scheme of the screw MFEC: *1* – stator of the motor (brake) unit; *2* – hollow stationary shaft; *3* – external rotor-screw; *4* – the bottom of the screw conveyor; *5* – body; *6* – bottom heating inductors; *7* – axial channels of the rotor-screw; *8* – input of the power supply voltage

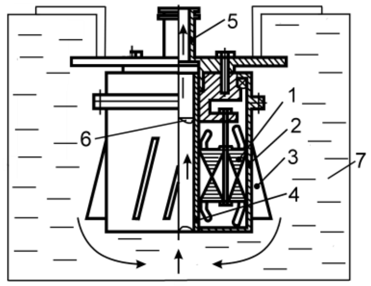

Figure 2. MFEC of the submersible type: *1* – stator; *2* – external rotor; *3* – shoulder blades; *4* – internal rotor; *5* – pressure nozzle; *6* – pump blades; *7* – reservoir

The principles of the creation of MFEC can be divided into the following groups: structural and functional integration; integration of thermal processes; self-regulation from the division into components of full power; gearless provision of low rotation frequency and multiple division of torque; non-critical to the energy quality of the power source according to the harmonic composition.

The conditions of placing the HFR MFEC in the technological environment of the processed material for the two analyzed structures (Fig. 1, Fig. 2) are such that it will always have an inequality of specific active resistances and complex magnetic permeability's in individual elements of the array. This inequality generates asymmetric currents in the rotor, which, according to a well-known rule, can be divided into two symmetrical component systems with positive (direct magneto-motive force (MMF)) and negative (reverse MMF) orders of phase direction.

MFEC, which includes at least two (conditionally driving and braking) electromagnetic modules, consisting of stators and active zones of the general MFR, work for a short time, periodically or continuously in one of the following modes:

a) the corresponding direction of direct and reverse MMF rotating synchronous magnetic fields of the modules, which create when interacting with the eddy currents of the HFR, which rotates according to the direct MMF direction fields, the total electromagnetic moment, multiple times increased in relation to the nominal (forced mode) [20];
b) the opposite direction, respectively, of direct and reverse MMF rotating synchronous magnetic fields of the modules, which create, when interacting with eddy currents of MFR of different frequencies, determined by the ratio of slips of driving unit and braking unit, electromagnetic torques of opposite directions, which form, when the MFEC is loaded, the frequency of rotation is 5...10 times lower in relation to the synchronous without application mechanical gearbox.

Thus, an alternative method of gearless obtaining of low rotation frequencies of the MFEC is implemented. The need to multiply the resulting torque of the screw MFEC can arise in two cases:

- difficult start-up in conditions of solid mass of material;
- forced mode by moment when the screw conveyor is fastened during the movement period.

At the same time, the braking module of the MFEC is either completely disconnected from the network, or it is turned on according to the rotation with the motor module for a time of no more than 0.2 s.

In the course of the conducted research, the modernization of the design of the MFEC was carried out in order to eliminate the shortcomings of the previous development. In particular, this applies to the following structural changes:

1) recalculation of the geometry of the screw conveyor blade, its outer diameter and angle of attack (Fig. 3) [21, 22];
2) transition to a single-module design (Fig. 4) with the possibility of increasing the length of the screw conveyor (Fig. 5);
3) change in the design of the support frame (Fig. 6).

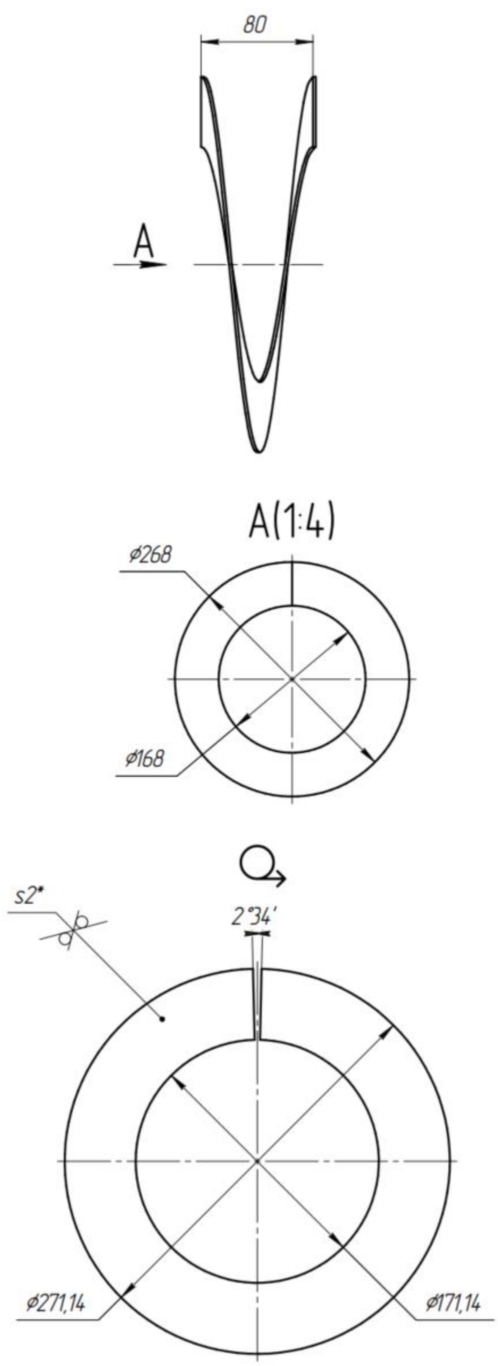

Figure 3. Drawing of the sweep of the screw conveyor pen

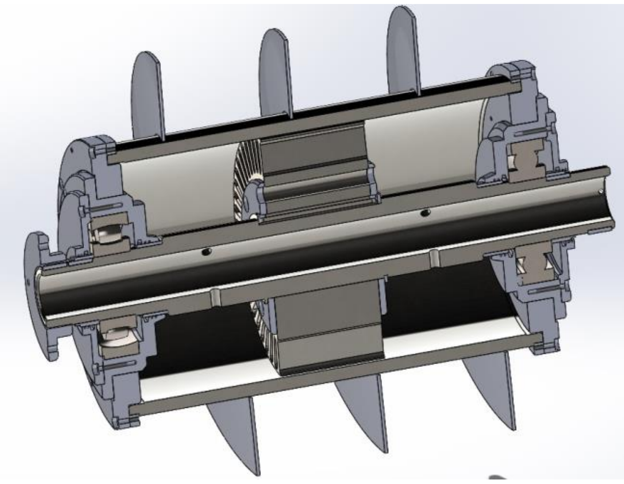

Figure 4. The construction of one module of the MFEC

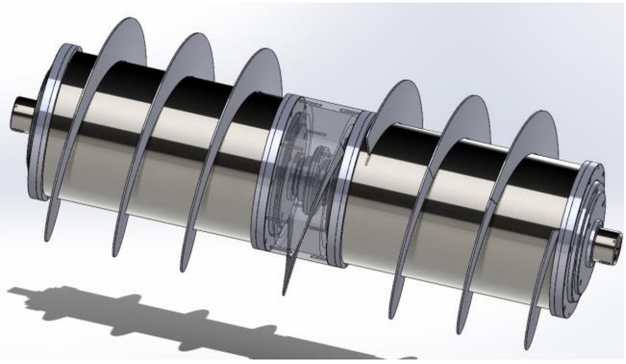

Figure 5. Combination of two modules of MFEC

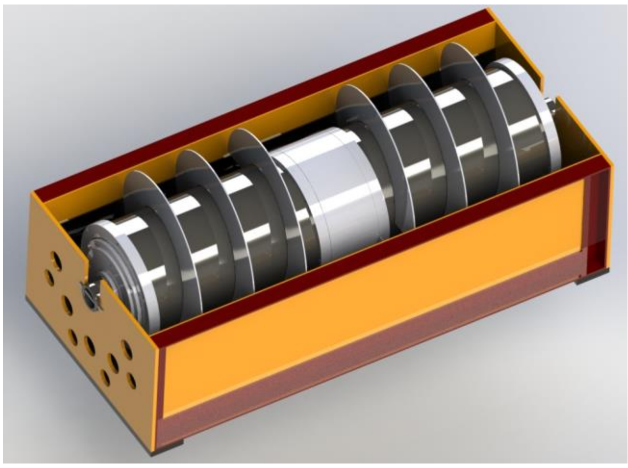

Figure 6. Two-module screw unit

In the previous modification, the loose material experienced complications when advancing along the length of the screw conveyor body. In this connection, a revision of the configuration of the turns of the screw was performed. Increasing the diameter, reducing the pitch of the screw and recalculating the angle of inclination of the screw conveyor pen should ensure the smooth passage of the material along the body of the screw conveyor and its uniform mixing.

The proposed design of the frame of the unit covers the active zone of the screw conveyor and contributes to the uniform advancement of loose material. The side walls of the frame can be used either to install thermal insulation or, if necessary, to place electric heating elements in order to intensify the reduction of humidity. Additional holes on the end wall are designed to prevent the formation of granules of loose material and ensure its uniform composition.

CONCLUSIONS

During the design and construction work, a deep modernization of the screw-type MFEC was carried out in order to eliminate the shortcomings that were discovered in the course of previous experimental and production studies.

Changing the size and configuration of the screw conveyor pin helps to eliminate the problem of material jamming between adjacent turns of the screw conveyor screw. The transition to a single-module design simplifies the process of manufacturing and installation of the MFEC, allows you to perform an arbitrary increase in length, as well as to switch to independent control of each of the modules. Modification of the frame of the unit allows for a more uniform distribution of loose material along the length of transportation, and also provides the possibility of more effective coverage of the side walls by heating elements.

The following studies consist in the refinement of the design methodology of MFEC, the determination of optimal parameters to ensure maximum productivity, modeling in order to achieve a balance between mechanical and thermal power, and the production of experimental samples for the verification of theoretical studies.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

REFERENCES

1. Sebastião, I.B., Bhatnagar, B., Tchessalov, S., Ohtake, S., Plitzko, M., Luy, B., & Alexeenko, A. (2019). Bulk dynamic spray freeze-drying part 1: modeling of droplet cooling and phase change. *Journal of Pharmaceutical Sciences, 108*(6), 2063–2074. https://doi.org/10.1016/j.xphs.2019.01.009

2. Oladosu, K.O., Babalola, S.A., Kareem, M.W., Ajimotokan, H.A., Kolawole, M.Y., Issa, W.A., ... & Ponle, E.A. (2023). Optimization of fuel briquette made from bicomposite biomass for domestic heating applications. *Scientific African, 21*, e01824. https://doi.org/10.1016/j.sciaf.2023.e01824

3. Miao, Z., Grift, T.E., Hansen, A.C., & Ting, K.C. (2014). Flow performance of ground biomass in a commercial auger. *Powder technology, 267*, 354–361. https://doi.org/10.1016/j.powtec.2014.07.038

4. Rigacci, M., Sato, R., & Shirase, K. (2020). Experimental evaluation of mechanical and electrical power consumption of feed drive systems driven by a ball-screw. *Precision Engineering, 64*, 280–287. https://doi.org/10.1016/j.precisioneng.2020.04.016

5. Ryu, B., Chung, J., Kumagai, M., Mato, T., Ando, Y., Gunji, S., ... & Park, S. (2023). Best thermoelectric efficiency of ever-explored materials. *iScience, 26*(4), 106494. https://doi.org/10.1016/j.isci.2023.106494

6. Bujak, J. (2008). Mathematical modelling of a steam boiler room to research thermal efficiency. *Energy, 33*(12), 1779–1787. https://doi.org/10.1016/j.energy.2008.08.004

7. Chuang, H.C., & Lee, C.T. (2019). The efficiency improvement of AC induction motor with constant frequency technology. *Energy, 174*, 805–813. https://doi.org/10.1016/j.energy.2019.03.019

8. Zablodskiy, M., Pliuhin, V., & Chuenko, R. (2018). Simulation of induction machines with common solid rotor. *Technical Electrodynamics, 6*, 42–45. https://doi.org/10.15407/techned2018.06.042

9. Zablodskiy, N., & Pliugin, V. (2015). 3D magnetic filed distribution in a screw double-stator induction motor. In *2015 16th International Conference on Computational Problems of Electrical Engineering (CPEE)* (pp. 239–241). IEEE. https://doi.org/10.1109/CPEE.2015.7333386

10. Pliuhin, V., Zablodskiy, M., Sukhonos, M., Tsegelnyk, Y., Piddubna, L. (2023). Determination of massive rotary electric machines parameters in ANSYS RMxprt and ANSYS Maxwell. In: Arsenyeva, O., et al. (eds.) *Smart Technologies in Urban Engineering*. LNNS, vol. 536 (pp. 189–201). Springer. https://doi.org/10.1007/978-3-031-20141-7_18

11. Zablodskiy, M.M., Kovalchuk, S.I., Pliuhin, V.E., & Tietieriev, V.O. (2022). Indirect field-oriented control of twin-screw electromechanical hydrolyzer. *Electrical Engineering & Electromechanics, 1*, 3–11. https://doi.org/10.20998/2074-272X.2022.1.01

12. Gulbahce, M.O., Mcguiness, D.T., & Kocabas, D.A. (2018). Shielded axially slitted solid rotor design for high-speed solid rotor induction motors. *IET Electric Power Applications, 12*(9), 1371–1377. https://doi.org/10.1049/iet-epa.2018.5210

13. Fan, Z., Yi, H., Xu, J., Xie, K., Qi, Y., Ren, S., & Wang, H. (2021). Performance study and optimization design of high-speed amorphous alloy induction motor. *Energies, 14*(9), 2468. https://doi.org/10.3390/en14092468

14. Ochman, A., Chen, W.Q., Błasiak, P., Pomorski, M., & Pietrowicz, S. (2021). The use of capsuled paraffin wax in low-temperature thermal energy storage applications: an experimental and numerical investigation. *Energies, 14*(3), 538. https://doi.org/10.3390/en14030538

15. Pliuhin, V., Zablodskiy, M., Tsegelnyk, Y., & Slovikovskyi, O. (2022). Development of imitation model of an electromechanical energy converter with a solid rotor in ANSYS RMxprt, Maxwell and Twin Builder. *Lighting Engineering & Power Engineering, 61*(1), 21–29. https://doi.org/10.33042/2079-424X.2022.61.1.03

16. Pliuhin, V., Petrenko, O., Tsegelnyk, Y., Duniev, O., Yehorov, A., & Khudiakov, I. (2022). Optimization of electromechanical energy converters with a solid rotor output parameters in ANSYS RMxprt. *Lighting Engineering & Power Engineering, 61*(3), 74–85. https://doi.org/10.33042/2079-424X.2022.61.3.01

17. Ilioaia, C., Johnson, M.P., Horton, P., & Ruban, A. V. (2008). Induction of efficient energy dissipation in the isolated light-harvesting complex of Photosystem II in the absence of protein aggregation. *Journal of Biological Chemistry, 283*(43), 29505–29512. https://doi.org/10.1074/jbc.M802438200

18. Diskin, D., & Tartakovsky, L. (2020). Efficiency at maximum power of the low-dissipation hybrid electrochemical–otto cycle. *Energies, 13*(15), 3961. https://doi.org/10.3390/en13153961

19. Zhang, X., & Zhao, L.D. (2015). Thermoelectric materials: Energy conversion between heat and electricity. *Journal of Materiomics, 1*(2), 92–105. https://doi.org/10.1016/j.jmat.2015.01.001

20. Markovic, M., & Perriard, Y. (2011). An analytical solution for the torque and power of a solid-rotor induction motor. In *2011 IEEE International Electric Machines & Drives Conference (IEMDC)* (pp. 1053–1057). IEEE. https://doi.org/10.1109/IEMDC.2011.5994746

21. PowderProcess. (2023). Screw Conveyor design calculations step by step, Engineering resources for powder processing industries. https://powderprocess.net/Equipments%20html/Screw_Conveyor_Design.html

22. KWS Manufacturing Company Ltd. (2023). Screw conveyor capacity, Conveyor solutions. https://kwsmfg.com/engineering-guides/screw-conveyor/screw-conveyor-capacity/

Конструктивні особливості шнекового агрегату для переробки сипучих речовин

Микола Заблодський, Владислав Плюгін

Анотація. Дана стаття присвячена опису конструкції багатофункціонального перетворювача енергії (БФПЕ) шнекового типу. БФПЕ є асинхронним двигуном із зовнішнім порожнистим суцільним ротором. На поверхні ротора, який представляє собою сталеву трубу, приварені витки шнека. При подачі живлення на обмотку статора (яка візуально нагадує намотаний ротор асинхронного двигуна) магнітне поле не тільки приводить в обертання ротор, але і за рахунок утворення вихрових струмів нагріває останній. Таким чином, в одному пристрої реалізована ідея поєднання кількох функціональних компонентів: змішування, підігріву та транспортування по витках шнека сипучого матеріалу. Зазначені операції реалізуються без використання зовнішнього електроприводу, нагрівачів, а лише за рахунок принципу роботи БФПЕ. Раніше досліджувалась двомодульна конструкція БФПЕ, але експериментальні дослідження вказали на певні недоліки обраного підходу. У даній роботі зроблена спроба показати альтернативну конфігурацію БФПЕ, засновану на виконанні незалежних одиночних модулів, які можуть бути об’єднані в безперервний гвинт завдяки перехідним кріпленням. Крім того, переглянуто підхід до блоку живлення та системи управління модулями. Дана стаття є однією з серії робіт, присвячених детальному опису конструкції БФПЕ.

Ключові слова: перетворювач енергії, електромеханічний агрегат, шнековий конвеєр, сушіння, змішування, сипучий матеріал, суцільний ротор, багатофункціональний.

NOTES ON CONTRIBUTORS

Mykola Zablodskiy
zablodskiynn@nubip.edu.ua

D.Sc., Professor
Department of Electrical Engineering, Electromechanics and Electrotechnology
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
https://orcid.org/0000-0001-8889-8158
https://www.webofscience.com/wos/author/record/O-8435-2018/
https://scopus.com/authid/detail.uri?authorId=55923967000

Vladyslav Pliuhin
vladyslav.pliuhin@kname.edu.ua

D.Sc., Professor
Department of Urban Power Supply and Consumption Systems
O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
https://orcid.org/0000-0003-4056-9771
https://www.webofscience.com/wos/author/record/F-4627-2018/
https://scopus.com/authid/detail.uri?authorId=57204286328