Development of Electrical Equipment Classification for Electric Vehicles in Order to Increase the Range

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Abstract. At the present time, there is an increase in environmentally friendly vehicles, in particular it is introduction of electric vehicles. The variable operating conditions of these vehicles, which are characteristic of the Russian Federation territory, cause a decrease in the power reserve and an increase in the energy consumption. The use of existing methods to increase the power reserve of electric vehicles, which consist in the improvement of traction motors and energy storage systems, is impossible when it is in operation. However, the solution to this problem can be achieved by changing the modes of operation of electrical energy consumers, who receive it from a high-voltage battery. The article presents an analysis of previously performed work in the field of increasing the power reserve and reducing the electric energy consumption of an electric vehicle. The need to develop a classification of electric energy consumers, which will be one of the method stages for increasing the range of electric vehicles by controlling the power from electric energy consumers, has been identified. Experimental studies and highly specialized marketing questionnaires, which revealed the amount of energy required for the operation of consumers of electrical energy in an electric vehicle, were carried out.

1. Introduction

Modern trends in the development of road transport, aimed at improving its environmental friendliness, require an increase in the fuel efficiency of vehicles using traditional fuel or switching to the use of alternative, more environmentally friendly forms of energy necessary for driving [1, 2, 3, 4, 5, 6, 7, 8, 9]. At the present time, one of the rapidly developing forms of environmentally friendly transport are electric vehicles. January 1, 2019 in the world, the number of electric registered vehicles exceeded 4 million units, and according to forecasts of the Bloomberg agency, by 2035 its number could reach 250 million units. This growth is due to the reduction in the cost of high-voltage batteries, which are the most expensive element of modern electric vehicles and have a relatively low capacity. The capacity of high-voltage batteries is one of the factors affecting the range of electric vehicles.

In the variable climatic conditions that are typical for the territories of the Russian Federation, the chemical reactions occurring in high-voltage batteries slow down, and their capacity decreases, therefore, the power reserve decreases. At the same time, the temperature deviation from comfortable microclimatic values (above +20 °C or below +5 °C), an increase in the dark time of day leads to the need to use additional equipment, which increases the consumption of electricity stored in the high-voltage battery of an electric vehicle [10, 11, 12]. This dependence is due to the peculiarities of the electrical systems of the considered vehicles. When the power supply system from the high-voltage battery is turned off (the electric car does not work) the electrical equipment systems receive

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energy from a 12V battery. When the electric motor and the power supply system from the high-voltage battery of the elements of the electric vehicle are turned on, consumers of electrical energy begin to take part of its energy. Therefore, the work of electrical systems during idle time or movement of an electric vehicle leads to a decrease in the amount of stored energy in the high-voltage battery, which is necessary for the movement of the vehicle, therefore, it causes a decrease in the power reserve.

Methods of increasing the power reserve are the improvement of traction motors, energy storage systems, as well as the regulation of the modes of operation of the vehicle, namely, the speed limit and features of the electrical equipment. However, the application of the first two methods when the vehicle is in use cannot be performed. In this case, the constant observance of the required speed limit to reduce energy consumption is also not always possible. Therefore, our research is aimed at developing a technique for reducing energy consumption and increasing the power reserve of electric vehicles by controlling the power of electrical consumers. Improving the comfort and safety of modern vehicles leads to an increase in the number of electrical energy consumers and at the initial stage, in order to systematize the elements under study, we need to develop a classification. Thus, the purpose of this article is to develop a classification of electric energy consumers in an electric vehicle for the further creation of a method for increasing the power reserve of the vehicles in question by controlling the power of the electrical equipment elements.

2. Methodology
The most common methods of increasing the power reserve, which are considered in modern studies, are the improvement of the system of accumulation of electric energy and electric motors. It is presented in the researches of A. F. Burke, A. Emadi, Y. J. Lee, K. Rajashekara, Languang Lu, A. Khaligh, R. Woods, Daj Rand and other [13, 14, 15, 16]. Creating an electric vehicle power supply system from alternative energy sources is also considered as a method, which is presented in the works of K.T. Nghuen, T. A. Ocran, J. Cao, B. Cao, X. Sun, P. Plishner, H.C. Lovatt, V.S. Ramsden, B.C. Mecrow [17-21].

The application of these methods to improve electric vehicles that are in operation is impossible. Therefore, an increase in the power reserve of the operated electric vehicles is possible by choosing a rational speed limit, which will ensure minimal energy consumption, or by controlling the work of consumers of electrical energy, which also receives energy from a high-voltage battery. This is presented in the researches of A.E. Chernov, D.A. Sosnin and others. At the same time, an increase in the comfort and safety of vehicles leads to an increase in the number of consumers of electrical energy, and, consequently, increases its consumption by an electric vehicle. A large number of electrical equipment makes it difficult to conduct its research. This is indicated in the works of K. Raif, A.E. Chermenina, A.I. Feschenko, S.A. Feofanov, D.A. Sosnin. This problem has been proposed to be solved by systematization and development of the classification of consumers of electrical energy.

The existing classifications of consumers of electric energy are developed for traditional vehicles and have conditional division into groups according to the mode of operation of the equipment: continuous-nominal mode; short-time mode; intermittent mode. However, they do not take into account the influence of electric energy consumers on its consumption by an electric vehicle and do not allow to clearly separate existing electrical equipment. Therefore, the purpose of the study presented in this article is to develop a classification of consumers of electric energy in an electric vehicle, which will take into account the impact of their work on the energy consumption of the vehicle in question and clearly divide the existing electrical equipment systems into groups, which will be one of the elements of the method for increasing the electric vehicle's power reserve by managing the load from consumers of electrical energy.
2.1. Methodology of research

Initially, experimental and highly specialized marketing research was conducted to develop a classification. Then, the results were processed using statistical methods and cluster analysis methods. The purpose of the experimental study was to determine the power of consumers of electrical energy. Voltage and current in the circuits of electrical energy consumers necessary to perform cluster analysis were measured using ticks AC and DC UT210E. The obtained values were used to calculate the power and amount of energy consumed by the elements of the electrical system.

The purpose of a highly specialized marketing research was to identify the operating time of electric energy consumers during the operation of electric vehicles. This stage was conducted using questionnaires, which include twelve questions. Pre-survey was conducted in a focus group, which allowed to identify incorrect, inaccurate and incomprehensible questions. After the adjustment, the questionnaire was distributed to drivers who own electric vehicles. On January 1, 2019, the number of registered electric vehicles in the Russian Federation was 3600 units. Based on this value, the permissible error, the degree of reliability of the result obtained, the required sample size was 167 people.

The data obtained as a result of the experimental stage, the survey, their analysis and processing, made it possible to calculate the amount of energy necessary for the operation of each consumer of electrical energy. Then, these values were processed using cluster analysis, which made it possible to form a classification by the amount of energy consumed by the equipment. However, this equipment must be pre-distributed on managed and unmanaged in order to use the classification as one of the elements of the method for increasing the power reserve by controlling the power of consumers of electrical energy. This stage of classification was performed on the basis of expert evaluation.

Thus, the classification of consumers of electrical energy, which includes consideration of the operating modes of electrical equipment, the ability to control them and the amount of energy consumed during their work, was obtained.

3. Discussion of research results

The amount of electrical energy consumed by electrical equipment during its operation is determined by its power, which depends on the strength of the current and voltage in the electrical circuit, and the time of its operation. So a consumer of electrical energy of small power, for example, a bulb of headlights of "dim light", but with a long operating time can take a significant amount of electrical energy from a high-voltage battery. Therefore, during the preliminary stage of developing a classification, namely, conducting experimental research and a highly specialized marketing questionnaire, the power of electrical energy consumers and the time of their work under operating conditions were identified. A fragment of the results are presented in table 1.

| Name of the consumer of electrical energy | Consumer power, W | Time of work of a electrical energy consumer, h |
|-----------------------------------------|-------------------|-----------------------------------------------|
| low beam headlamp bulbs                 | 100               | 0.46                                          |
| air condition                           | 400               | 0.46                                          |
| audio system                            | 100               | 0.46                                          |
| rear window heating                      | 200               | 0.08                                          |

The results of the preliminary stage of experimental studies allowed us to calculate the amount of energy that consumers receive electrical energy. Calculated data was a classification criterion for the amount of energy consumed by electrical equipment of an electric vehicle. At the same time, the ability to control the operating modes of the electrical energy considered consumers, where they were divided into managed and unmanaged, was also taken into account. However, this classification is applicable only to consumers of electrical energy, included in the work periodically for a long period of time. This is due to the lack of ability to control electrical systems that are constantly included in...
the work, since this group includes the safety systems and the functioning of the electric vehicle. Separation of electrical energy consumers, included in the work periodically for a short time, is also not provided, which is due to the insignificance of the influence of their operating modes on the amount of energy stored in the high-voltage battery of an electric vehicle. A fragment of the developed classification of consumers of electrical energy is presented in Figure 1.

![Diagram of electrical energy consumers classification](image)

**Figure 1.** A fragment of the developed classification of electric energy consumers of an electric vehicle.

Classification of electric energy consumers will be applied as one of the stages in the development of methods for increasing the power reserve of electric vehicles by controlling the power of electric energy consumers. Knowing the amount of energy consumed by electrical equipment and its group in the classification, we will be able to determine when it will be necessary to change its mode of operation, taking into account the residual power reserve.

4. **Conclusion**

Operation of electric vehicles in variable operating conditions, which are typical for the territory of the Russian Federation, causes a decrease in the power reserve and an increase in power consumption. At the same time, the existing methods of increasing the power reserve by improving traction motors or electric vehicle power supply systems are impossible during the operation of the considered vehicles. However, reduction of electric power consumption of electric vehicles and increase in power reserve is possible as a result of changes in the modes of operation of consumers of electric energy.

This article presents the development of an electric energy consumer classification, which will be one of the stages of creating a method for increasing the power reserve of electric vehicles by controlling the power of electric energy consumers. During the preliminary stage, experimental studies and highly specialized marketing questionnaires, which made it possible to identify the power of electrical energy consumers and the time of their work under operating conditions, were carried out. The amount of energy required for the operation of electrical equipment elements is calculated on the basis of the values obtained. The classification of electrical energy consumers in an electric vehicle, a fragment of which is presented in the article, was developed as a result of cluster analysis of calculated data.

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