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Studying the Patterns of the Urban Charging Infrastructure Operation for their Energy Supply from Renewable Sources

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ABSTRACT: A current area of the energy supply for urban infrastructure is the application of renewable energy sources. In 2019, the share of energy produced by them reached 11% (for solar energy) and 22% (forwind energy) of the energy produced during the year. However, these systems require an increase in efficiency that can be achieved by introducing electric vehicles. They can accumulate, store and transfer surplus energy to the city network. The solution to this problem is to organize as mart charging infrastructure. Existing studies in the field of charging infrastructure organization for electric vehicles consider only models to locate the charging stations in the city or the calculation of their required number. These calculations are based on socio-economic factors and images of the potential owner of an electric vehicle. Therefore, the aim of this study is to develop a methodology for determining the location of charging stations and their required number. The calculation will conclude the operating features of the existing charging infrastructure, which has not been implemented to date. Thus, the purpose of this article is to research the operation of the existing charging infrastructure. This will provide an opportunity to develop approaches to the energy supply of charging infrastructure and urban networks from renewable energy sources. The article presents an analysis of data on the number of charging sessions during the year, month and day. This data enable constructing curves of the charging session number and suggest ways to conduct the next stages of this study.

Keywords: chargers, charging sessions, city's electric network, electric vehicle, renewable energy source, public charging infrastructure

Abbreviations: IRENA, International Renewable Energy Agency, V2G, vehicle-to-grid.

I. INTRODUCTION

Renewable energy sources is an environmentally area for the development of energy supply facilities in cities [1-3]. In 2018, their share in the total amount of electricity generated reached 26% [4]. This value is the result of lower equipment costs and creating the stations from renewable energy sources. At the present time, wind and sun are the most developed types of renewables. In 2018, they produced more than 9% of the total amount of energy generated [4]. This value continues to grow. In 2019, it reached 11% and 22% of the total amount of energy generated per year for the sun and wind, respectively [5].

These technologies of the energy supply to the facilities in cities have some disadvantages, for example, the inconstancy of the generated energy. The solution to this problem is the introduction of rechargeable batteries in the energy supply system. However, the element of the system increases capital costs. According to IRENA, these elements may be electric vehicles in the future, as their number will increase to 160 million units by 2030 [6]. However, the implementation of this approach requires the development of smart charging infrastructure that provides energy to the electricity network of the city.

At present, the development of electric transport also requires creating the charging infrastructure [7, 8]. In 2018, the most developed charging infrastructure was located in the Netherlands [9]. Here, the number of charging stations per 100 km of roads was 19.3 units. In the world, the total number of charging stations exceeded 5 million units [9]. However, only 540,000 charging stations were public. Lack of a developed charging infrastructure can ensure this ratio of values, which is observed in the cities of the Russian Federation. In this case, the number of "sockets" organized by owners of electric vehicles increases. According to IRENA, further development of a self-organized charging infrastructure greatly increases the energy consumption during peak hours in the city's electric network [10]. Therefore, the creation of a public charging infrastructure is a prerequisite for the development of electric vehicles. Moreover, they can simultaneously be used as movable energy storage devices for organizing energy supply of city facilities from renewable sources.

At the present time, there are studies aimed at organization of the charging infrastructure [11-13]. The authors of these researches, as a rule, determine the location of the charging stations or calculate their required number. The development of a model to locate the charging stations is based on the distance to the electrical network or the walking distance of the charging station for electric vehicle drivers. The calculation of the required charging station number takes into account socio-economic factors and the image of the potential owner of an electric vehicle. In this case, the principles of the existing charging infrastructure operation, as a rule, are not considered. Although the authors of the studies aimed at designing auto service enterprises note the importance of this research stage [14-15]. It will reduce the capital costs of networking and operating costs for electric vehicle owners. Therefore, this study aims at developing a methodology for calculating the required number of charging stations for electric vehicles and their location in the city. It will be based not only on the image of a potential owner of electric vehicles, but also on the features of the existing charging infrastructure operation.

The purpose of this article is to study the existing charging infrastructure and assess the possibility of its energy supply from renewable energy sources.

II. LITERATURE REVIEW

Renewable energy sources considered in current research are a way to reduce the load on the city's electric network during peak hours [16]. Bernie (2009) proposed creating a charging station with the photovoltaic system for electric vehicles in car parking near workplaces [17]. In his opinion, this organization of charging infrastructure will decreases the peak load on the city's electric network in the evening. However, there are studies that consider the possibility of replenishing energy in a home electric network with photovoltaic panels. In this case, the authors analyze the balance of electric energy, as well as the technical characteristics of electric vehicles used to replenish energy in the network [18-20]. The results of these researches showed that the use of electric vehicles to replenish energy in home electric networks can reduce peak load by 37%.

The implementation of these methods requires creating intelligent control systems for the charging infrastructure, which is an area of future research [21]. The V2G system is a necessary element in the development of intelligent charging infrastructure, since it enables to coordinate the actions of electric vehicle owners as participants in the city's electric network. At the present time, researchers have established that uncontrolled charging of electric vehicles increases the energy losses and changes the peak load in the city electric network [22]. These problems are addressed by a strategy of managing the charging time of an electric vehicle. It enables reducing the cost of generating the necessary energy.

The influence of the charging infrastructure on the load of the city's electric network is changed by selecting the optimal type of stations (fast charging stations/battery exchange, home charging stations, public charging stations/workstations) [23]. However, this method is usually used only at the design stage. When charging infrastructure is operated, reducing the peak load in the electrical network is achieved by means of intelligent control systems. They take into account the periods preferred by owners of electric vehicles for charging [24].The time of connecting and disconnecting electric vehicles from charging stations is determined using sensors installed in vehicles or connection objects [25, 26]. These devices also provide a differential charge of batteries or transfer energy back to the city's electric network. In this case, rate regulation is implemented by modeling a multilayer market [27]. It includes aggregators (sellers and buyers of energy), owners of electric vehicles (sellers of energy aggregators) and elements of a smart city energy system (buyers of electricity). The results of this simulation show that the proposed approach increases the utility of electric vehicles in comparison with the classical method of their operation. Drude *et al.*, (2014) noted that the implementation of this approach requires strict regulation of rates [28]. Otherwise, electricity rater scan drastically reduce.

The development of these technologies is accompanied by the creation of chargers using renewable energy sources. Singh *et al.*, (2012) a device for introducing charging infrastructure into an intelligent network [29]. This device can satisfy various requirements of electric vehicle owners, as it changes the charging speed, battery status, and more. Gurkaynak and Khaligh (2009) proposed a sustainable system for charging an electric vehicle from a home electric network with photovoltaic panels [30]. However, an important stage in the creation of a charging station is also the development of basic physical and electrical requirements for publicly accessible charging stations powered by renewable energy sources [31]. They were derived from a comparative analysis of various mechanisms for converting energy from renewable sources.

Integration of renewable energy sources into the charging infrastructure helps to reduce the peak load in the city's electric network and increase the profitability of charging stations. The introduction of photovoltaic panels and a wind generator into a fast charging station enabled reducing the capital cost of installing the stations [32]. The development of such technologies increases the involvement of various energy companies in the creation of charging infrastructure [33, 34].

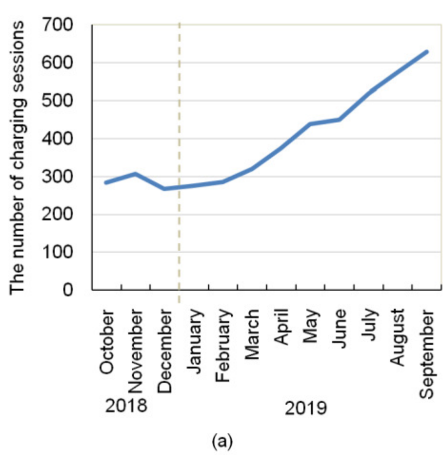
An important condition for designing a network of charging stations is to determine their optimal position in the city and the required number. The location of charging stations with renewable energy sources, as a rule, is based on minimizing energy losses and voltage deviations in the distribution network [35, 36]. The calculation of the charging station number is based on the theory of queuing systems and simulation of the features of their functioning [37, 38]. However, until now, researchers in the field of charging infrastructure organization have not developed comprehensive methods for calculating the parameters of the charging infrastructure for energy supply from renewable energy sources. They did not consider the features of the existing network of charging stations. But this approach enable reducing capital costs for owners of infrastructure and operating costs for owners of electric vehicles. Moreover, the obtained patterns contribute to assessing the possibility of energy supply of the existing charging infrastructure from renewable energy sources, which will expand the previous research results of the authors [1].

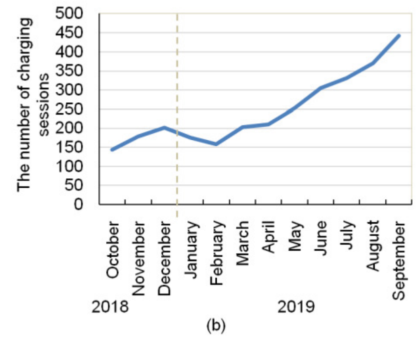
III. RESEARCH METHODOLOGY

The charging infrastructure is described using data on the number of charging sessions. They were measured during the year at different times of the day in the three cities of the Russian Federation that had the largest number of charging stations as of July 1, 2019. These were Moscow, St. Petersburg and Tyumen.
The source data for the analysis are:
— the number of charging sessions performed by a set of charging stations during the day;
— the number of electric vehicles using public charging infrastructure;
— the number of charging stations in the city;
— time of day at which the charging session is performed.
Data was obtained using Plug Share. Their processing and analysis were performed in Microsoft Excel.
The results of the study were:
— the curves of the charging session number performed by public charging stations during the day, in different months of the year;
— the curves of the electric vehicle number charged from the public charging infrastructure in different months;
— the curves of the charging session number of one electric vehicle during the month;
— the utilization rate curve of a public charging station during the day.
The results enable developing an approach to the selection of renewable energy sources for energy supply of the public charging infrastructure.

IV. RESULTS AND DISCUSSION

The number of charging sessions performed by public charging stations during the day is stochastic. This statement is consistent with the views of Li R. and Liu X. [38, 39]. However, they did not consider the features of charging infrastructure operation. The approach is proposed to study charging infrastructure in the field of urban passenger public transport [40-42].





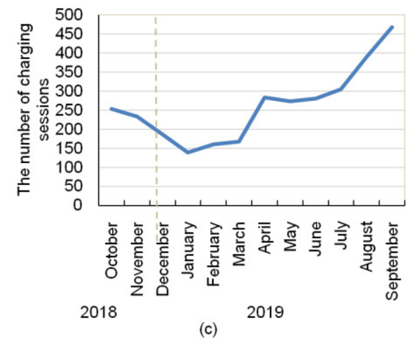
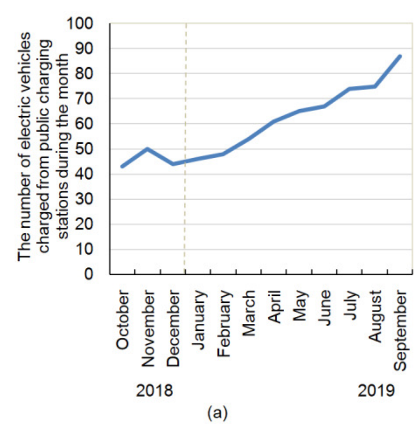


Fig. 1. Curves of the charging session number performed by the public charging infrastructure during the year in: (a) Moscow, (b) St. Petersburg, (c) Tyumen.

The number of charging sessions in each month was determined using the mathematical expectation of the constructed distribution function [37]. The results are presented by curves that reflect the change in the number of charging sessions in different cities. They are shown in Fig. 1.
The data analysis showed that as the ambient temperature observed in Tyumen in the winter decreases, the number of charging sessions performed by the public charging infrastructure also decreases. The authors hypothesized that air temperature affects the number of electric vehicles in operation.
However, the analysis of previously research [40, 43, 44] in the field of organizing the charging infrastructure do not confirm this hypothesis, as well as the curves shown in Fig. 2 do not confirm this hypothesis.



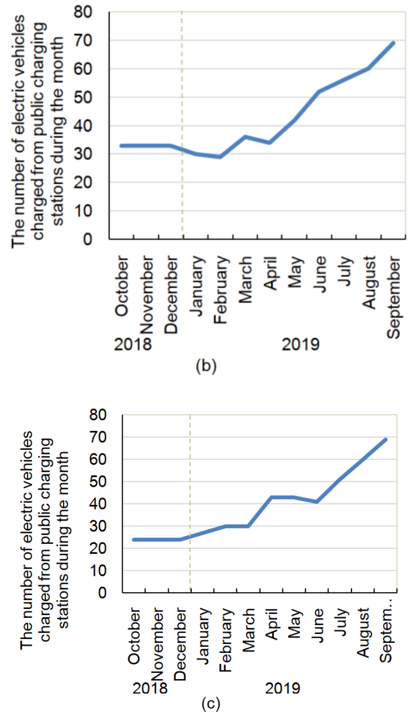
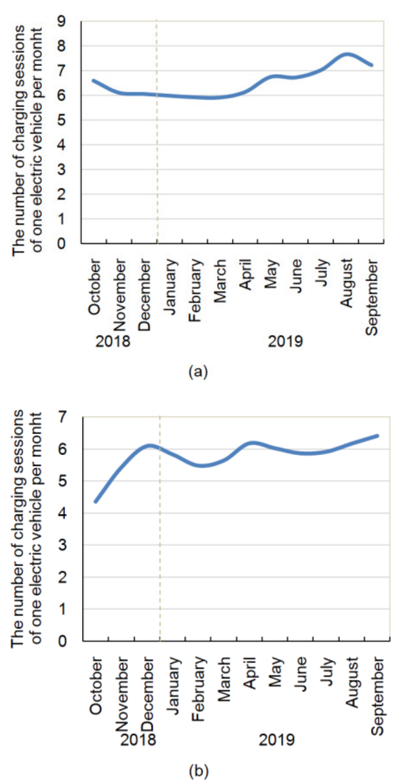


Fig. 2. Curves of the electric vehicle number charged from the public charging infrastructure in: (a) Moscow, (b) St. Petersburg, (c) Tyumen.

The number of electric vehicles using public charging infrastructure in the winter does not change. This hypothesis is also confirmed by data on the number of charging sessions of an electric vehicle per month. It is shown in Fig. 3.



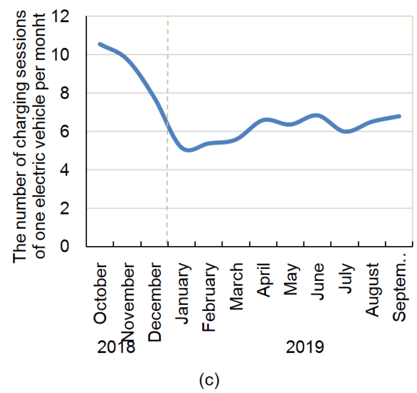


Fig. 3. Curves of the charging session number ofan electric vehicle performed by the public charging infrastructure during the month in: (a) Moscow, (b) St. Petersburg, (c) Tyumen.

As the ambient temperature decreases, the number of charging sessions of one electric vehicle performed by the public charging infrastructure during the month also decreases. Consequently, the number of charging sessions in home ownership increases in the winter. The causes of this phenomenon were established in previous studies [45, 46]. These were a decrease in the speed of energy transfer to the traction battery of an electric vehicle, and, consequently, an increase in the duration of the charge.

These curves will enable developing tools for more even distribution of demand throughout the year in cold climatic regions [1, 21]. It will increase the efficiency of using the energy system from renewable energy sources [19]. Also, the results will be the basis for the development of the algorithm for selecting the necessary equipment.

The development of renewable energy sources for energy supply of the charging infrastructure should be accompanied by the creation of an approach for electric vehicle owners to the period of vehicle charge [25, 26]. The curves describing the utilization rate of the charging station during the day are presented in Fig. 4.

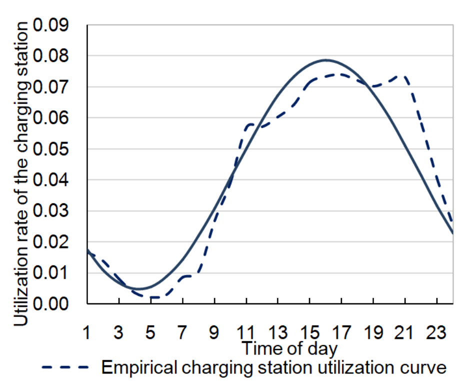


Fig. 4. Curves of the charging station utilization rate during the day.

The data analysis showed that the peak in the number of charging sessions performed by public charging stations was in the daytime. This distribution facilitates the energy supply of charging stations from photovoltaic panels [1]. However, a detailed study of the results indicated that a great utilization rate of the charging sessions is observed in the evening. In this case, the energy supply of the charging infrastructure from renewable energy sources can be difficult [24]. It is due to the fact that the electric vehicle must transfer surplus energy to the city's electric network in the evening. Therefore, the following stages of this study require the development of a method for stimulating and implementing intelligent control systems. This will enable shifting the utilization curve of the charging stations in the period from 9:00 a.m. to 17:00 p.m.

V. CONCLUSION

The development of electric vehicles is an area that contributes to increasing the share of energy generated by renewable energy sources.

An analysis of previous researches showed that the technology for generating, storing and transmitting energy by electric vehicles is developed. However, the implementation of this approach requires the development of an approach to calculating the required number of charging stations and their location. Experimental study enables obtaining the curves of changes in demand for charging stations during the year, as well as the distribution of the charging session number during the day.

The authors found that as the ambient temperature decreases, the demand for charging stations also decreases in the winter. It is caused by an increase in the duration of the charge time of the electric vehicle. A study of the charging session distribution showed that it requires the introduction of incentive measures for charging electric vehicles in the morning and afternoon. This will enable reducing the load on the electric network of the city in the evening peak hours.

VI. FUTURE SCOPE

The results of the study provide tools for a more even distribution of demand throughout the year in cold climatic regions. This will enable increasing the efficiency of using the energy system from renewable energy sources. Also, the results will be the basis for the development of an algorithm for selecting the necessary equipment.

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Conflict of Interest. The authors declare no conflict of interest.

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