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COMPLEX METHODOLOGY OF MANAGING THE DEVELOPMENT OF THE CHARGING STATION NETWORK

The paper examines the problem of managing the operation and development of the electric vehicle charging infrastructure. Enterprises providing electric vehicle charging services together with their operating environment form a complex hierarchical system. The multi-criteria task of adaptive control of such a system must be considered in different aspects depending on the goals of control at different levels of the system hierarchy. The formation of scientifically based typical and promising charging infrastructure solutions requires the complex application of optimization models and algorithms, taking into account the coverage of the territory by the system of charging stations, the scale of the enterprise that provides services to the customers of the system, as well as the interests and needs of all target groups affected by the system. Therefore, the purpose of this study is to form a comprehensive method of system management of the development of charging infrastructure for electric vehicles, which includes the specified models and algorithms. To solve the set goal, a set of target indicators was formed for various variants of the hierarchical structure of the system. The target indicators are based on models of energy efficiency of electric vehicles, models of the theory of mass service systems and models of car service efficiency. A morphological model of the system containing four functional elements was built: enterprise, electric vehicle, transport flow and environment. An algorithm has been developed that implements the method of system management of the charging infrastructure and takes into account the interests of three target groups: customers, entrepreneurs and the social environment. The proposed methodology can be used in the algorithms of smart management systems of the network of charging stations and modules of intelligent transport systems to evaluate the impact of the charging infrastructure on the performance indicators of road transport.

Key words: *electric vehicle, charging infrastructure, multi-criteria task, set of target indicators, morphological matrix.*

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КОМПЛЕКСНА МЕТОДИКА КЕРУВАННЯ РОЗВИТКОМ МЕРЕЖІ ЗАРЯДНИХ СТАНЦІЙ

В роботі досліджується проблема керування роботою та розвитком зарядної інфраструктури електромобілів. Підприємства, що надають послуги зарядки електромобілів, разом із середовищем їх функціонування утворюють складну ієрархічну систему. Багатокритеріальну задачу адаптивного керування такою системою необхідно розглядати в різних аспектах залежно від цілей керування на різних рівнях системної ієрархії. Формування науково обґрунтованих типових та перспективних рішень зарядної інфраструктури вимагає комплексного застосування оптимізаційних моделей та алгоритмів із врахуванням покриття території системою зарядних станцій, масштабу підприємства, яке надає послуги клієнтам системи, а також інтересів та потреб всіх *цільових груп, на які впливає система. Тому метою даного дослідження є формування комплексної методики системного управління розвитком зарядною інфраструктурою для електромобілів, яка охоплює зазначені моделі та алгоритми. Для вирішення поставленої мети сформовано комплекс цільових показників для різних варіантів ієрархічної структури системи. Цільові показники базуються на моделях енергетичної ефективності електромобілів, моделях теорії систем масового обслуговування та моделях ефективності автосервісу. Побудовано морфологічну модель системи, що місить чотири функціональні елементи: підприємство, електромобіль, транспортний потік та середовище. Розроблено алгоритм, який реалізує методику системного керування зарядною інфраструктурою та враховує інтереси трьох цільових груп: клієнтів, підприємців та соціального середовища. Запропоновану методику можна застосовувати в алгоритмах розумних систем керування мережею зарядних станцій та модулів інтелектуальних транспортних систем для оцінювання впливу зарядної інфраструктури на показники ефективності автомобільного транспорту.*

Ключові слова: *електромобіль, зарядна інфраструктура, багатокритеріальна задача, комплекс цільових показників, морфологічна матриця.*

Statement of the problem

Currently, there is a growing popularity of electric vehicles (EVs) as a sustainable and efficient alternative to traditional vehicles with internal combustion engines. The positive attitude of consumers of transport services towards electric vehicles is due to the government's policy on public awareness of global energy and environmental problems. Electric vehicles are generally more energy efficient than gasoline and diesel vehicles, converting a higher percentage of electricity from the grid into power at the wheels. Electric vehicles produce zero emissions, which helps reduce air pollution, however, the overall environmental impact depends on the source of electricity used for charging. With rising fuel prices, owners are also attracted by the economic efficiency of electric cars. Compared to traditional vehicles, they have lower operating costs and maintenance requirements due to fewer moving parts, no need for oil changes, and less brake wear due to regenerative braking. In addition, the instantaneous torque provides quick acceleration and controllability of the electric vehicle. Many electric vehicle models are equipped with advanced technological features, including regenerative braking systems, intelligent energy management systems and driver assistance systems.

Despite the mentioned advantages of using electric vehicles, there are problems related to the limited infrastructure of charging stations in certain regions, which can prevent their rapid implementation. In order to create typical charging infrastructure solutions for electric vehicles at the level of the charging station and network of charging stations, it is necessary to solve the system problems of determining their rational structure and parameters.

Enterprises providing electric vehicle charging services together with their operating environment form a complex hierarchical system. The multi-criteria task of adaptive control of such a system must be considered in different aspects depending on the control objectives. It is advisable to organize the hierarchy of subsystems and elements of the studied system according to the territorial distribution or scale of the enterprise. In addition, the choice of criteria for the effectiveness of its operation depends on the needs of customers of charging stations and other target groups seeking to realize their economic and social goals. Only the complex application of models and algorithms taking into account the above-mentioned factors will ensure the formation of scientifically based typical and promising charging infrastructure solutions for the development of electric mobility of the population and obtaining the corresponding positive effects.

Analysis of recent research and publications

To satisfy customers and owners of charging infrastructure facilities, as well as to reduce its impact on the environment, it is necessary to rationally organize the work of these facilities with the possibility of their further development. The process of managing the charging infrastructure includes monitoring the operation of charging stations with the verification of defined activity indicators: for different target groups [1-3], at different levels of business decomposition [4], at different levels of management [5]. But these groups of indicators are not related to each other and are not integrated into the general methodology. In work [4], a charging station is considered as a special case of a car service enterprise, the evaluation method proposed in [4] does not take into account the specifics of charging stations as infrastructure objects. The structure of models for evaluating the efficiency of an enterprise in work [5] is considered only from the point of view of business success and has only an economic context. Some scientists have attempted to determine the system's efficiency criteria, taking into account the needs of both business and system customers [1, 4, 6], adding to the system indicators the customer loyalty coefficient within the customer radius. However, there is no formalization of the calculation of the client radius in the cited works. Scientists offer only subjective constant estimates of this parameter (5 km) [6-7], which are difficult to adapt to other studies. And the customer loyalty ratio is used as a basic partial parameter to determine the main indicator of system efficiency. The social impact of the charging infrastructure is determined in work [8] by the prospective environmental effect and the shortage of electrical energy in the power system at the location at the predicted values of the demand for charging. Optimization of the network of charging stations by territorial distribution is devoted to articles [9-17].

The analysis of recent studies showed that, despite the urgency of the problem of optimizing the charging infrastructure, there are currently no system solutions for it.

Formulation of the purpose of research

The purpose of this study is to develop a comprehensive method of system management of the charging infrastructure for electric vehicles. To achieve this purpose, the following tasks must be solved:

– determination of the structure of the system of charging stations;
– determination of a set of target indicators for the task of optimization of the charging station system;
– development of a comprehensive methodology for managing the development of the charging station system.

Presentation of the main research material

The hierarchical structure of the system of charging stations can be determined depending on the selected type of decomposition. The regional system consists of urban and non-urban subsystems, which in turn are formed from local subsystems of a lower level. Based on the results of [4], it is possible to set the depth of system decomposition from the network of charging stations to the level of one charging station or a separate charging/discharging process.

Taking into account the designations that were introduced in work [1], a set of target performance indicators is proposed in the task of rational management of the system of charging stations, taking into account various representations of the system structure (fig. 1). To simplify the perception of the specified complex in fig. 1 shows only urban subsystems of the average level of territorial distribution.

Each target indicator is a point in the three-dimensional space "Territorial allocation − Enterprise scale − Target groups" and represents a target function in the task of optimizing the operation of the charging station system.

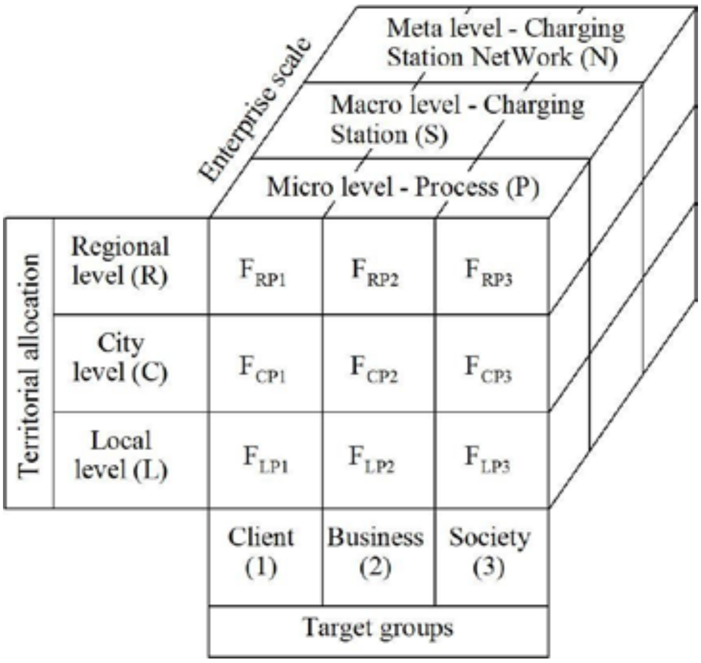

Fig. 1. The set of target indicators of the operation and development of the charging station system

The indicators of the upper levels of the territorial distribution of the system will be determined by convolution of the indicators of the lower level. The target efficiency indicators for different decompositions of the network of charging stations can be approximated by the convolution of the target indicators of the corresponding subsystems. However, at each level of decomposition, it is possible to set additional properties of the system. The performance indicator for the *Z*-th target group (client, entrepreneur (business), society) is generally determined as follows:

$$F_{X^iY^jZ} = \sum_{1}^{N}\sum_{1}^{M} F_{X^{i-1}Y^{j-1}Z}, \qquad (1)$$

де where $F_{X^iY^jZ}$ is the target indicator at the *i*-th territorial level and the *j*-th level of system scaling; *N* is the number of subsystems at the (*i*-1)-th territorial level; *M* is the number of subsystems for the (*j*-1) scale of the enterprise providing charging infrastructure services.

Models and algorithms of target indicators that take into account customer and business requirements are based on car service efficiency models, models of the theory of mass service systems and are described by the authors in works [1, 3]. The target indicator, which takes into account the requirements of the social environment, is proposed to be determined by the following expression:

$$F_{X^iY^jZ} = \alpha I_{e.e} \times \beta I_{e.i} \times \gamma I_s , \quad (2)$$

where $F_{X^iY^jZ}$ is the target function of social efficiency at the i-th territorial level and the j-th level of system scaling; $I_{e.e}$, $I_{e.i}$, I_s is indicators of energy efficiency, environmental impact and safety of the charging infrastructure, respectively; α, β and γ are the weighting coefficients of the corresponding partial indicators of social efficiency.

In work [1], only a consolidated algorithm for optimizing the system of charging stations based on social efficiency indicators is given.

In order to assess the impact of the essential properties of the charging station system on its social efficiency indicators and determine the weighting factors of these indicators, it is necessary to build appropriate regression models. The basis for such models are the results of morphological analysis of the system. The system of charging stations consists of four functional elements: "Enterprise" that provides charging infrastructure services; "Electric vehicle (EV)"; "Transport flow" around the charging infrastructure; "Environment". Morphological characteristics of the functional elements "Transport flow" and "Environment", as well as their implementation options are presented in the paper [18]. The morphological structure of the functional elements "Car service enterprise" and "Vehicle", proposed in works [4, 18], does not take into account the specifics of the functioning of the charging infrastructure. The functional elements "Enterprise" and "EV" defined on their basis were introduced into the morphological model of the charging station system. The corresponding fragment of the developed morphological matrix of the system is shown in fig. 2.

Enterprise					Electric vehicle				
1. Number of charge points	2. Charging speed	3. Connectors types	4. Power Output Level	5. Digitalization level	6. Vehicle category	7. Vehicle age, years	8. Technology level	9. Battery capacity, kWh	10. Range, km
1.1. 1-2	2.1. Level 1 Charging	3.1. Type 1 J1772	4.1. Low	5.1. Very low	6.1. M1	7.1. Up to 5	8.1. Very low	9.1. 20-30	10.1. Up to 200
1.2. 3-4	2.2. Level 2 Charging	3.2. Type 2 Mennekes	4.2. Middle	5.2. Low	6.2. M2	7.2. 5-10	8.2. Low	9.2. 30-40	10.2. 200-300
1.3. 5-6	2.3. DC Fast Charging	3.3. Type 1 CCS Combo 1	4.3. High	5.3. Middle	6.3. M3	7.3. 10-15	8.3. Middle	9.3. 40-50	10.3. 300-400
1.4. 7-8	2.4. Combined speed	3.4. Type 2 CCS Combo 2		5.4. High	6.4. N1	7.4. 15-20	8.4. High	9.4. 50-60	10.4. 400-500
1.5. 9-10		3.5. CHAdeMO		5.5. Very high	6.5. N2	7.5. More than 20	8.5. Very high	9.5. 60-70	10.5. 500-600
1.6. >10		3.6. GB/T			6.6. N3			9.6. 70-80	10.6. More than 600
		3.7. Tesla Super-charger						9.7. 80-90	
		3.8. Combined charging						9.8. More than 90	

Fig. 2. Attributes and options for implementation of functional elements "Enterprise" and "Electric vehicle"

The digitization level of the charging station depends on the availability of various payment methods (credit/debit cards, mobile applications) and subscription services, user interface; possibilities of real-time monitoring, conducting remote diagnostics; the presence of intelligent functions (planning, load management and integration with home energy systems). The technology level is determined by technological functions: connectivity options, driver-assistance systems, smart energy management systems, and others.

The morphological model and experimental values of the target indicator of social efficiency are the basis for determining its model values for the purpose of evaluation or forecasting. Experimental values of the partial energy efficiency indicator $I_{e.e}$ can be obtained by "white box" models based on the models used in [8, 19]. The environmental impact indicator $I_{e.i}$ takes into account the presence of renewable energy sources (such as solar panels) to power the charging process, which contributes to the sustainable development of the region. It is advisable to determine the social security indicator I_s based on the principles stated in [20]. In addition, charging stations must provide safety features such as overcurrent protection, ground fault protection, and emergency shutdown mechanisms.

Performance indicators for the three target groups are not independent and require consistency in the system management process. The described results made it possible to form a complex methodology for managing the development of the charging station system, the algorithm of which is presented in fig. 3.

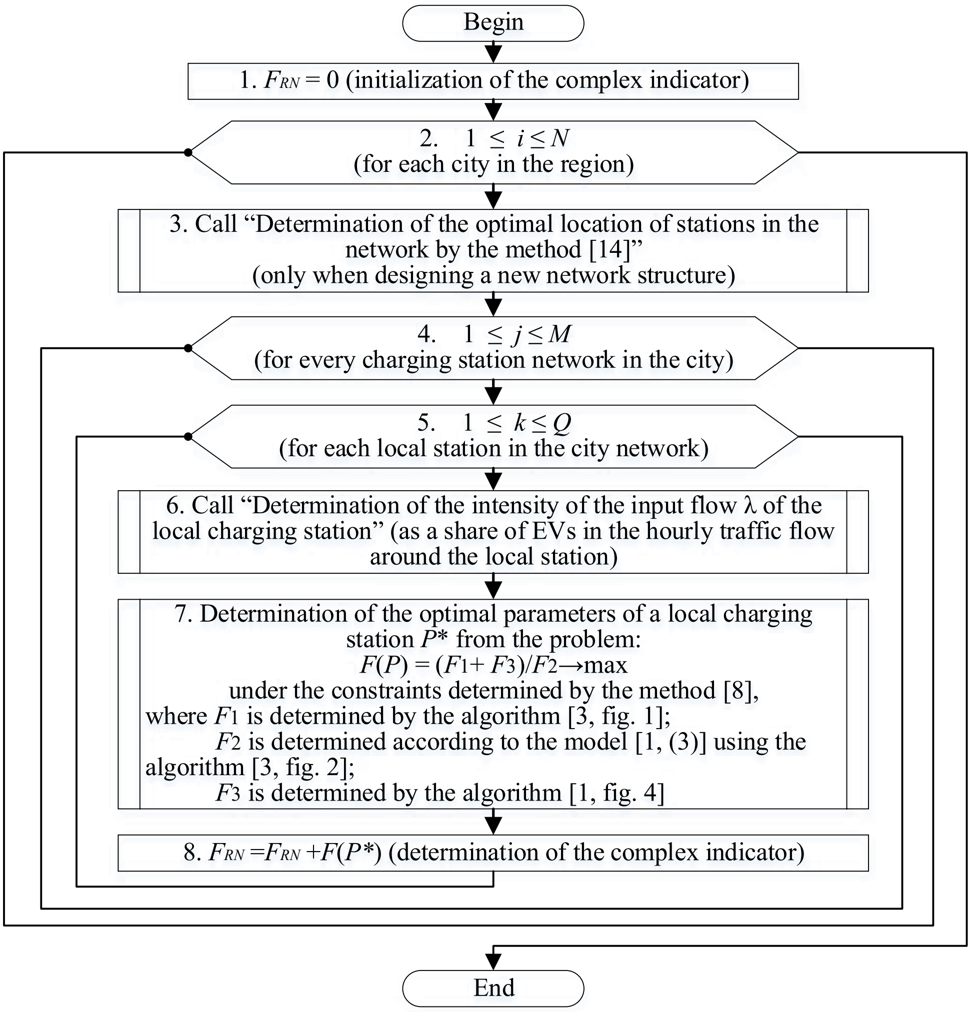

Fig. 3. System management algorithm for charging infrastructure development

Conclusions

Based on the analysis of the latest research on the management of the charging infrastructure, a set of target performance indicators of the charging station system and its morphological model, consisting of four functional elements: enterprise, electric vehicle, transport flow and environment, have been developed. The specified morphological model and set of indicators are scientifically based, as they are based on adequate models of the energy efficiency of electric vehicles, models of the theory of mass service systems, and models of the efficiency of a car service. The proposed comprehensive methodology for managing the development of the charging infrastructure combines three different options for presenting the system, which makes it possible to take into account the maximum number of factors that affect its efficiency. The proposed methodology can be used in the algorithms of smart management systems of the network of charging stations and modules of intelligent transport systems to assess the impact of the charging infrastructure on the operational efficiency of electric transport.

Bibliography

1. Smieszek M., Kostian N., Khrutba V., Mateichyk P., Mosciszewski J. A Multi-Level Approach to the Target Development of the Electric Vehicle Charging Stations Network. *Transportation Research Procedia*. 2023. Vol. 74. P. 1187-1194. URL: https://doi.org/10.1016/j.trpro.2023.11.260 (date of access: 10.09.2024).

2. Ren H., Zhang A., Wang F., Yan X., Li Y., Duić N., Shafie–khah M., Catalao J.P. Optimal scheduling of an EV aggregator for demand response considering triple level benefits of three-parties. *International Journal of Electrical Power & Energy Systems*. 2021. Vol. 125. 106447. URL: https://doi.org/10.1016/j.ijepes.2020.106447 (date of access: 10.09.2024).

3. Kostian N., Smieszek M., Mateichyk P. Coordination of optimisation targets at different levels of charging infrastructure development management. *Research Journal*. 2023. Vol. 30, no. 4 – part II. P. 153-162. URL: https://doi.org/10.7862/rz.2023.hss.69 (date of access: 10.09.2024).

4. Tarandushka L., Mateichyk V., Kostian N., Tarandushka I., Rud M. Assessing the quality level of technological processes at car service enterprises. *Eastern-European Journal of Enterprise Technologies*. 2020. Vol. 2, no. 3 (104). P. 58-75. URL: https://doi.org/10.15587/1729-4061.2020.200332 (date of access: 10.09.2024).

5. Андрусенко С.І., Бугайчук О.С. Моделювання бізнес-процесів підприємства автосервісу : монографія. К. : Кафедра, 2014. 328 с.

6. Марков О.Д., Ковальов А.В., Скиба А.П., Приз О.О. Оптимізація виробничої структури автосервісу. *Вісник Національного транспортного університету. Серія «Технічні науки»*. К. : НТУ, 2016. Вип. 1 (34). С. 247-254.

7. Марков О.Д., Гульчак О.Д., Точигін М.О. Логістика в системах автосервісу. *Міжнародний науковий журнал «Інтернаука»*. 2022. № 9. С. 23-32. URL: https://doi.org/10.25313/2520-2057-2022-9 (дата звернення: 14.09.2024).

8. Йовченко А.В. Дослідження можливості енергосистеми України в забезпеченні обслуговування парку електромобілів. *Вісник ХНТУ*. 2024. № 2(89). С. 27-31. URL: https://doi.org/10.35546/kntu2078-4481.2024.2.3 (дата звернення: 14.09.2024).

9. Любий Є.В., Ларін Д.О. Підхід щодо формування мережі зарядних станцій електромобілів у напрямку Харків-Бердянськ. *Системи управління, навігації та зв'язку*. 2020. Вип. 2(60), С. 44-50. URL: https://doi.org/10.26906/SUNZ.2020.2.044 (дата звернення: 14.09.2024).

10. Zhenzhao Li. Research on the distribution of electric vehicle charging station. *4th international conference on energy science and applied technology,* AIP Conference Proceedings, Chongqing City, China, 29 January 2019. Vol. 2066(1). 020021. URL: https://doi.org/10.1063/1.5089063 (date of access: 15.09.2024).

11. Anbang Zuo. Prediction and Distribution of Ev Charging Stations. *4th international conference on energy science and applied technology,* AIP Conference Proceedings, Chongqing City, China, 29 January 2019. Vol. 2066(1). 020048. URL: https://doi.org/10.1063/1.5089090 (date of access: 15.09.2024).

12. Shengcan Yu. The planning system of charging network. *4th international conference on energy science and applied technology,* AIP Conference Proceedings, Chongqing City, China, 29 January 2019. Vol. 2066(1), 020041. URL: https://doi.org/10.1063/1.5089083 (date of access: 15.09.2024).

13. Gavranovic H., Barut A., Ertek G., et al. Optimizing the Electric Charge Station Network of ESARJ. *Procedia Computer Science*. 2014. Vol. 31, P. 15-21. URL: https://doi.org/10.1016/j.procs.2014.05.240 (date of access: 15.09.2024).

14. Тарандушка Л.А., Костьян Н.Л., Тарандушка І.П., Курко С.С., Клімов Е.С., Мельниченко М.В. Методика визначення та розташування оптимальної кількості зарядних станцій для електротранспорту в населеному пункті. *Центральноукраїнський науковий вісник. Технічні науки : зб. наук. пр.* Кропивницький : ЦНТУ, 2022. Вип. 6(37). – Ч. 2. С. 57-67. URL: https://doi.org/10.32515/2664-262X.2022.6(37).2.57-67 (дата звернення: 15.09.2024).

15. Thingvad A., Andersen P.B., Unterluggauer T., Træholt C., Marinelli M. Electrification of personal vehicle travels in cities – Quantifying the public charging demand. *eTransportation*. 2021. Vol. 9. 100125. URL: https://doi.org/10.1016/j.etran.2021.100125 (date of access: 15.09.2024).

16. Unterluggauer T., Rich J., Andersen P.B., Hashemi S. Electric vehicle charging infrastructure planning for integrated transportation and power distribution networks: A review. *eTransportation*. 2022. Vol. 12. 100163. URL: https://doi.org/10.1016/j.etran.2022.100163 (date of access: 15.09.2024).

17. Hisatomo Hanabusa, Ryota Horiguchi. A Study of the Analytical Method for the Location. Planning of Charging Stations for Electric Vehicles. *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems. KES 2011: Knowledge-Based and Intelligent Information and Engineering Systems* / Springer-Verlag Berlin Heidelberg, 2011. P. 596-605. URL: https://doi.org/10.1007/978-3-642-23854-3_63 (date of access: 15.09.2024).

18. Smieszek M., Kostian N., Mateichyk V., Mosciszewski J., Tarandushka L. Determination of the Model Basis for Assessing the Vehicle Energy Efficiency in Urban Traffic. *Energies*. 2021. Vol. 14(24), 8538. URL: https://doi.org/10.3390/en14248538 (date of access: 15.09.2024).

19. Rigas E.S., Ramchurn S.D., Bassiliades N. Algorithms for electric vehicle scheduling in large-scale mobility-on-demand schemes. *Artificial Intelligence*. 2018. Vol. 262 P. 248-278. URL: https://doi.org/10.1016/j.artint.2018.06.006 (date of access: 15.09.2024).

20. Paramud Y., Rak T., Torskyi M. Principles of monitoring and control of the charging stations network for electric vehicles. *CSN*. 2020. Vol. 2, no. 1. P. 59-67. URL: https://doi.org/10.23939/csn2020.01.059 (date of access: 15.09.2024).

References

1. Smieszek, M., Kostian, N., Khrutba, V., Mateichyk, P., Mosciszewski, J. (2023) A Multi-Level Approach to the Target Development of the Electric Vehicle Charging Stations Network. *Transportation Research Procedia*, 74. pp. 1187–1194. https://doi.org/10.1016/j.trpro.2023.11.260

2. Ren H., Zhang A., Wang F., Yan X., Li Y., Duic N., Shafie-khah M., Catalao J.P. (2021) Optimal scheduling of an EV aggregator for demand response considering triple level benefits of three-parties. *International Journal of Electrical Power & Energy Systems*, 125, 106447. https://doi.org/10.1016/j.ijepes.2020.106447

3. Kostian N., Smieszek M., Mateichyk P. (2023) Coordination of optimisation targets at different levels of charging infrastructure development management. *Research Journal*, 30, No. 4, part II, pp. 153-162. https://doi.org/10.7862/rz.2023.hss.69

4. Tarandushka L., Mateichyk V., Kostian N., Tarandushka I., Rud M. (2020) Assessing the quality level of technological processes at car service enterprises. *Eastern-European Journal of Enterprise Technologies*, 2, pp. 58–75, https://doi.org/15587/1729-4061.2020.200332

5. Andrusenko S. I., Buhaichuk O. S. (2014) Modeliuvannia biznes–protsesiv pidpryiemstva avtoservisu: monohrafiia [Simulation of Business Processes at autoservice enterprises: Monograph]. K.: Kafedra, 328 p. [in Ukrainian].

6. Markov O.D., Kovalev A.V., Skyba A.P., Pryz O.O. (2016) Optymizatsiia vyrobnychoi struktury avtoservisu. [Optimization of industrial structure Car]. *Visnyk National Transport University. Scientific and Technical Collection*, Kyiv: National Transport University, Issue 1 (34). pp. 247-254. [in Ukrainian].

7. Markov O.D., Hulchak O.D., Tochyhin M.O. (2022) Lohistyka v systemakh avtoservisu. [Logistics in car service systems]. *International scientific journal «Internauka»*, № 9, pp. 23-32. [in Ukrainian]. https://doi.org/10.25313/2520-2057-2022-9

8. Yovchenko A.V. (2024) Doslidzhennia mozhlyvosti enerhosystemy Ukrainy v zabezpechenni obsluhovuvannia parku elektromobiliv. [Study of the possibility of the energy system of Ukraine in providing service to the fleet of electric vehicles]. *Visnyk of Kherson National Technical University*, № 2(89), pp. 27-31. [in Ukrainian]. https://doi.org/10.35546/kntu2078-4481.2024.2.3

9. Liubyi, Ye., Larin, D. (2020) Pidkhid shchodo formuvannia merezhi zariadnykh stantsii elektromobiliv u napriamku Kharkiv-Berdiansk. [An Approach to Forming of Electromobiles Charging Stations Network in the Kharkiv-Berdyansk Direction]. *Control, Navigation and Communication Systems*, 2(60), pp. 44-50. [in Ukrainian]. https://doi.org/10.26906/SUNZ.2020.2.044

10. Zhenzhao Li. (2019) Research on the distribution of electric vehicle charging station. 4th international conference on energy science and applied technology. Chongqing City, China, *AIP Conference Proceedings*, 2066, 020021. https://doi.org/10.1063/1.5089063

11. Anbang Zuo. (2019) Prediction and Distribution of Ev Charging Stations. 4th international conference on energy science and applied technology. Chongqing City, China, *AIP Conference Proceedings*, 2066, 020048. https://doi.org/10.1063/1.5089090

12. Shengcan Yu. (2019) The planning system of charging network. 4th international conference on energy science and applied technology. Chongqing City, China, *AIP Conference Proceedings*, 2066, 020041. https://doi.org/10.1063/1.5089083

13. Gavranovic H., Barut A., Ertek G., et al. (2014) Optimizing the Electric Charge Station Network of ESARJ. *Procedia Computer Science*, 31, pp. 15-21. https://doi.org/10.1016/j.procs.2014.05.240

14. Tarandushka L., Kostian N., Tarandushka I., Kurko S., Klimov E., Melnychenko M. (2022) Metodyka vyznachennia ta roztashuvannia optymalnoi kilkosti zariadnykh stantsii dlia elektrotransportu v naselenomu punkti. [Method of Determining and Locating the Optimal Number of Charging Stations for Electric Transportation in Settlement]. *Central Ukrainian Scientific Bulletin. Technical Sciences*, Kropyvnytskyi: Central Ukrainian National Technical University, Issue 6(37), part II, pp. 57-67. [in Ukrainian]. https://doi.org/10.32515/2664-262X.2022.6(37).2.57-67

15. Thingvad A., Andersen P.B., Unterluggauer T., Træholt C., Marinelli M. (2021) Electrification of personal vehicle travels in cities – Quantifying the public charging demand. *eTransportation*, Volume 9, 100125, https://doi.org/10.1016/j.etran.2021.100125

16. Unterluggauer T., Rich J., Andersen P.B., Hashemi S. (2022) Electric vehicle charging infrastructure planning for integrated transportation and power distribution networks: A review. *eTransportation*, Volume 12, 100163, https://doi.org/10.1016/j.etran.2022.100163

17. Hisatomo Hanabusa, Ryota Horiguchi. (2011) A Study of the Analytical Method for the Location. Planning of Charging Stations for Electric Vehicles. International Conference on Knowledge-Based and Intelligent Information and Engineering Systems. KES 2011: Knowledge-Based and Intelligent Information and Engineering Systems, 596–605. https://doi.org/10.1007/978-3-642-23854-3_63

18. Smieszek M., Kostian N., Mateichyk V., Mosciszewski J., Tarandushka L. (2021) Determination of the Model Basis for Assessing the Vehicle Energy Efficiency in Urban Traffic. *Energies*, 14(24), 8538. https://doi.org/10.3390/en14248538

19. Rigas E.S., Ramchurn S.D., Bassiliades N. (2018) Algorithms for electric vehicle scheduling in large-scale mobility-on-demand schemes. *Artificial Intelligence*, 262, pp. 248-278. https://doi.org/10.1016/j.artint.2018.06.006

20. Paramud Y., Rak T., Torskyi M. (2020) Principles of monitoring and control of the charging stations network for electric vehicles. *CSN*, Volume 2, Number 1, pp. 59-67. https://doi.org/10.23939/csn2020.01.059