ДОДАТОК А

Апробація результатів кваліфікаційної роботи

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Міністерство освіти і науки України
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кафедра комп'ютерно-інтегрованих технологій, автоматизації та робототехніки
Харківський національний університет міського господарства
імені О.М. Бекетова
Братиславський університет економіки та менеджменту
Громадська організація «Перспектива»
Угорський університет сільського господарства та природничих наук

МАТЕРІАЛИ

I International Conference
«Sustainable smart cities and communities:
business and innovation solutions»
(Сталі розумні міста та спільноти:
бізнес та інноваційні рішення)
SSC&C2025

21 квітня 2025

[електронне видання]

Харків 2025

Рисунок А.1 – Титульний аркуш

Сталі розумні міста та спільноти: бізнес та інноваційні рішення 2025: матеріали І-ої Міжнародной конференції, Харків, 21 квітня 2025.: тези доповідей / [редкол. І.Ш. Невлюдов (відповідальний редактор)].-Харків: [електронний друк], 2025. – 68 с.

У збірник включені тези доповідей, які присвячені сучасним цифровим технологіям та автоматизації для сталого розвитку розумних міст; роботизованим системам та автономним технологіям у міському середовищі; циркулярной економіки та зеленой енергетики в автоматизованих системах; розумні транспортні системи та мобільність майбутнього; кіберфізичні системи та безпека даних у міській автоматизації; HMI та цифрові платформи для інтеграції міських послуг; автоматизація промисловості та міської інфраструктури: виклики та рішення ресурсоефективності.

Редакційна колегія: І.Ш. Невлюдов, І.В.Колупаєва, Ю.В.Ромашов В.В. Євсєєв.

Sustainable smart cities and communities: business and innovation solutions 2025: Proceedings of I st I International Conference, Kharkiv, April 21, 2025: Thesises of Reports / [Ed. I.Sh. Nevlyudov (chief editor).] .- Kharkiv .: [electronic version], 2025. - 68 p.

The collection includes abstracts of reports dedicated to modern digital technologies and automation for the sustainable development of smart cities; robotic systems and autonomous technologies in the urban environment; circular economy and green energy in automated systems; smart transport systems and mobility of the future; cyber-physical systems and data security in urban automation; HMI and digital platforms for the integration of urban services; automation of industry and urban infrastructure: challenges and solutions for resource efficiency.

Editorial board: Igor Nevludov, Irina Kolupaieva, Yurii Romashov,Vladyslav Yevsieiev

Результати наукових досліджень, що представлені у збірнику, виконані в межах реалізації **міжнародного проєкту Еразмус+ Жан Моне Модуль «Україна-ЄС: рішення циклічної економіки для розумних та сталих міст» («Ukraine-EU: Circular Economy Solutions 4 Smart and Sustainable Cities (Eco4Smart)») – # 101127659)**

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Рисунок А.2 – Опис конференції

ЗМІСТ

Рисунок А.3 – Зміст конференції

Рисунок А.4 – Друга сторінка змісту конференції

A GENERALISED MATHEMATICAL MODEL OF ELECTRICITY CONSUMPTION FOR ELECTRIC DRIVES IN SMART CITIES APPLICATIONS

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Annotation: The generalised mathematical model of electricity consumption is developed by using electromechanical analogies and Lagrange's equations of 2-nd kind in the view of the system of two first order and one two order ordinary differential equations with the related initial conditions. It allows representing the dependency between supplied voltage and the electricity consumption of the electric drive. This mathematical model is for following researches directed to formulate and to solve the problem of the optimal control theory, so that it allows developing the energy efficient automated controls for electric drives required in smart cities applications.

Key words: electricity consumption, electric drive, mathematical modelling, smart sites.

RELEVANCE. Automated electric drives are principal structural elements in a lot of technical systems involved in households and industrial applications at present. The green transition ambitions of the EU make more significant importance of electric drives, because they have zero own carbon emission, and they can provide carbon neutrality together with the green power generating technologies like solar, wind, hydro and nuclear. Although automated electric drives are known and widely used a lot of times, they are traditionally designed without energy efficiency demands and they provide only the stability of exploitational modes. At the same time, energy efficiency demands require more careful mathematical modelling of the processes in the automated electric drive to represent dependencies between automated controls and energy consumptions, as it is discussed for an example in the published explorations [1,2]. So, developments of the improved mathematical modelling of the processes inherent for the automated electric drives are the relevant problem due to relationships with energy efficiency demands for infrastructures of smart cities. The purpose of this research is in development of a generalized mathematical model of the electricity consumption in electric drives providing the required detailing to represent dependencies between automated controls and energy consumptions.

RESULTS. An electric drive provides required operations due to electric voltages supplied on the electric motor, so that the corresponding electric power is consumed to have the required angular velocity of the output shaft of the electric drive with corresponding exploitation loads. If an electric drive is considered as an automation object, then the supplied voltage is chosen to provide the required angular velocity of the output shaft of the electric drive during an operation, so that to represent the dependence between controls and electricity consumptions it is necessary to represent the dependence between the supplied voltage and angular velocity of the output shaft of the electric drive with correspondent exploitation loads. Taking into account all these circumstances, to represent the dependence between controls and electricity consumptions it is required to consider automated electric drive as the electromechanical system, and the electromechanical analogies with Lagrange's equations of 2-nd kind are used to do it.

The electric drive with the direct current electric motor is considered [1, 2], so that the electric charge q_e in the rotor winding and the angle φ of rotation of the output shaft are considered as the generalised coordinates representing the electric drive as the electromechanical system. It is assumed, that the rotation angle of the rotor of electric motor is defined by the rotation angle of the output shaft are related

$$\varphi_e = \varphi_e(\varphi), \tag{1}$$

where φ_e is the rotation angle of the rotor of the electric motor.

Рисунок А.5 – Тезиси, перша сторінка

The electromechanical analogies and the Lagrange's equations of the 2-nd kind lead to the systems of two differential equation of second order, but it is possible to exclude the electric charge q_e from these equations, so that after correspondent equal transformations these equations will have the following view with the related initial conditions:

$$L_e \frac{dI}{dt} = -R_e I - B_e \frac{d\varphi_e}{d\varphi}\frac{d\varphi}{dt} + U_e(t), \tag{2}$$

$$\left(J_e\left(\frac{d\varphi_e}{d\varphi}\right)^2 + J_m(\varphi)\right)\frac{d^2\varphi}{dt^2} + \left(2J_e\frac{d\varphi_e}{d\varphi}\frac{d\varphi_e}{dt^2} + \frac{dJ_m}{d\varphi}\right)\frac{d\varphi}{dt} = B_e\left(\frac{d\varphi_e}{d\varphi}\right)^2\frac{d\varphi}{dt} - M\left(t,\varphi,\frac{d\varphi}{dt}\right), \tag{3}$$

$$I(t_0) = I_0, \quad \varphi(t_0) = \varphi_0, \quad \frac{d\varphi}{dt}(t_0) = \omega_0, \tag{4}$$

where t is the time; $I = dq_e/dt$ is the electric current in the rotor winding; L_e, R_e, B_e and J_e are the inductance, the resistance of the rotor winding, the electrotechnical characteristic of the electric motor and the moment of inertia of their rotor; $U_e(t)$ is the voltage supplied to the electric motor; $J_m(\varphi)$ is the moment of inertia of the mechanical parts of the electric drive and loads; $M(t,\varphi,d\varphi/dt)$ is the generalised mechanical couple representing the loads relatively the rotation axis of the output shaft of the electric drive; t_0 is the given initial time, and I_0, φ_0, ω_0 are the given values of the electric current, rotation angle, rotation velocity at the initial time $t = t_0$.

To estimate the consumed electric energy, the mathematical model (2)–(4) of the electric drive must be complemented by the following differential equation and the related initial condition:

$$\frac{dE}{dt} = I(t)U_e(t), \quad E(t_0) = E_0, \tag{5}$$

where $E = E(t)$ is the consumed electric energy before the time t and E_0 is the consumed electric energy before the initial time $t = t_0$.

The mathematical model (2)–(5) gives the representation of dependency between the voltage $U_e(t)$ supplied to electric motor and electricity consumption $E(t)$ of the electric drive. The energy efficient automated control for the electric drive must be due to the choice of the voltage $U_e(t)$ supplied to electric motor, and to have such energy efficient controls, it is necessary to formulate and to solve the related problem of the optimal control theory on the basis of the developed mathematical model (2)–(5).

CONCLUSIONS. The generalised mathematical model of electricity consumption in electric drives is developed in the view of the system of ordinary differential equations with the related initial conditions. It is shown, that estimations of the electricity consumptions require considering of the electric drive as the electromechanical system, so that at least two generalised coordinates are necessary. The view of the differential equations of the developed mathematical model is significantly defined by the relation between the rotation angles of the rotor of electric motor and the output shaft of the electric drive. Continuation of this research is planned to consider the particular examples of electric drives with different relations between the rotation angles of the rotor of electric motor and the output shaft.

REFERENCES:

1. Kolupaieva, I., Nevliudov, I., Romashov, Y., Tiesheva, L., & Vértesy, L. (2024). Intelligent Automated Control in Accordance with Resource Efficiency Criteria toward Circular Economy Transition. Lecture Notes in Networks and Systems, 1089 LNNS, pp. 133–141, https://doi.org/10.1007/978-3-031-67195-1_17

Рисунок А.6 – Тезиси та перелік посилань, друга сторінка

2. Nevliudov, I., Omarov, M., Romashov, Y., Muradova, V., & Vzhesnievskyi, M. (2023). One approach to find optimal controls for discrete dynamic systems with numerical methods application. Advanced Mathematical Models and Applications, 8 (3), pp. 548–564.

3. Nevliudov, I., Yevsieiev, V., Maksymova, S., Demska, N., Kolesnyk, K., & Miliutina, O. (2022, September). Object Recognition for a Humanoid Robot Based on a Microcontroller. In *2022 IEEE XVIII International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH)* (pp. 61-64). IEEE.

4. Attar, H., Abu-Jassar, A. T., Amer, A., Lyashenko, V., Yevsieiev, V., & Khosravi, M. R. (2022). Control system development and implementation of a CNC laser engraver for environmental use with remote imaging. *Computational intelligence and neuroscience*, *2022*(1), 9140156.

5. Nevliudov, I., Yevsieiev, V., Baker, J. H., Ahmad, M. A., & Lyashenko, V. (2020). Development of a cyber design modeling declarative Language for cyber physical production systems. *J. Math. Comput. Sci.*, *11*(1), 520-542.

6. Yevsieiev, V. Comparative Analysis of the Characteristics of Mobile Robots and Collaboration Robots Within INDUSTRY 5.0. / V. Yevsieiev, D. Gurin // Sectoral research XXI : characteristics and features : collection of scientific papers "SCIENTIA" with proceedings of the VI International Scientific and Theoretical Conference, September 8, 2023. - Chicago : European Scientific Platform, 2023. - P. 92-94.

7. Abu-Jassar, A. T., Attar, H., Amer, A., Lyashenko, V., Yevsieiev, V., & Solyman, A. (2025). Development and Investigation of Vision System for a Small-Sized Mobile Humanoid Robot in a Smart Environment. *International Journal of Crowd Science*, *9*(1), 29-43.

8. Nevliudov, I., Yevsieiev, V., Maksymova, S., Demska, N., Kolesnyk, K., & Miliutina, O. (2023, September). Mobile Robot Navigation System Based on Ultrasonic Sensors. In *2023 IEEE XXVIII International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED)* (Vol. 1, pp. 247-251). IEEE.

9. Abu-Jassar, A. T., Attar, H., Amer, A., Lyashenko, V., Yevsieiev, V., & Solyman, A. (2024). Remote Monitoring System of Patient Status in Social IoT Environments Using Amazon Web Services (AWS) Technologies and Smart Health Care. *International Journal of Crowd Science*, *8*.

10. Yevsieiev, V., Abu-Jassar, A., & Maksymova, S. (2024). Calculation of the Distance to Objects in Collaborative Robots Workspace Using Computer Vision. *Journal of universal science research*, *2*(11), 240-255.

11. Yevsieiev, V., Maksymova, S., Gurin, D., & Alkhalaileh, A. (2024). Data Fusion Research for Collaborative Robots-Manipulators within Industry 5.0. *ACUMEN: International journal of multidisciplinary research*, *1*(4), 125-137.

12. Yevsieiev, V., Alkhalaileh, A., Maksymova, S., & Gurin, D. (2024). Research of Existing Methods of Representing a Collaborative Robot-Manipulator Environment within the Framework of Cyber-Physical Production Systems. *Multidisciplinary Journal of Science and Technology*, *4*(9), 112-120.

13. Yevsieiev, V., Abu-Jassar, A., Maksymova, S., & Gurin, D. (2024). Human Operator Identification in a Collaborative Robot Workspace within the Industry 5.0 Concept. *Multidisciplinary Journal of Science and Technology*, *4*(9), 95-105.

Рисунок А.7 – Перелік посилань, друга сторінка

ДОДАТОК Б

Демонстраційний матеріал

№ доку-мента	Позначення	Найменування	Додаткові відомості
		Текстові документи	
1	ГЮИК.425541.014 ПЗ	Пояснювальна записка	А4, 94 с.
		Додаткові матеріали	
2		Апробація результатів	А4, 7 с.
		кваліфікаційної роботи	
3		Демонстраційний	А4, 12 с.
		матеріал	
4			
5			
6			
7			

Змін.	Арк.	Номер докум.	Підпис	Дата	ГЮИК.ХХХХХХ.016 ВД		
Розроб.		Шевченко А. Д.			Моделювання електромеханічних процесів в електроприводах систем автоматизації	Літера: Н	Аркуш: 1 / Аркушів: 1
Перевір.		Ромашов Ю. В.				Кафедра КІТАР ХНУРЕ	
Н.контр.		Стародубцев М.Г.					
Затв.		Невлюдов І.Ш.					