DOI: https://doi.org/10.15407/pmach2026.01.028

UDC 621.313

CONSTRUCTION OF A MULTIPARAMETER MATHEMATICAL MODEL OF THE POWER PLANT STRUCTURAL ELEMENTS

Oleksandr M. Minko
alexandr.minko@i.ua,
ORCID: 0000-0003-3206-0131

National Aerospace University
"Kharkiv Aviation Institute",
17, Vadyma Manka str., Kharkiv,
61070, Ukraine

Multiparametric mathematical model of the stator and rotor of a power machine, which is capable of describing electrodynamic, mechanical and heat-ventilation processes occurring in an electromechanical energy converter (using the example of a turbogenerator), has been obtained. It is substantiated that any power plant contains an electromechanical energy converter and the area of research is also within the scope of electrical machines and cannot be considered separately. The logic and sequence of building a multiparametric model are shown in matrix form and in numerical form. The mathematical model uses a parametric mathematical apparatus and is implemented using sequentially dependent quantities, including geometric dimensions, winding current indicators, electromagnetic induction, temperature indicators and mechanical load indicators. The developed model allows to reduce the time for designing a power machine. Multiparameterization in complex design significantly expands the intellectual content of models and significantly increases the information quality of mathematical models, which, with a sufficient level of automation, allows for much more efficient adoption of design and engineering decisions in the design of structural elements of power plants and power machines as a whole. By modeling processes that are different in nature, the result of the development of individual power machine units allows to obtain such indicators of the design unit as current load, mechanical effects from electromechanical torque and rotor mass, and the required level of heat removal from the structural elements of the power machine.

***Keywords**: power plant, electromechanical energy converter, multiparametric design, turbogenerator, multi-physical processes.*

Introduction

The complex equipment of power plants (PP), created on the basis of converters of various types of energy, such as steam turbine and gas turbine plants, necessarily includes electromechanical energy converters (EMEC) of various types. EMEC in the broad sense are represented by a large range of power machines and equipment for the power and machine-building industries. This range includes power machines (PM), which operate in the mode of converting electrical energy into mechanical energy (engines), mechanical one – into electrical energy (generators), as well as energy indicators (transformers, compensators, etc.). It is this equipment that is the key to the technological feasibility and reliability of the work of enterprises both in the generation of various types of energy (thermal and nuclear power plants), and in the metallurgical and petrochemical sectors of industry. In addition, EMEC is an integral part of ground-based energy complexes and is considered as structural elements of the PP, in which thermodynamic, hydrodynamic, gas-dynamic and electrodynamic processes of energy conversion occur [1–2].

Optimization and improvement of structural, energy, mass-dimensional and regime indicators of the abovementioned elements of power plants and mechanisms significantly increase the overall level of efficiency, competitiveness and reliability of the abovementioned enterprises, therefore methodological issues of construction and development of mathematical models of power plants are recognized as an urgent scientific and technical problem.

The **aim** of the paper is to develop a mathematical model of the structural parts of a power plant using the example of a synchronous turbogenerator, which would allow to combine multi-physical processes (electrodynamic, mechanical and heat-ventilation) that occur during the operation of a power plant, in order to make the best calculation and design decisions during development.

Problem statement and solution methodology

From the general theory of EMEC it is known that the mathematical model of a separate unit (or element) of an electric machine should describe its main functions in operating or design conditions and provide the main information regarding its design. For example, the mathematical model of the stator winding should contain the

---

rated current, voltage level and cross-sectional area of the current-carrying part. In some cases, it is possible to expand the mathematical model with information about the number of parallel branches in a phase, the thickness of the electrical insulation and the total length of the winding. However, all this belongs to the field of classical mathematical apparatus, while in the scope of multi-parametric mathematical modeling, mathematical models become significantly more complicated and provide more information about physical processes (electromagnetic, electromechanical and heat-ventilation) [3]. In addition, the mathematical model may also contain an operational element, when it is important, for example, to specify the thickness of the core winding sleeve in the model or to obtain information about the type of finning and its material or cooling tube used in the heat exchanger, etc.

Such information, embedded in the mathematical model, complicates its calculation, but qualitatively describes the functional unit of the PM in a new way and provides additional information that significantly changes the intellectual composition of the model and raises it to a higher level in its design value, about its design and its inherent physical processes [4]. Therefore, such a multi-parametric mathematical model allows to solve several problems at once when designing this unit, in particular, to set the limiting current density in the conductor and determine the maximum ability to remove excess heat from it under given design conditions [5–9].

In order to substantiate the multi-parametric mathematical apparatus, we will develop a mathematical model of the stator of a powerful turbogenerator, show the logic of its obtaining and highlight the results that are achieved using such a mathematical model.

Construction of a mathematical model in general form

To obtain a multi-parametric mathematical model of the stator in a general form, we note the necessary conditions [10]:

– elementary representation of the model components without complex differential and integral expressions (where possible) for the purpose of practical use of the mathematical model;

– for better perception of the mathematical model, we will compile it in a matrix form.

Let's assume that the conditional matrix of the parametric data array has a size of 3×3 and contain elements $a_{11} \dots a_{33}$, then we will denote the series of quantities dependent on a as a set $b_1 \dots b_m$. We will assign the name of the matrix – Stator(a), and define six (by the number of columns and the matrix term) multi-parametric dependencies (criteria). In Fig. 1 we will see a general form of the mathematical model of the stator of the PM in a multi-parametric representation [11, 12].

Fig. 1 shows an array of variables a, a number of dependent secondary variables $b(a)$, parametric design criteria and a multi-parametric matrix modifier, which, during its further calculation, will help organize a Boolean function for programming a mathematical model [13].

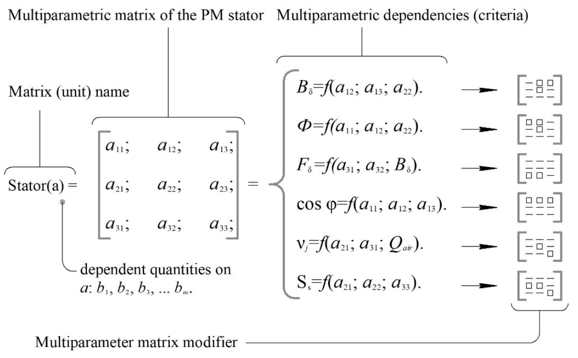

Fig. 1. General view of the mathematical model of the PM stator in multi-parametric representation

The purpose of building a multi-parametric mathematical model is to obtain functional dependencies of the PM stator, among which it is proposed to establish the following criteria.

1. Electromagnetic: B_δ – value of induction in the air gap, Gn; F_δ – value of magnetomotive force in the air gap, A.

2. Electromechanical: Φ – magnetic flux per pole at nominal voltage level (in this case, with a “star” phase connection scheme), Wb; S_s – cross-sectional area of the stator core, mm^2.

3. Heat-ventilation: v_j – speed of movement of the cooling medium in the radial ventilation channels of the stator core, m/s.

4. Operational (or energy): cos φ – indicator of active power utilization as part of the full power of the PM, p.u.

The abovementioned indicators were selected as those that substantiate the economic, technological and functional feasibility, which should be relied on when designing a competitive electromechanical energy converter of any type [14].

Based on the needs of establishing these dependencies, the composition of the multi-parametric matrix is determined, in which we have collected:

a) indicators specified by the project: nominal PM level (U_n), preliminary value of stator winding current (I_n) and desired value of active PM (P_a);

b) indicators inherent in typical electric machines from previous design experience: outer diameter of the stator core (D_a), inner diameter of the stator core (D_1), depth of the stator core groove (h_{n1});

c) indicators of the first approximation (as generally recommended) of the geometry of the stator core ventilation channels: thickness of the stator core package (b_p), width of the radial ventilation channel of the stator core (b_{r1}), i.e. the distance between the stator core packages, and the diameter of the axial ventilation channels of the stator core (d_v).

Development of a mathematical model in numerical form

Having performed the mathematical transformation and simplification of the mathematical calculations, we obtain a numerical mathematical model, which is shown in Fig. 2, which contains a personalized multi-parameterization matrix, dependent quantities on the a-elements that participate in the calculation of functional dependencies, and simple mathematical expressions with which it is possible to establish the values of the abovementioned design criteria (B_δ, Φ, F_δ, S_s, v_j and cos φ).

About Fig. 2: it should be noted that when calculating the magnetomotive force in the air gap (F_δ), the induction index in the air gap (B_δ) is expected to be used, therefore, in general, the dependence F_δ takes on the following form: $F_\delta = f\left(a_{31};\, a_{32};\, a_{13};\, a_{22}\right)$. In addition, to calculate the speed of movement of the cooling medium in the radial ventilation channels of the stator core (v_j) the model does not contain data on the volumetric flow rate (Q_{air}) of this medium, and therefore, additional calculation is required [15]:

$$Q_{air} = \frac{102 \cdot \eta_{fan} \cdot Q_{cool}}{H_{fan} \cdot P_{cool}},$$

where Q_{cool} – electric energy losses for cooling the PM stator, kW; η_{fan} – fan efficiency, p.u.; P_{cool} – hydrogen excess pressure (if provided) under the PM housing, Pa; H_{fan} – pressure that the fan can produce at the maximum temperature in the PM, Pa.

Similarly to the mathematical model of the stator, the conditional matrix of the rotor parametric data array has a size of 3×3 and contains elements $a_{11} \dots a_{33}$. In view of this, we denote a series of values dependent on a as a set of variables $b_1 \dots b_m$. We assign the name of the matrix – Rotor, and define six (by the number of columns and matrix term) multi-parametric dependencies (criteria). In Fig. 3 we see a mathematical model of the PM rotor in a multi-parametric representation.

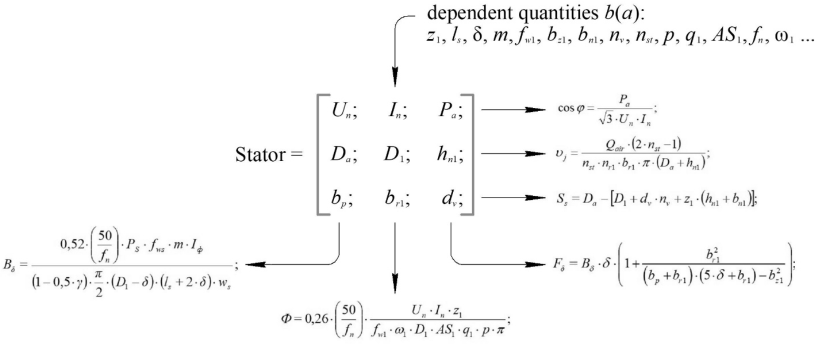

Fig. 2. Multi-parametric mathematical model of the turbogenerator stator

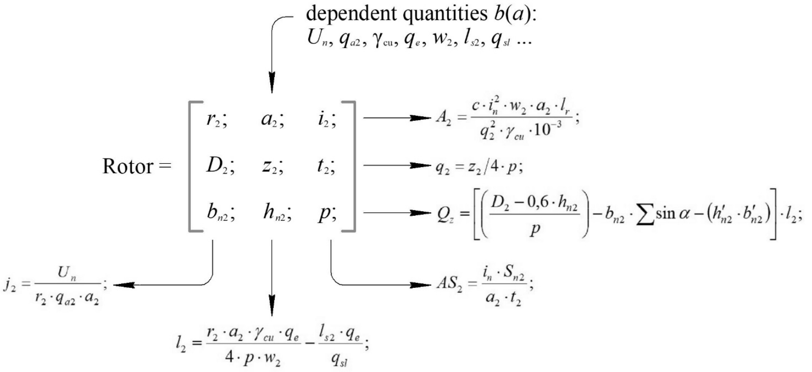

Fig. 3. Multi-parametric mathematical model of a turbogenerator rotor

The purpose of building a multi-parametric mathematical model is to obtain functional dependencies of the PM rotor, among which it is proposed to establish the following criteria [16]:

– heat-ventilation: A_2 – equations of the rotor thermal load, W;

– operational: AS_2 – linear rotor load, A/mm.

Based on the needs of establishing these dependencies, the composition of the multi-parametric matrix is determined, in which we have collected:

a) indicators specified by the project: the preliminary value of the rotor winding current (i_n) and the number of pairs of poles of the stator winding (p);

b) indicators inherent in typical electric machines from previous design experience or information from similar projects: the outer diameter of the rotor shaft (D_2), the depth of the rotor shaft groove (h_{n2}) and the width of the rotor shaft groove (b_{n2});

c) first approximation indicators (as generally recommended, or reference ones): the number of wound rotor slots (z_2), the rotor toothed distribution along its outer diameter (t_2), the number of parallel branches of the rotor winding (a_2) and the ohmic resistance of the rotor winding, when the rotor winding is constructed as a bar, wire, die-cast, cast (r_2).

When considering Fig. 3 in detail, it should be noted that when calculating the cross-sectional area of the rotor shaft toothed zone (Q_z), the model does not contain data on the sum of the projections of the rotor slot width onto its transverse axis ($\Sigma \sin \alpha$) and requires additional calculation [17]:

$$\sum \sin\alpha = \frac{1-\cos\gamma\cdot\frac{\pi}{2}}{\sin\frac{\pi\cdot p}{z_2'}},$$

where cos γ is the projection of the rotor slot width onto its transverse axis, p.u.; z'_2 is the number of rotor slot distributions, p.u.

Using the multi-parametric rotor model (Fig. 3), the following results are achieved:

– determination of the basic rotor geometry, in the area of which the winding will be laid;

– determination of the electromagnetic parameters of the rotor winding, which will be further used in the design of the current-carrying elements of the winding and rotor coils;

– determination of the electromechanical parameters of the rotor, which can be used in the development of the end parts of the rotor shaft (the interface zone with the PM load, or with the turbine, as well as the interface zone of the rotor with the bearing);

– clarification of the rotor slot distribution and the geometry of the slot as a whole;

– clarification of the overall dimensions of the rotor and its mass indicator by calculating the cross-section of the rotor shaft (barrel);

– information on the degree of efficiency of the rotor use in terms of its linear load indicator and information on the general temperature state of the rotor for its further analysis and optimization of the PM cooling system indicators.

In addition, the use of the obtained results is appropriate when creating the unification of rotor parts, such as winding insulation sleeves, band rings, fan rotor attachment parts, the geometry of places on the rotor that are connected to the oil trap and bearing.

Conclusions

1. An approach is proposed that allows to structurally and consistently organize the calculation of the main units of the EMEC, determine the main indicators of the calculation unit. A matrix form of a mathematical multi-parametric model of the basic model of the stator, rotor and turbogenerator is compiled. The use of these models provides the determination of:

– the main geometry of the EMEC structural unit;

– the main electromagnetic indicators in the EMEC air gap;

– electromechanical indicators of the EMEC and the level of permissible mechanical loads;

– indicators of the thermal state of the EMEC; as well as clarification

– previously accepted (preliminary or reference) values of individual indicators, such as the thickness of the stator core package, the thickness of the insulation of the windings, the length of the rotor shaft and its mass, etc.;

– overall dimensions and mass indicators of the PM;

– informativeness of the utilization coefficients of individual PM units.

2. Further development of the multi-parametric mathematical apparatus will allow to improve the quality of design decisions at the initial stages of development of structural elements of the electric power system, in particular, when determining the layout of such equipment as the coupling of the rotor with the bearing assembly, the joint operation of the heat exchanger and the stator ventilation channels, the determination of critical current loads in the windings of the electric power system, etc.

3. To increase the level of automation and reduce the time for modeling multi-physical processes in the scope of multi-parametric design of structural elements of the electric power system, it is necessary to develop a software calculation block that would simultaneously cover all types of processes: electrodynamic, mechanical and heat-ventilation, which is a separate problem and requires additional consideration.

References

1. Minko, O. M. (2019). *Rozrobka funktsionalnoi skhemy parohazovoi turbinnoi ustanovky z kombinovanym rezhymom roboty* [Development of a functional scheme of a combined cycle gas turbine plant]. Proceedings of the IV All-Ukrainian scientific and practical Internet conference of students, postgraduates and young scientists "Actual problems of modern energy". Kherson: KhNTU, pp. 29–32 (in Ukrainian).
2. Shevchenko, V. V., Minko, A. N., & Lazurenko, K. A. (2025). Optimization of the design and parameters of electromechanical energy converters using multiparametric design techniques. *Problems of the regional energetic*, no. 4 (68), pp. 63–76. https://doi.org/10.52254/1857-0070.2025.4-68.05.
3. Minko, O. (2025). Multiparametric mathematical model of the stator of a powerful electric machine. Proceedings of VIII International Conference «Innovative Technologies in Science and Education. European Experience» (December 20–24, 2025, Dnipro, Ukraine). Dnipro: Zhurfond, pp. 118–122.
4. Holovan, I. & Popovych, O. (2025). *Vrakhuvannia v slabkozviazanii kolo-polovii modeli asynkhronnoho dvyhuna vytisnennia navedenoho strumu v koli rotora* [Accounting for the displacement of reduced current in the rotor circuit in a weakly coupled circular-field model of an asynchronous motor]. *Tekhnichna elektrodynamika – Technical Electrodynamics*, no. 3, pp. 22–30 (in Ukrainian). https://doi.org/10.15407/techned2025.03.022.
5. Shynkarenko, V. & Chyhir, R. (2024). Constructive-synthesizing modelling of multifractals based on multiconstructors. 14th International scientific and practical programming conference, UkrPROG 2024, CEUR Workshop Proceedings, vol. 3806, pp. 75–88.
6. Zinovkin, V., Krysan, Y., & Shylo, S. (2025). Devising a method for large-scale modeling of non-stationary electromagnetic processes in power transformer equipment under sharply changing loads. *Eastern-European Journal of Enterprise Technologies*, vol. 6, no. 8 (138), pp. 6–23. https://doi.org/10.15587/1729-4061.2025.348152.
7. Kostikov, A., Shubenko, O., Tarasova, V., Babak, M., & Mazur, A. (2025). *Enerhozberezhennia pry intehratsii u teplovu skhemu parovoi turbiny absorbtsiinoho bromisto-litiievoho teplovoho nasosu, shcho obihrivaietsia paroiu* [Energy savings when integrating a steam-heated lithium bromide absorption heat pump into a steam turbine thermal scheme]. *Enerhotekhnolohii ta resursozberezhennia – Energy Technologies & Resource Saving*, vol. 85, no. 4, pp. 38–53 (in Ukrainian). https://doi.org/10.33070/etars.4.2025.03.
8. Spirzewski, M. & Nowak, M. M. (2025). A similarity-based scaling methodology for the thermal-hydraulic design of dual fluid reactor demonstrators. *Energies*, vol. 18, iss. 22, article 5935. https://doi.org/10.3390/en18225935.
9. Podoltsev, O. D. & Bondar, R. P. (2020). *Modeliuvannia poviazanykh elektromekhanichnykh ta teplovykh protsesiv v liniinomu mahnitoelektrychnomu dvyhuni na osnovi teorii multyfizychnykh kil* [Modeling of coupled electromechanical and thermal processes in a linear magnetoelectric motor based on the theory of multiphysical circuits]. *Tekhnichna elektrodynamika – Technical Electrodynamics*, iss.2, pp. 50–55 (in Ukrainian). https://doi.org/10.15407/techned2020.02.050.
10. Vaskovskyi, Yu. & Nesterenko, D. (2025). *Kompleksna multyfizychna matematychna model fizychnykh protsesiv v potuzhnykh tiahovykh elektrychnykh mashynakh* [Complex multiphysics mathematical model of physical processes in traction electric machines]. *Tekhnichna elektrodynamika – Technical Electrodynamics*, no. 2, pp. 49–56 (in Ukrainian). https://doi.org/10.15407/techned2025.02.049.
11. Hruboi, O. P., Shoful, A. K., Kliuchnikov, O. O., Fedorenko, H. M., Kensytskyi, O. H. (2012). *Modeliuvannia nahrivu elementiv statora y rotora hidroheneratora-dvyhuna Dnistrovskoi HAES* [Modeling the heating of the elements of the stator and rotor of the hydrogenerator-motor of the Dniester hydroelectric power plant]. *Problemy bezpeky atomnykh elektrostantsii i Chornobylia* – Problems of nuclear power plants' safety and of Chornobyl, no. 1, pp. 77–87 (in Ukrainian).
12. Ostashevskyi, M. O. & Yurieva, O. Yu. (2018). *Elektrychni mashyny i transformatory* [Electrical machines and transformers: basic principles]: a tutorial by Milykh, V. I. (eds). Kyiv: Karavela, 452 p. (in Ukrainian).
13. Zablodskyi, M. M., Pyliuhin, V. Ye., & Bur, K. (2013). *SAPR elektromekhanichnykh prystroiv* [AD of electromechanical devices]: a textbook. Part 2. Alchevsk: Lado, 320 p. (in Ukrainian).

14. Zozulin, Yu. V., Antonov, O. Ye., Bychik, A. M., Borychevskyi, A. M., Kobz, K. O., Livshyts, O. L., Rakohon, V. H., Rohovyi, I. Kh., Khaimovych, L. L., & Cherednyk, V. I. (2011). *Stvorennia novykh typiv ta modernizatsiia diiuchykh turboheneratoriv dlia teplovykh elektrychnykh stantsii* [Creation of new types and modernization of existing turbogenerators for thermal power plants]. Kharkiv: Private Company "Kolehium", 228 p. (in Ukrainian).
15. Satake, Y., Takahashi, K., Waki, T., Onoda, M., & Tanaka, T. (2015). Development of large capacity turbine generators for thermal power plants. *Mitsubishi Heavy Industries Technical Review*, vol. 52, no. 2, pp. 47–54. https://power.mhi.com/randd/technical-review/pdf/index_14e.pdf.
16. Qi, S., Zhang, Y., Wang, R., Huang, L., & Li, S. (2019). Design of multi-parameter sensor system based on algorithm correction. *2019 IEEE 3rd International Conference on Circuits, Systems and Devices (ICCSD)*, Chengdu, China, pp. 39–44. https://doi.org/10.1109/ICCSD.2019.8843216.
17. Hraniak, V., Kupchuk, I., Zlotnitskyi, V., & Saftiuk, Y. (2024). Features of the influence of the technical parameters of asynchronous motor on the formation of its three-phase stator current system. *Engineering, Energy, Transport AIC*, vol. 125, no. 2, pp. 124–129. https://doi.org/10.37128/2520-6168-2024-2-14.

Received 19 January 2026 *Accepted 16 March 2026* *Published 30 March 2026*

Побудова мультипараметричної математичної моделі структурних елементів енергетичної установки

О. М. Мінко

Національний аерокосмічний університет «Харківський авіаційний інститут»,
61000, м. Харків, вул. Вадима Манька, 17

Отримано мультипараметричну математичну модель статора й ротора енергетичної машини, здатну описувати електродинамічні, механічні й тепло-вентиляційні процеси, що відбуваються в електромеханічному перетворювачі енергії (на прикладі турбогенератора). Показано логіку й послідовність побудови такої моделі в матричному і чисельному вигляді. У математичній моделі використовується параметричний математичний апарат, а реалізується вона за допомогою послідовно залежних величин, серед яких геометричні розміри, показники струму обмоток, електромагнітної індукції, температур і механічного навантаження. Розроблена модель дозволяє зменшити час на проєктування енергетичної машини.

***Ключові слова**: енергетична установка, електромеханічний перетворювач енергії, мультипараметричне проєктування, турбогенератор, багатофізичні процеси.*

Література

1. Мінко О. М. Розробка функціональної схеми парогазової турбінної установки з комбінованим режимом роботи. Матеріали IV-ї Всеукраїнської науково-практичної інтернет-конференції студентів, аспірантів і молодих вчених «Актуальні проблеми сучасної енергетики». Херсон: ХНТУ, 2019. С. 29–32.
2. Shevchenko V. V., Minko A. N., Lazurenko K. A. Optimization of the design and parameters of electromechanical energy converters using multiparametric design techniques. *Problems of the regional energetic*. 2025. No. 4 (68). P. 63–76. https://doi.org/10.52254/1857-0070.2025.4-68.05.
3. Minko O. Multiparametric mathematical model of the stator of a powerful electric machine. Proceedings of VIII International Conference «Innovative Technologies in Science and Education. European Experience» (December 20–24, 2025, Dnipro, Ukraine). Dnipro: Zhurfond, 2025. P. 118–122.
4. Головань І., Попович О. Врахування в слабкозв'язаній коло-польовій моделі асинхронного двигуна витіснення наведеного струму в колі ротора. *Технічна електродинаміка*. 2025. № 3. С. 22–30. https://doi.org/10.15407/techned2025.03.022.
5. Shynkarenko V., Chyhir R. Constructive-synthesizing modelling of multifractals based on multiconstructors. 14th International scientific and practical programming conference, UkrPROG 2024, CEUR Workshop Proceedings. 2024. Vol. 3806. P. 75–88.
6. Zinovkin V., Krysan Y., Shylo S. Devising a method for large-scale modeling of non-stationary electromagnetic processes in power transformer equipment under sharply changing loads. *Eastern-European Journal of Enterprise Technologies*. 2025. Vol. 6. No. 8 (138). P. 6–23. https://doi.org/10.15587/1729-4061.2025.348152.
7. Костіков А., Шубенко О., Тарасова В., Бабак М., Мазур А. Енергозбереження при інтеграції у теплову схему парової турбіни абсорбційного бромісто-літієвого теплового насосу, що обігрівається парою. *Енерготехнології та ресурсозбереження*. 2025. Т. 85. № 4. С. 38–53. https://doi.org/10.33070/etars.4.2025.03.

8. Spirzewski M., Nowak M. M. A similarity-based scaling methodology for the thermal-hydraulic design of dual fluid reactor demonstrators. *Energies*. 2025. Vol. 18. Iss. 22. Article 5935. https://doi.org/10.3390/en18225935.
9. Подольцев О. Д., Бондар Р. П. Моделювання пов'язаних електромеханічних та теплових процесів в лінійному магнітоелектричному двигуні на основі теорії мультифізичних кіл. *Технічна електродинаміка*. 2020. Вип. 2. С. 50–55. https://doi.org/10.15407/techned2020.02.050.
10. Васьковський Ю., Нестеренко Д. Комплексна мультифізична математична модель фізичних процесів в потужних тягових електричних машинах. *Технічна електродинаміка*. 2025. № 2. С. 49–56. https://doi.org/10.15407/techned2025.02.049.
11. Грубой О. П., Шофул А. К., Ключніков О. О., Федоренко Г. М., Кенсицький О. Г. Моделювання нагріву елементів статора й ротора гідрогенератора-двигуна Дністровської ГАЕС. *Проблеми безпеки атомних електростанцій і Чорнобиля*. 2012. № 1. С. 77–87.
12. Осташевський М. О., Юр'єва О. Ю. Електричні машини і трансформатори: навч. посібник / за ред. В. І. Мілих. Київ: Каравела, 2018. 452 с.
13. Заблодський М. М., Пилюгін В. Є., Бур К. САПР електромеханічних пристроїв: навчальний посібник. Алчевськ: Ладо, 2013. Ч. 2. 320 с.
14. Зозулін Ю. В., Антонов О. Є., Бичік А. М., Боричевський А. М., Кобз К. О., Лівшиць О. Л., Ракогон В. Г., Роговий І. Х., Хаймович Л. Л., Чередник В. І. Створення нових типів та модернізація діючих турбогенераторів для теплових електричних станцій. Харків: ПФ «Колегіум», 2011. 228 с.
15. Satake Y., Takahashi K., Waki T., Onoda M., Tanaka T. Development of large capacity turbine generators for thermal power plants. *Mitsubishi Heavy Industries Technical Review*. 2015. Vol. 52. No. 2. P. 47–54. https://power.mhi.com/randd/technical-review/pdf/index_14e.pdf.
16. Qi S., Zhang Y., Wang R., Huang L., Li S. Design of multi-parameter sensor system based on algorithm correction. *2019 IEEE 3rd International Conference on Circuits, Systems and Devices (ICCSD)*, Chengdu, China. 2019. P. 39–44. https://doi.org/10.1109/ICCSD.2019.8843216.
17. Hraniak V., Kupchuk I., Zlotnitskyi V., Saftiuk Y. Features of the influence of the technical parameters of asynchronous motor on the formation of its three-phase stator current system. *Engineering, Energy, Transport AIC*. 2024. Vol. 125. No. 2. P. 124–129. https://doi.org/10.37128/2520-6168-2024-2-14.