Original Study Article
DOI: https://doi.org/10.17816/2074-0530-629143 EDN: WULWVI

Developing a Hybrid Wireless Power Transfer System for Electric Vehicles

Egor M. Klimov[1], Anatoly M. Fironov[1], Ruslan A. Maleev[1], Sergey M. Zuev[2,3]

[1] Moscow Polytechnic University, Moscow, Russia;
[2] MIREA-Russian Technological University, Moscow, Russia;
[3] Central Research Automobile and Automotive Engines Institute NAMI, Moscow, Russia

ABSTRACT

BACKGROUND: Today, automotive research organizations worldwide are actively developing wireless power transfer systems for electric vehicles. The key advantage of such systems is their ability to resupply power on board the moving vehicle without using a contact slider.

AIM: This study aims to increase the energy efficiency of electric vehicles by using a hybrid wireless power transfer system.

MATERIALS AND METHODS: The study used a mathematical model of urban driving cycle as provided by UNECE Regulation No. 83.

RESULTS: We developed a structural diagram of a hybrid wireless power transfer system and determined its operational algorithm for the urban driving cycle. The author reviewed and analyzed the relative contemporary research and development and various wireless power transfer systems for electric vehicles. The target of this study is a magnetic coupling resonant wireless power transfer system with one primary coil for power transfer and a battery of supercapacitors for accumulation.

CONCLUSION: Automotive companies and research institutes may use the proposed traction voltage system and its operational algorithm to design urban passenger vehicles.

Keywords: electric vehicle; traction voltage system; capacitive storage; wireless power transfer system.

To cite this article:
Klimov EM, Fironov AM, Maleev RA, Zuev SM. Developing a Hybrid Wireless Power Transfer System for Electric Vehicles. *Izvestiya MGTU «MAMI»*. 2025;19(1):401–409. DOI: 10.17816/2074-0530-629143 EDN: WULWVI

Submitted: 13.06.2024 **Accepted:** 26.07.2025 **Published online:** 26.07.2025

Оригинальное исследование

DOI: https://doi.org/10.17816/2074-0530-629143 EDN: WULWVI

Разработка ёмкостно-индуктивной системы электроснабжения электромобиля

Е.М. Климов[1], М.А. Фиронов[1], Р.А. Малеев[1], С.М. Зуев[2,3]

[1] Московский политехнический университет, Москва, Россия;
[2] МИРЭА — Российский технологический университет, Москва, Россия;
[3] Центральный научно-исследовательский автомобильный и автомоторный институт «НАМИ», Москва, Россия

АННОТАЦИЯ

Обоснование. В настоящее время автомобильные научно-исследовательские организации по всему миру ведут активные разработки в области бесконтактного электроснабжения электромобилей. Основным преимуществом таких систем является возможность пополнения запасов энергии на борту транспортного средства в процессе его движения без использования скользящего контакта.

Цель работы — повышение энергоэффективности электромобиля путём применения ёмкостно-индуктивной системы электроснабжения.

Материалы и методы. При проведении исследований была использована математическая модель городского цикла движения согласно Правилам № 83 ЕЭК ООН.

Результаты. Разработана структурная схема ёмкостно-индуктивной системы электроснабжения, и определён алгоритм её работы в городском цикле. Проведены обзор и анализ современных научно-исследовательских и опытно-конструкторских разработок по теме работы, а также различных систем бесконтактного электроснабжения электромобилей. В качестве объекта исследования выбрана резонансная система бесконтактного электроснабжения с одной первичной обмоткой как способ передачи энергии и батарея ионисторов как способ накопления.

Заключение. Предложенная система тягового электрооборудования и алгоритм её работы могут быть использованы автомобильными предприятиями и НИИ для конструирования городских пассажирских транспортных средств.

Ключевые слова: электромобиль; система тягового электрооборудования; ёмкостный накопитель энергии; бесконтактное электроснабжение.

Как цитировать:
Климов Е.М., Фиронов М.А., Малеев Р.А., Зуев С.М. Разработка ёмкостно-индуктивной системы электроснабжения электромобиля // Известия МГТУ «МАМИ». 2025. Т. 19, № 1. С. 401–409. DOI: 10.17816/2074-0530-629143 EDN: WULWVI

Рукопись получена: 13.06.2024 **Рукопись одобрена:** 26.07.2025 **Опубликована online:** 26.07.2025

INTRODUCTION

Analysis of storages for contemporary electric vehicles has identified the main disadvantages of batteries, including low energy density, power, and performance with increased current and low ambient temperature [1]. As a result, the electric vehicle has a range several times less than that of a similar wheeled vehicle with an internal combustion engine. In addition, the charging time of a traction battery is several hours, while it takes about a minute to fill the fuel tank of a passenger car. In the premises, the problem of developing an alternative traction voltage system is highly relevant.

A system of wireless power transfer to an electric vehicle could be a promising solution. Table 1 summarizes research and development related to wireless power transfer systems for electric vehicles [2–11].

MAGNETIC COUPLING RESONANT WIRELESS POWER TRANSFER SYSTEM WITH ONE PRIMARY COIL

Fig. 1 shows the circuit of an electric vehicle's wireless power transfer system with one primary coil [1].

To compensate for reactive power, capacitors C_p and C_s and inductors L_s are used in the circuit. The primary coil L_1 is installed under the road surface and has inductive coupling with the secondary coil L_2 installed in the electric vehicle. The voltage to the primary winding is applied from the power source U1. The output voltage is converted by a single-phase full-wave rectifier to charge the traction battery.

The highest system efficiency is achieved by transferring power at the resonant frequency:

$$\omega_D = \frac{1}{\sqrt{L_{1s}C_{1p}}} = \frac{1}{\sqrt{L_{2s}C_{2p}}}. \qquad (1)$$

Inductivity of compensating coils are determined based on the inductivity of primary and secondary coils [12]:

$$L_{1s} = \alpha_1 L_1; \quad L_{2s} = \alpha_2 L_2, \qquad (2)$$

where α is the design factor randomly selected in the range $0<\alpha\leq 1$.

Capacity of series capacitors:

$$C_{1s} = \frac{1}{\omega_d^2 L_1(1-\alpha_1)}, \; C_{2s} = \frac{1}{\omega_d^2 L_2(1-\alpha_2)}. \qquad (3)$$

The inverter output voltage characteristic:

$$U_1 = \frac{2\sqrt{2}}{\pi} U_{1,DC} \sin\left(\frac{\pi D}{2}\right), \qquad (4)$$

where D is the filling factor of the inverter.

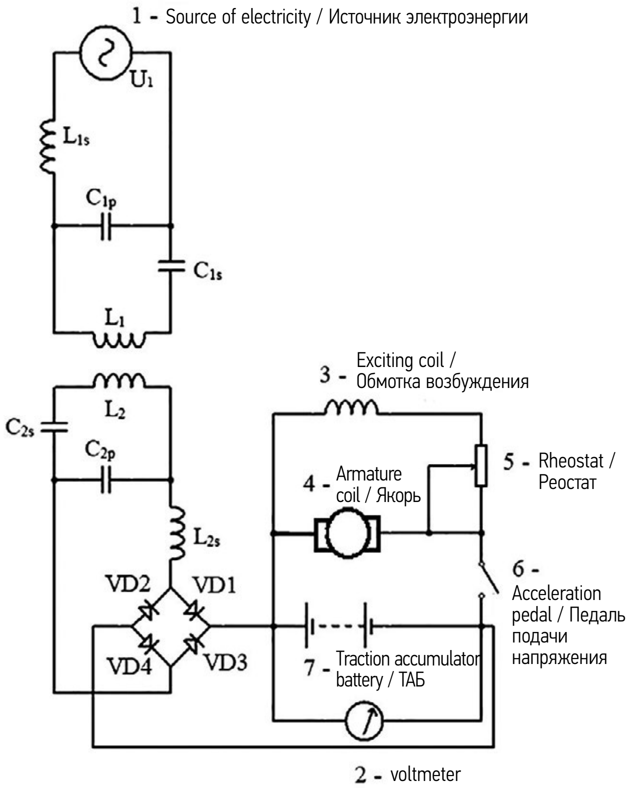

Fig. 1. Circuit diagram of an electric vehicle's wireless power transfer system with one primary coil.
Рис. 1. Электрическая схема системы бесконтактного электроснабжения электромобиля с одной первичной обмоткой.

Table 1. Some developments of wireless power transfer systems for electric vehicles
Табл. 1. Некоторые разработки в области бесконтактного электроснабжения электромобилей

R&D	Country	Year	Vehicle type	Power, kW	Efficiency, %	Frequency, Hz
Bombardier PRIMOVE	Canada	2018	Tram, electric bus	200	85	20
KAIST OLEV 4G	Republic of Korea	2015	Electric bus	100	80	20
Qualcomm FABRIC	USA	2017	Electric vehicle	20	85	85
ORNL	USA	2022	Tractor, electric bus, electric vehicle	200	85	85
Electreon	Israel	2023	Tractor, electric bus, electric vehicle	70	85	85
Toyota	Japan	2020	Electric bus, electric vehicle	10	85	85

The applicable rectifier input voltage is determined by formula (5):

$$U_2 = \frac{2\sqrt{2}}{\pi} U_{2,DC} \approx 0{,}9 U_{2,DC}. \quad (5)$$

Primary and secondary currents:

$$I_{L1} = \frac{U_1}{j\omega_d \alpha_1 L_1},\ I_{L2} = \frac{U_2}{j\omega_d \alpha_2 L_2}. \quad (6)$$

Inverter output current:

$$I_1 = \frac{MU_1}{\omega_d \alpha_1 L_1 \alpha_2 L_2}. \quad (7)$$

Rectifier output current:

$$I_2 = \frac{MU_2}{\omega_d \alpha_1 L_1 \alpha_2 L_2}. \quad (8)$$

Thus, the transferred power can be calculated as:

$$P_2 = \frac{MU_1 U_2}{\omega_d \alpha_1 L_1 \alpha_2 L_2}. \quad (9)$$

The main advantages of single primary coil systems are ease of control and high specific primary power. The disadvantages include low specific secondary power.

Fig. 2 shows the circuit of an electric vehicle's magnetic coupling resonant wireless power transfer system with multiple primary coils [1].

MAGNETIC COUPLING RESONANT WIRELESS POWER TRANSFER SYSTEMS WITH MULTIPLE PRIMARY COILS

In this system, inverters and compensators are connected in parallel, allowing to implement a system with multiple primary coils. Voltage is separately supplied to each coil. In all other respects, the design and the operating principle are similar to the system discussed above.

The output power:

$$P_2 = \left| \sum_{n=1;3;5...} \frac{M_{n2} U_n U_2}{\omega_d \alpha_1 L_1 \alpha_2 L_2} \right|. \quad (10)$$

Analyzing (10), we may conclude that the transferred power is determined as the modulus of the sum of powers of primary coils. Thus, turning on any primary coil does not necessarily lead to increased power in the secondary one as the magnetic induction vector may be directed against the main flux. In this case, the inverter controlling the negatively coupled coil must be switched off.

Fig. 3 shows the temporal variation curves of system efficiency [12]. The characteristic indicates that the system efficiency is very high (about 92%).

The main advantage of the system is its high efficiency. Disadvantages include a complex control system and low specific primary power.

ELECTRIC COUPLING WIRELESS POWER TRANSFER SYSTEM

The above-mentioned vehicle power transfer systems include the air-core transformer. Thus, their operation is based on Faraday's law of induction:

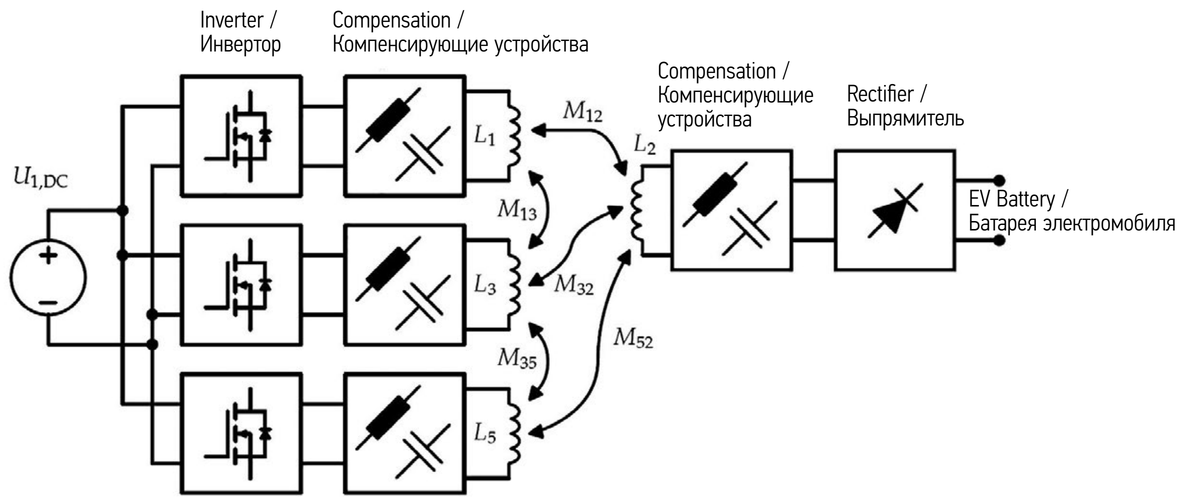

Fig. 2. Circuit diagram of an electric vehicle's magnetic coupling resonant power transfer system with multiple coils.
Рис. 2. Электрическая схема резонансной системы электроснабжения электромобиля с несколькими первичными обмотками.

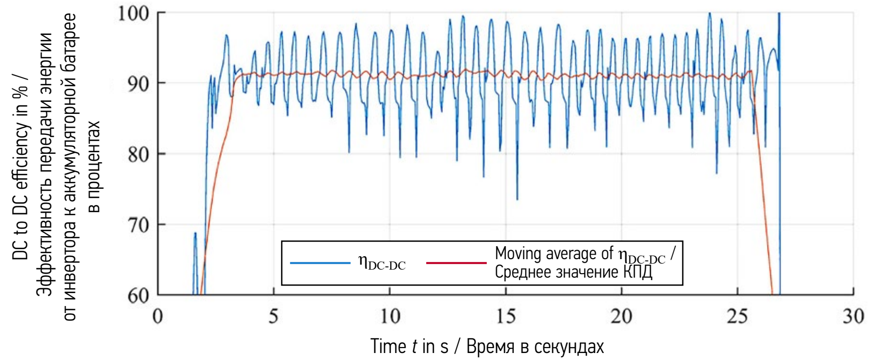

Fig. 3. Temporal variation curves of system efficiency: DC to DC efficiency (%) is the energy transfer efficiency from inverter to battery in percent; time *t*, (s) is the time in seconds; η_{DC-DC} is the efficiency; moving average of η_{DC-DC} is the average efficiency.
Рис. 3. Кривые изменения КПД системы во времени.

$$\varepsilon = w\frac{d\Phi}{dt}, \quad (11)$$

where w is the number of coil turns; Φ is the magnetic flux (Wb).

This section discusses power transfer using an air capacitor.

The electric coupling power transfer system [13] is shown in Fig. 4.

The power supply feeds a transformer connected to power supply cables. An electrostatic field is generated between them and the neutral plate of the capacitor. To match the input voltage and the charging voltage of the on-board storage, a switching converter is used.

Power transferred through the air capacitor to the vehicle:

$$P = 2K_0\pi f_0 CV^2, \quad (12)$$

where f_0 is the resonance frequency (Hz); C is the capacitance of the air capacitor (Ф); V is the line voltage (V); K_0 is the coupling factor.

Advantages:

- High efficiency;
- High controllability of the electric vehicle;
- Able to supply other vehicles, including those with dielectric propellers.

Disadvantages:

- Large dimensions;
- Low energy density;
- High power supply requirements.

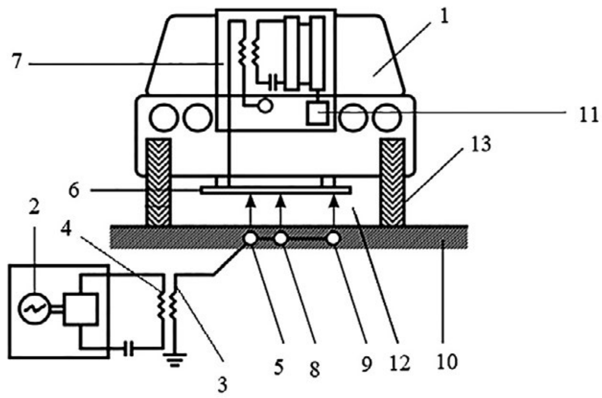

Fig. 4. Electric coupling power transfer system of an electric vehicle: *1*: aelectric vehicle; *2*: power supply; *3*: secondary coil of transformer; *4*: primary coil of transformer; *5, 8, 9*: power supply cables; *6*: neutral plate; *7*: switching converter; *10*: bearing surface; *11*: on-board energy storage; *12*: air gap; *13*: wheel.
Рис. 4. Устройство системы электроснабжения транспортного средства методом электростатической индукции: *1* — электромобиль; *2* — источник электроэнергии; *3* — вторичная обмотка трансформатора; *4* — первичная цепь трансформатора; *5, 8, 9* — сетевые кабели; *6* — нейтральная пластина; *7* — преобразовательно-коммутационная аппаратура; *10* — опорная поверхность; *11* — бортовой накопитель энергии; *12* — воздушный промежуток; *13* — колесо.

DEVELOPING A STRUCTURAL DIAGRAM OF A TRACTION VOLTAGE SYSTEM OF AN ELECTRIC VEHICLE WITH A HYBRID WIRELESS POWER TRANSFER SYSTEM

The review and analysis of various wireless power transfer systems and relative R&D showed multiple prospects for using inductive coupling systems with one primary coil. Their advantages include small dimensions, high energy density, possible use of power supplies with low parameters, ease of operation, and high efficiency.

Electric traction systems for vehicles have some advantages [14]. However, the specific energy of traction batteries does not exceed 576 J/g, which is about 100 times lower than that of gasoline or diesel fuel. In the premises, electric vehicles are equipped with batteries weighing about 30% of the vehicle's gross weight with the range equal to a similar vehicle [1]. On the contrary, electric vehicles are now mainly used in cities, where the driving cycle involves constant alternation of acceleration, steady movement, braking, and stopping.

The cycle provided by UNECE Regulation No. 83 [14] is taken as the fuel efficiency and exhaust toxicity test cycle. According to the rules, the cycle consists of two parts, namely urban and highway. The research and calculations will be based on the urban electric vehicle; thus, it is advisable to use the first part of the cycle only (Fig. 5). The total duration of the urban driving cycle is 195 s.

Let us analyze the urban driving cycle. The distance between stops is small (about 300–500 m) as there are multiple traffic obstacles, including traffic lights, pedestrian crossings, speed bumps, etc. In the premises, an electric vehicle requires a relatively small amount of power to cover the distance from stop to stop. However, frequent acceleration requires high power consumption. Overcoming the vehicle's inertia requires up to 80% of the storage capacity [1]. Therefore, power storages shall have a high specific power to have acceptable weight and dimensions.

It is a well-known fact that capacitive storages (CS) have high specific power, but relatively low energy density, while properties of chemical accumulators are exactly the opposite [1]. In addition, electric double layer capacitors offer simple design, ease of use, safety, environmental friendliness, and, most importantly, the ability to quickly accumulate and release stored energy. CS may be operated at low below-zero temperatures and withstand deep discharges, overcharges, and short circuits. In particular, molecular energy storages (MES) have more than 500,000 battery cycles, which is three orders of magnitude longer than that of batteries [15–18].

Fig. 6 shows a traction voltage system for an electric vehicle with a hybrid wireless power transfer system developed by the Trucks Laboratory (Land-Based Vehicles Department) of Moscow Polytechnic University.

The primary coil of the air-core transformer, to which the alternating supply voltage is applied, is located under the bearing surface. The primary current flow generates an alternating magnetic field that penetrates the turns of the secondary coil, which can be installed either inside the tires or at the bottom of the electric vehicle. In the secondary coil, a self-induction EMF is generated and supplied to the rectifier input. If the secondary coil is installed inside the buses, brushes and slip rings are used to supply the EMF. A single-phase full-wave rectifier is provided to convert alternating current to direct current and control the charging voltage of the capacitor. During acceleration or steady movement of the electric vehicle, the capacitor voltage is supplied to both the armature coil and the excitation coil of the traction motor. The DC motor torque is transferred to the drive wheel via the drive gear. During regenerative braking, the torque from the drive wheel is supplied to the DC machine using the above systems, and the DC machine is switched to the generator mode.

Fig. 7 shows the operational algorithm of the traction voltage system (TVS) in the urban driving cycle.

CONCLUSION

Thus, the study allowed to build a diagram of the traction voltage system of an electric vehicle with hybrid wireless power transfer system and its operational

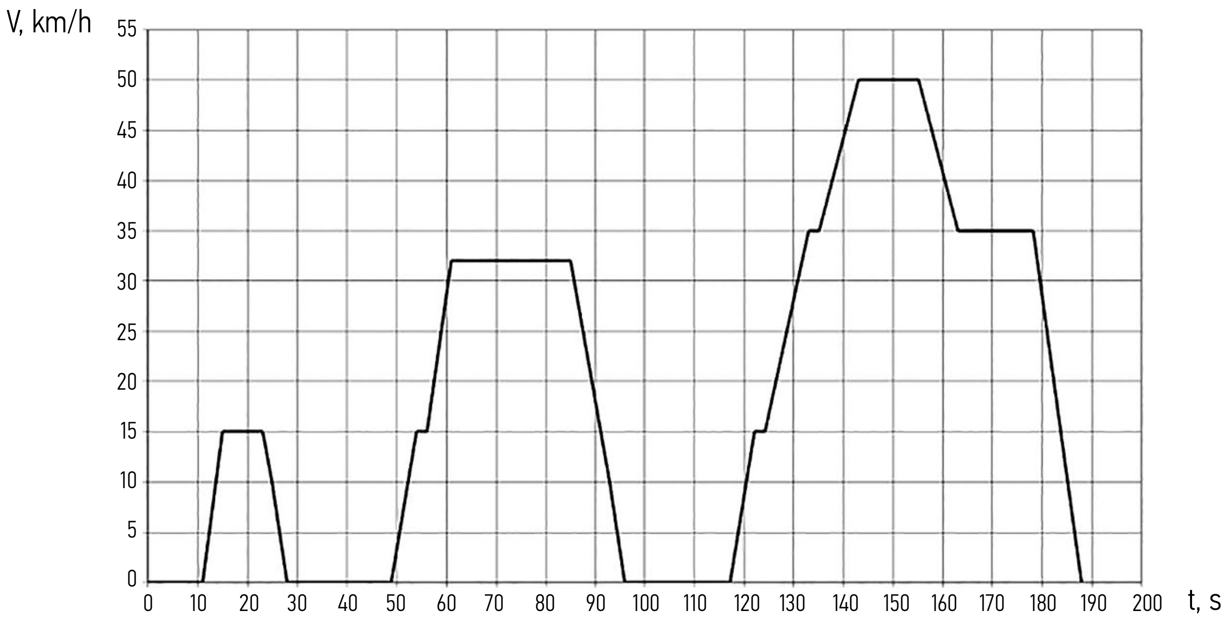

Fig. 5. Estimated urban driving cycle as provided by UNECE Regulation No. 83.
Рис. 5. Расчётный городской цикл движения согласно Правилам ЕЭК ООН № 83.

DOI: https://doi.org/10.17816/2074-0530-629143

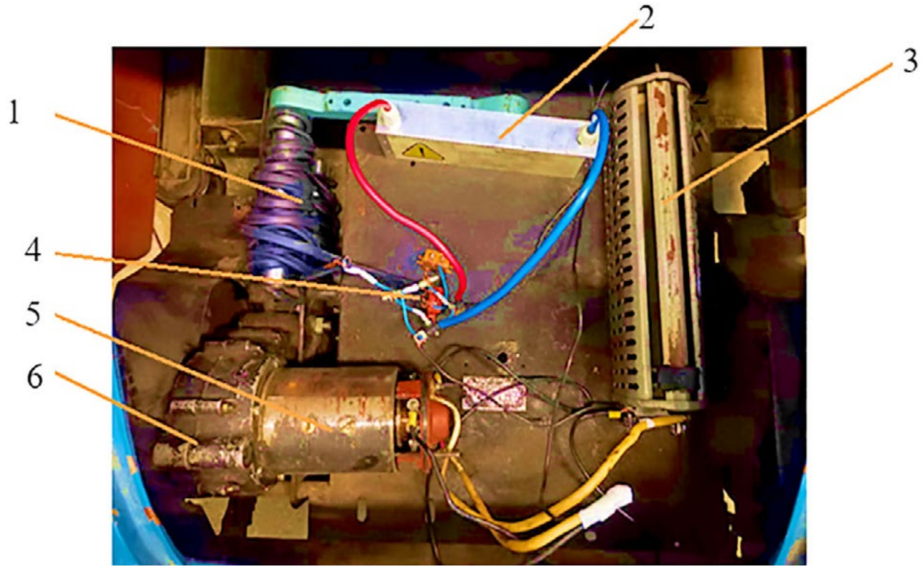

Fig. 6. The traction electric system of a prototype: *1*: secondary coil; *2*: capacitor; *3*: rheostat; *4*: rectifier; *5*: traction motor; *6*: axle drive.
Рис. 6. Система тягового электрооборудования ходового макета: *1* — вторичная обмотка; *2* — конденсаторная батарея; *3* — реостат; *4* — выпрямитель; *5* — тяговый электродвигатель; *6* — главная передача.

algorithm for the urban driving cycle based on UNECE Regulation No. 83.

This work will be continued in the form of the implementation of a mathematical model of the developed system. The introduction of traction electrical equipment system with inductive energy transfer and its capacitive storage will improve the energy efficiency of electric vehicles.

ADDITIONAL INFORMATION

Author contributions: E.M. Klimov: writing the text of the manuscript; A.M. Fironov: expert opinion, search for publications on the topic of the manuscript; R.A. Maleev: approval of the final version; S.M. Zuev: creation of images. All the authors approved the version of the manuscript to be published and agreed to be accountable for all aspects of the work, ensuring that issues related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

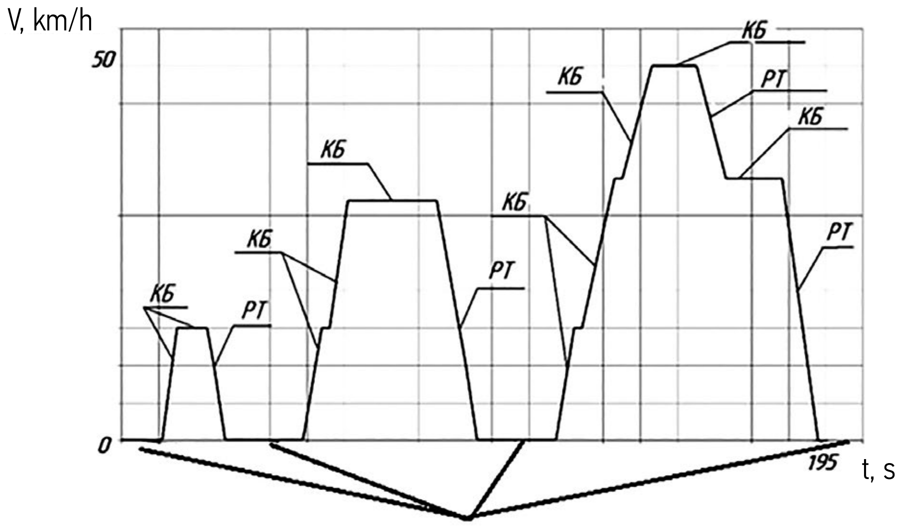

Fig. 7. Operational algorithm of the traction voltage system in the urban driving cycle: КБ: the capacitor is used for driving; РТ: regenerative braking.
Рис. 7. Алгоритм работы СТЭО в городском цикле движения: КБ — использование энергии конденсаторной батареи для движения; РТ — рекуперативное торможение.

Ethics approval: N/A.

Funding sources: No funding.

Disclosure of interests: The authors have no relationships, activities, or interests for the last three years related to for-profit or not-for-profit third parties whose interests may be affected by the content of the article.

Statement of originality: No previously obtained or published material (text, images, or data) was used in this study or article.

Data availability statement: The editorial policy regarding data sharing does not apply to this work as no new data was collected or created.

Generative AI: No generative artificial intelligence technologies were used to prepare this article.

Provenance and peer review: This paper was submitted unsolicited and reviewed following the standard procedure. The peer review involved two external reviewers, a member of the editorial board, and the in-house scientific editor.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. Е.М. Климов — написание текста рукописи; А.М. Фиронов — экспертная оценка, поиск публикаций по теме статьи; Р.А. Малеев — утверждение финальной версии; С.М. Зуев — создание изображений. Все авторы одобрили рукопись (версию для публикации), а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой её части.

Этическая экспертиза. Неприменимо.

Источники финансирования. Отсутствуют.

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.

Оригинальность. При создании настоящей работы авторы не использовали ранее опубликованные сведения (текст, иллюстрации, данные).

Доступ к данным. Редакционная политика в отношении совместного использования данных к настоящей работе не применима, новые данные не собирали и не создавали.

Генеративный искусственный интеллект. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовали.

Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

REFERENCES | СПИСОК ЛИТЕРАТУРЫ

1. Klimov EM, Fironov AM, Maleev RA, et al. Development of an algorithm for the operation of an electric vehicle electric drive in the urban cycle. *Izvestiya MGTU "MAMI"*. 2023;17(2):137–145. doi: 10.17816/2074-0530-321355 (In Russ.) EDN: ZMGPZP

2. Suul JA, Guidi G. Overview and Electro-Technical Evaluation of the State-of-the-Art for Conductive and Inductive Power Transfer Technologies. SINTEF Energy Research Report. 2018. Available online: https://www.sintef.no/globalassets/project/elingo/18-0733-rapport-3-technology-for-dynamic-on-road-6-til-nett.pdf (accessed 02.05.2023).

3. Bombardier's PRIMOVE E-buses Pass 500,000 km Milestone. Available online: https://bombardier.com/en/media/news/bombardiers-primove-e-buses-pass-500000-km-milestone (accessed 02.05.2023).

4. Thai VX, Choi SY, Choi BH, et al. Coreless power supply rails compatible with both stationary and dynamic charging of electric vehicles. In *Proceedings of the 2015 IEEE 2nd International Future Energy Electronics Conference (IFEEC).* Taipei. Taiwan. 2015:1–5. [CrossRef]

5. Choi SY, Rim CT. Recent progress in developments of on-line electric vehicles. In *Proceedings of the 2015 6th International Conference on Power Electronics Systems and Applications (PESA).* Hong Kong, China. 2015:1–8. [CrossRef]

6. From Wireless to Dynamic Electric Vehicle Charging: The Evolution of Qualcomm Halo. Available online: https://www.qualcomm.com/news/onq/2017/05/wireless-dynamic-ev-charging-evolution-qualcomm-halo (accessed on 2 May 02.05.2023).

7. Laporte S, Coquery G. Deniau V, et al. Dynamic Wireless Power Transfer Charging Infrastructure for Future EVs. Experimental Track to Real Circulated Roads Demonstrations. *World Electr. Veh. J.* 2019;(10):84. [CrossRef]

8. Galigekere V, Ozpineci B. High Power and Dynamic Wireless Charging of Electric Vehicles (EVs). In *Proceedings of the 2021 U.S DOE Vehicle Technologies Office Annual Merit Review.* 2021.

9. Xue L, Galigekere V, Su GJ, Zeng, et al. Design and Analysis of a 200 kW Dynamic Wireless Charging System for Electric Vehicles. In *Proceedings of the 2022 IEEE Applied Power Electronics Conference and Exposition (APEC).* Houston. USA. 2022:1096–1103. [CrossRef]

10. Wireless Charging Electric Road Projects | Electreon. Available online: https://electreon.com/projects (accessed on 2 May 02.05.2023).

11. Maemura M, Wendt A. Dynamic Power Transfer as a Feature—Employing Stationary WPT Devices for Dynamic Operation. In *Proceedings of the 2020 IEEE PELSWorkshop on Emerging Technologies: Wireless Power Transfer (WoW).* Seou. Republic of Korea. 2020:50–55. [CrossRef]

12. Noeren J, Parspour N, Elbracht L. An Easily Scalable Dynamic Wireless Power Transfer System for Electric Vehicles. *Energies.* 2023;(16):3936. doi: 10.3390/en16093936 EDN: HSOFOM

13. Strebkov DS. Resonance methods of power supply of contactless high-frequency electric transport. *Energy Bulletin.* 2018;(24). (In Russ.) EDN: VAIBWM

14. Polyakov NA. Dissertation for the degree of Candidate of Technical Sciences, Electric starter system for starting vehicles using a combined source of electrical energy. Moscow. 2005:22. (In Russ.) EDN: NNMYLV

15. Lavrikov AA, Maleev RA, Zuev SM, et al. Mathematical modeling of an adapter for equalizing battery voltages. *Bulletin of Moscow State Technical University "MAMI".* 2019;41(3):57–66. doi: 10.31992/2074-0530-2019-41-3-57-65 (In Russ.) EDN: JJQDIV

16. Zuev SM. Energy efficiency of electrical equipment systems of autonomous objects. Moscow. 2022:170. ISBN 978-5-16-017104-3 doi: 10.12737/1740252 (In Russ.) EDN: SDSSKE

17. Zuev SM, Varlamov D O, Lavrikov AA, et al. Electrical equipment and electronics of cars. A brief explanatory Russian-English terminological dictionary. Moscow. 2021:200. doi: 10.12737/1242228 (In Russ.) EDN: CKQFIL

18. Maleev RA, Zuev SM, Lavrikov AA, Grebenchikov NP. Study of operating modes of capacitive energy storage devices in automobile engine starting systems. *Bulletin of Moscow State Technical University MAMI.* 2019;39(1):29–35. doi: 10.31992/2074-0530-2019-39-1-29-35 (In Russ.) EDN: YZZSKL

AUTHORS' INFO

*** Egor M. Klimov,**
Lecturer at the Electrical Equipment and Industrial Electronics Department;
address: 38 Bolshaya Semyonovskaya st, Moscow, Russia, 107023;
ORCID: 0009-0004-9739-0267;
eLibrary SPIN: 2759-7425;
e-mail: klimov.mami@yandex.ru

Anatoly M. Fironov,
Cand. Sci. (Engineering), Assistant Professor,
Assistant Professor of the Land Vehicles Department;
ORCID: 0000-0003-2683-9958;
eLibrary SPIN: 8824-5702;
e-mail: a.m.fironov@mospolytech.ru

Ruslan A. Maleev,
Cand. Sci. (Engineering), Assistant Professor,
Professor of the Electrical Equipment and Industrial Electronics Department;
ORCID: 0000-0003-3430-6406;
eLibrary SPIN: 7801-3294;
e-mail: 19rusmal@gmail.com

Sergey M. Zuev,
Cand. Sci. (Physics and Mathematics), Assistant Professor,
Head of the Department for Training Highly Qualified Personnel and Continuing Professional Education; Assistant Professor of the Optical-Electronic Devices and Systems Department;
ORCID: 0000-0001-7033-1882;
eLibrary SPIN: 6602-6618;
e-mail: sergei_zuev@mail.ru

ОБ АВТОРАХ

*** Климов Егор Михайлович,**
преподаватель кафедры «Электрооборудование и промышленная электроника»;
адрес: Россия, 107023, Москва, ул. Большая Семеновская, д. 38;
ORCID: 0009-0004-9739-0267;
eLibrary SPIN: 2759-7425;
e-mail: klimov.mami@yandex.ru

Фиронов Анатолий Михайлович,
канд. техн. наук, доцент,
доцент кафедры «Наземные транспортные средства»;
ORCID: 0000-0003-2683-9958;
eLibrary SPIN: 8824-5702;
e-mail: a.m.fironov@mospolytech.ru

Малеев Руслан Алексеевич,
канд. техн. наук, доцент,
профессор кафедры «Электрооборудование и промышленная электроника»;
ORCID: 0000-0003-3430-6406;
eLibrary SPIN: 7801-3294;
e-mail: 19rusmal@gmail.com

Зуев Сергей Михайлович,
канд. физ.-мат. наук, доцент,
начальник управления подготовки кадров высшей квалификации и ДПО; доцент кафедры Оптико-электронных приборов и систем;
ORCID: 0000-0001-7033-1882;
eLibrary SPIN: 6602-6618;
e-mail: sergei_zuev@mail.ru

* Corresponding author / Автор, ответственный за переписку